Applied Ergonomics 138 (2027) 104841

Contents lists available at ScienceDirect

Applied Ergonomics

journal homepage: www.elsevier.com/locate/apergo

Identifying the most comfortable interpersonal distances for autonomous vehicles' passengers

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ARTICLE INFO

Keywords:
NDRAs
Proxemics
Communication
Human-centred design
Autonomous vehicle
Self-driving car
AR

ABSTRACT

The evolution of autonomous vehicle interiors presents both opportunities and challenges in optimizing space for Non-Driving Related Activities (NDRAs). Previous research explored the reconfiguration of interiors in autonomous vehicles to support key activities such as reading, working, relaxing, and conversing. Building on this foundation, the present study examines how seating arrangements and interpersonal distances influence passenger comfort and conversational quality. Drawing on proxemics theory, the investigation considers the impact of gender, age, and nationality on interpersonal spatial preferences within vehicle cabins. Thirty-seven participants (aged 23–33) experienced three seating configurations -alpha (side-by-side), beta (opposite directions with parallel axes), and gamma (face-to-face)- in a virtual environment developed using Unity and accessed through HoloLens 2. Participants selected their preferred interpersonal distance from five predefined options while interacting in Augmented Reality (AR) with a virtual mannequin. Objective measurements were supplemented with subjective feedback from a post-test questionnaire. This study addresses the following research questions: 1) Which seating configuration is most comfortable for passengers during a conversation? 2) What are the ideal seating distances in each configuration? 3) How does gender influence interpersonal space requirements? 4) How does ethnicity impact interpersonal space preferences? Findings show no significant difference in distances chosen when conversing or not. Distance varied significantly with social relationships. Gender, body size, and culture influenced preferences. Results suggest the need for adaptable interior layouts that can accommodate diverse interpersonal spacing needs.

1. Introduction

The term Proxemics was first introduced by Edward T. Hall in 1963, who defined it as "the interrelated observations and theories on the use of space by humans as a specialized elaboration of culture" (Hall, 1966). Proxemics is therefore the study of how individuals perceive and utilize physical space in their interactions. Hall proposed that the distances individuals maintain during communication are not arbitrary but instead follow culturally determined patterns, exerting a significant influence on the nature of the interaction. Consequently, proxemics explores how interpersonal distances, and the utilization of surrounding space can convey nonverbal messages, express social relationships, and convey emotions and intentions, thus playing a crucial role in human communication.

Hall's classical proxemic theory categorizes interpersonal distance into four distinct categories (Fig. 1), each of which reflects a different relationship between individuals. These four types of distance are:

- Intimate distance (0 – 45 cm) indicates a close relationship and is common during intimate interactions like hugging or whispering.
- Personal distance (45 – 120 cm), seen among familiar individuals, such as friends, and is the distance for a handshake.

This article is part of a special issue entitled: Occupants Comfort published in Applied Ergonomics.

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https://doi.org/10.1016/j.apergo.2026.104841
Received 17 April 2025; Received in revised form 25 May 2026; Accepted 3 June 2026
Available online 15 June 2026

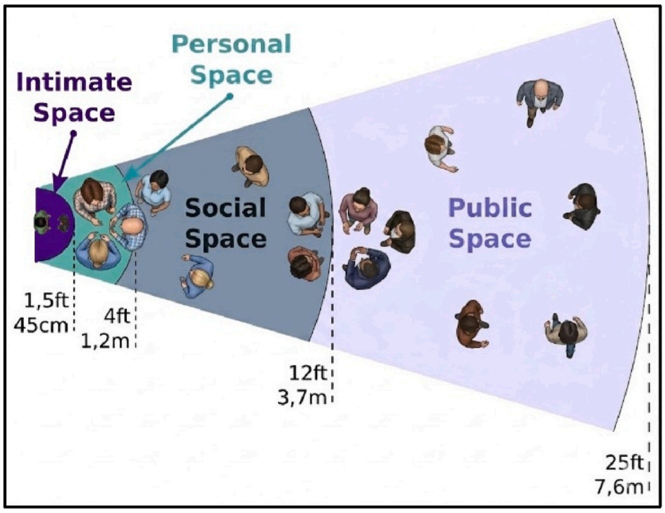

Fig. 1. Hall's interpersonal distances (Hall, 1966).

- Social distance (120 – 370 cm), used with acquaintances or somewhat familiar individuals, like colleagues, where closer interaction feels comfortable.
- Public distance (over 370 cm), maintained during public speaking situations, such as giving presentations in classrooms or at work.

Hall's theory (1966) suggests that people's choice of interpersonal distance during interactions is influenced by personal attitudes, personal characteristics (such as gender and age), and social context. Research supports gender (Aiello, 1987; Horenstein and Downey, 2003; Ozdemir, 2008; Smith, 1981; Patterson and Edinger, 1987) and age (Aiello, 1987; Ozdemir, 2008; Rapp, 2000; Burgess, 1983; Gérin-Lajoie et al., 2006) as factors influencing preferred interpersonal distance. In particular, regarding gender influence: Aiello (1987) analysed gender-based differences in human spatial behaviour, identifying how females typically prefer closer interpersonal distances than males, particularly in same-gender interactions; Patterson and Edinger (1987) examined the functional use of space in social interaction and found that males tend to maintain greater distances, especially when interacting with other males, whereas females exhibit more flexible spatial patterns, often allowing closer proximity; Ozdemir (2008), in a cross-cultural study conducted in shopping malls, further confirmed that female participants consistently tolerated shorter interpersonal distances than males across different cultural contexts. For this reason, this study will investigate the difference between the distances chosen by the two groups, Females and Males, considering subjects of very similar ages (ranging from 23 to 33 years) in order to have a sample with low variance.

In his theory, Hall also emphasizes the influence of cultural norms on preferred social distances, suggesting that what is intimate in one culture may be perceived differently in another. He categorized cultures into contact and noncontact groups, where contact cultures prefer closer interpersonal distances and more physical contact, while noncontact cultures exhibit the opposite. These distinctions are based on geographic location, with Southern European, Latin American, and Arabian cultures considered contact, and North American, Northern European, and Asian cultures as noncontact. In this study, the preferred interpersonal distance by ethnicity will also be investigated, dividing the analysed population into two groups: Asians and Europeans. In this study, we opted to simplify the categorization into contact and noncontact groups in this manner, considering the analysed population's limited geographical diversity. Moreover, when referring to Europe in this context, Southern and Central European countries will be included, thus serving as a subgroup of the contact group.

Proximity in confined space has been also studied in (Evans et al., 2007); in this paper, authors studied 139 US train passengers for investigating proximity effects on seated people and demonstrated that proximity, while being seated, is more stressful than the crowd-effect (car-density), well identifying a major issue in designing confined spaced for interactions. In (Ferrier-et al., 2018) authors analysed 19 volunteers in a virtual-scenario, involved in activities while seated, as driver, in a Level 5 autonomous vehicle; the effect of scenario and environment on perceived discomfort was investigated. The personal space was investigated too, without any other person inside the car and towards the external elements. VR was assessed as a very good method to perform that kind of experiments and to evaluate the existing gender effect. The same good results using VR environment were obtained in the study of Page Ive et al. (2015), while a study by Hecht et al. (2019) highlighted how the definition of Hall interpersonal distances depends on the type of interaction (Virtual based -vs -Real based) and on the gender.

More recently, in (Aasvik, 2024), authors investigated and found gender based differences in 1723 online survey responses for assessing perceived usefulness and comfort in AVs; in this study age-based differences were not highlighted, while Wang et al. (2023) describes the changes in social interaction while performing an experiment in RR and in VR environment with 128 volunteers; the sample was clustered by race, gender and ethnicity and some statistical significative differences have been found within the clusters. Finally, in (Peng et al., 2025), authors studied proxemics effects in SAE Level 4+ vehicle simulator on comfort and behavioural naturalness, by effectively using a VR simulator, demonstrating the powerful and usability of such type of device.

The wider study was done by Sorokowska et al. (2017); in 2017 authors explored how age, gender, and ethnicity influence individuals' choices regarding interpersonal space; the study involved 8943 participants of diverse ages, genders, and backgrounds from around the globe, that were required to respond to three graphic questions concerning the study of interpersonal distance with a stranger (Public distance), the interpersonal distance to maintain with an acquaintance (Social distance), and the distance to maintain with a close person (Personal distance). In each of the three questions, participants were asked to imagine themselves as Person A and select the most comfortable distance to maintain with Person B like in Fig. 2.

The results of the study by Sorokowska et al. (2017) reveal several trends:

- Females and individuals in colder regions tend to prefer greater distances from strangers.
- Elderly individuals and females generally prefer more distance from acquaintances.
- Elderly individuals and those living in warmer climates often prefer greater distances from individuals they consider close.

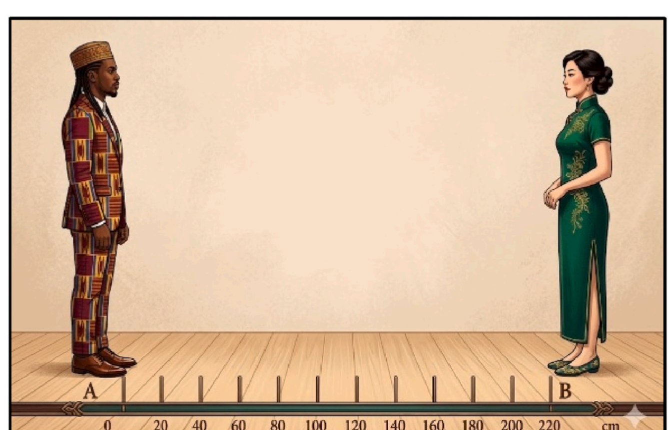

Fig. 2. Graphic of distance shown to participants.

- The interpersonal distances obtained are significantly lower in each area compared to those provided by Hall.

However, it's important to note that this study's main limitations arise from its reliance on questionnaire responses, which may not fully reflect how individuals behave when interacting with others in real-life situations. The study is therefore affected by bias, as it assumes that people are able to quantify interpersonal distances. In this study, we seek to address this limitation by enabling participants to engage with virtual mannequins. The decision to conduct the study in a virtual setting is driven by the intention to mitigate any potential influence of the interlocutor's physical traits on the test outcomes.

The previously mentioned studies mainly examined interpersonal distance in a standing position. Consequently, there is a question regarding whether the boundaries defining the four zones might vary in a seated setup. Sommer (1962) explored how individuals utilize space during social interactions and found that a face-to-face seating arrangement was preferred over a side-by-side arrangement. Participants in the experiment favoured sitting opposite each other in most cases, except when the sagittal distance between seats exceeded the transverse distance (Fig. 1 in Appendix 2).

In particular, for transverse chair distances equal to or less than 4 inches, approximately 122 cm, participants consistently preferred to sit facing each other (Fig. 2 in Appendix 2). Only for a transverse distance of 5 inches, approximately 152.4 cm, did participants prefer a side-by-side configuration, likely due to difficulties in communicating at such a far distance.

None of the studies mentioned above explored the discomfort people experience during a conversation, particularly related to excessive head rotation or limited legroom. To address this gap, Piro et al. (2019) investigated how seating arrangements affect posture and conversation quality, assessing discomfort when seats are positioned 1 m apart and set at angles of 0°, 45°, 90°, and 180° (Fig. 3 - a).

The research findings indicate that the 90° seating setup proved to be optimal in terms of both comfort and conversation quality, facilitating a comfortable posture with minimal discomfort and ensuring a high-quality conversation without strained eye contact. Conversely, the 0° configuration scored lowest in both discomfort and conversation quality, emerging as the least favoured option among all arrangements. Regarding posture, participants were observed to rotate their bodies to engage in conversation for the 0°, 45°, and 90° configurations.

The study was extended by Fiorillo et al. (2019), including seating arrangements set at angular distances of 22.5° and 120° from each other (Fig. 3 – b). The study found that the 120° seating configuration was the most preferred for both comfort and conversation quality, slightly outperforming the 90° arrangement. Participants favoured the 120° setup for its comfortable posture and good conversation quality without the need for forced eye contact. Additionally, in the 120° configuration, participants showed reduced head rotation, lowering the risk of discomfort perception.

The latest study by Fiorillo et al. (2021) focuses on legroom requirements in a face-to-face seating arrangement. They tested four distances between seat panels (44 cm, 51 cm, 58 cm, 65 cm) with a table in between. Results showed that 51 cm is optimal, balancing postural comfort, social interactions, and table accessibility. Decreasing the distance reduced comfort, while 65 cm provided comfort but compromised table accessibility, suggesting a need for a new table design.

Following the analysis of results obtained from previous studies, it was decided to investigate the optimal interpersonal distances for four different seating configurations (easily configurable in the interior layout of an autonomous driving vehicle (Chiriani et al., 2025) – Fig. 4). The transverse and sagittal distances investigated were: 50 cm, 70 cm, 90 cm, 110 cm, 130 cm, perfectly aligned with the interpersonal distance zones reported by Sorokowska et al. (2017). This study aimed to identify the most suitable distances, factoring in both physical discomfort and subjective comfort as variables. Participants had the opportunity to interact with a virtual mannequin in Augmented Reality mode, aiming to easily explore both personal and subjective distances without the physical characteristics of the interlocutor or their level of acquaintance influencing the study results. In the study of the face-to-face configuration, in perfect agreement with the distances analysed in the study by Fiorillo et al. (2021), the sagittal distances relative to the centroids of the seats analysed were: 90 cm (which considering the size of the seat used of 42.5 cm was almost equivalent to the distance of 44 cm from the front edges mentioned in the study), 110 cm (the last distance mentioned in the study), 130 cm, 150 cm, and 170 cm. The last three distances were added to assess whether, if available and without the constraint of the table, people would have preferred to have more legroom. Furthermore, gender and ethnicity analyses were conducted in alignment with prior research indicating their influence on interpersonal space preferences, employing clustering techniques on the participant population.

The analysis involved 37 people and the sample width allowed to realize a correlation among several factors; experiments were conducted for answering to the following four Research Questions:

1) Which seating configuration is most comfortable for passengers during a conversation?
2) What are the ideal seating distances in each configuration?
3) How does gender influence interpersonal space requirements?
4) How does ethnicity impact interpersonal space preferences?

2. Material and methods

Experimental setup was realized both in Real and in Virtual/Augmented Environment.

2.1. Devices and software

Hardware and software used to create and run the AR (Augmented

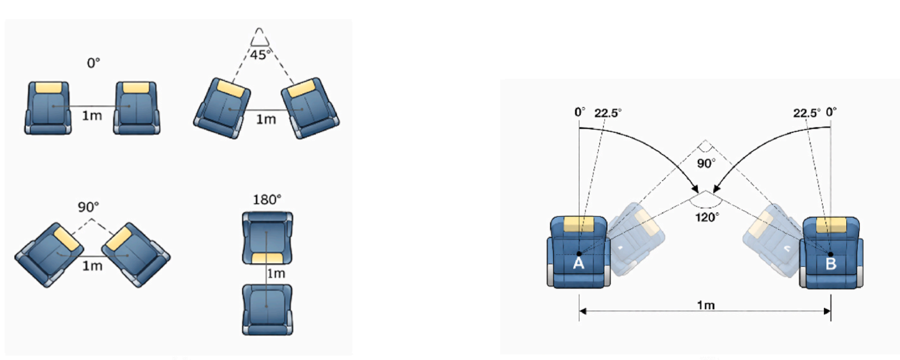

Fig. 3. Seating arrangements examined on: a) Piro's research, b) Fiorillo's research.

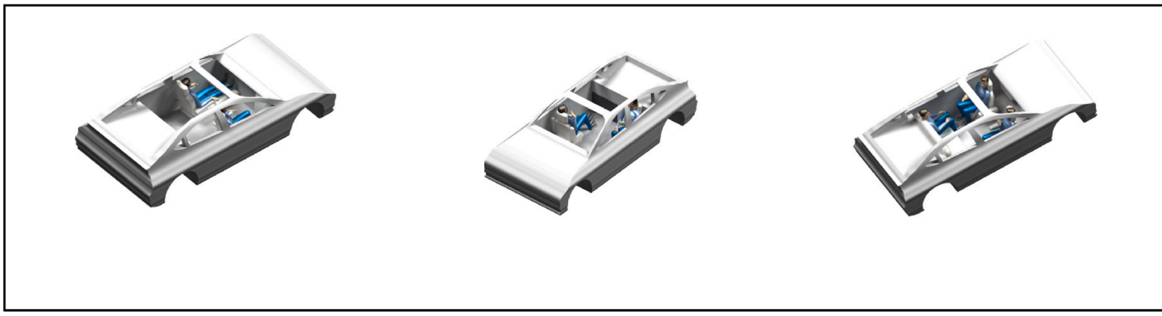

Fig. 4. Interior layout of an autonomous driving vehicle (Chiriani et al., 2025).

Reality) experiment includes the development platform (Unity), the mixed reality headset (HoloLens 2), and the statistical analysis tool (SPSS Statistics).

2.1.1. Graphic engine

Unity graphics engine, created by Unity Technologies, whose packages allow creating interactive contents including real-time architectural visualizations and 3D animations, was utilized in the 2020 version to create the AR environment.

2.1.2. Augmented reality device

In this study, participants were able to experience the AR environment by wearing the Microsoft HoloLens 2 device. This device, being a holographic computer that enables interaction with digital content and holograms displayed within the wearer's surroundings, allows users to see, hear, and interact with virtual content overlaid onto the real world (Cappetti et al., 2025). It is equipped with sensors, cameras, and advanced displays for offering realistic and immersive experiences.

2.1.3. Statistical analyses

SPSS Statistics software rel. 25, created by IBM, was used to perform data analysis. This software allows to perform advanced statistical analyses and to easily check the validity of dataset and the robustness of statistical findings.

2.2. Real reality environment materials

2.2.1. Chair

The chair that was used by the participant had a seat 44.2 long and 41.2 cm deep, placed at a height of 46 cm from the floor. The dimensions indicated in Appendix 2 - Fig. 3 are measured in cm.

2.3. Augmented reality environment materials

The AR environment was created to replicate the physical environment in order to overlap Virtual elements with physical ones in the spatial scenarios used during participants' interactions.

2.3.1. Mannequin model

The CAD model of the mannequin was obtained from the CGTrader open library. The genderless mannequin (Fig. 4a in Appendix 2) is 173.5 cm tall. In order to change his posture, the Mixamo software was used.

2.3.2. Chair model

The CAD model of the chair used was made by Fettih Moussa and found in the GrabCAD 3D model open library. The distance between the seat and the floor is 46.0 cm. The seat has a length of 46.5 cm and a width of 41.5 cm. The numbers in Fig. 4b in Appendix 2 are in cm.

2.3.3. Scenario

The five levels of AR setup-simulation are made in the same Unity scene. Each level is marked with a large yellow number.

In Levels 1, 2, 3 and 4, the five selectable distances are indicated as coloured spheres. Participants must position the chair so that its centre of gravity is on one of the spheres. There is a white arrow indicating the permitted direction of movement. In order to correctly position the chair, there are two vertical lines equidistant from each sphere of the same colour as the sphere between them, and two horizontal white lines equidistant to all spheres. The chair must be positioned so that its edges coincide with the four lines.

In Level 5 there are 49 spheres all white. Each of them is located at the intersection point of a red line and a blue line. The red lines have a transversal direction and each of them is identified by a number, which can be read both at its right end and at its left end. The blue lines have a sagittal direction and are identified by a letter. The participant will have to position the chair so that its center of gravity coincides with the sphere. To position it correctly, simply check that the red and blue lines cut the chair perfectly in half. To communicate the chosen position, participants must report both the letter and the number corresponding to the blue and red line.

2.4. Experimental setup

Three setups were designed to simulate different conversational scenarios through varying chair orientations and distances. They were named Alfa, Beta and Gamma Setup.

2.4.1. Alfa setup

Setup Alfa is the one shown in Fig. 5a in which the chair of the participant will be indicated in white, while that of the interlocutor will be coloured in grey. Chairs are positioned side-by-side and the spacing between the two parallel symmetrical axes of the seats is 50 cm. The distance of 50 cm was chosen because it is the distance that permits two seats to be exactly adjacent to each other, given that seats have an average width of 50 cm.

2.4.2. Beta setup

The two chairs are in opposite directions and their axes of symmetry are parallel. Both the vertical and horizontal axes of the two seats have a distance of 50 cm (Fig. 5b).

2.4.3. Gamma setup

Chairs are placed in opposite directions and with parallel and coincident vertical axes, at a distance of 90 cm (Fig. 5c) in order to consider the necessary legroom.

2.5. Participants

The study involved 37 participants, including 16 females and 21 males. The participants, who were aged between 23 and 33, were

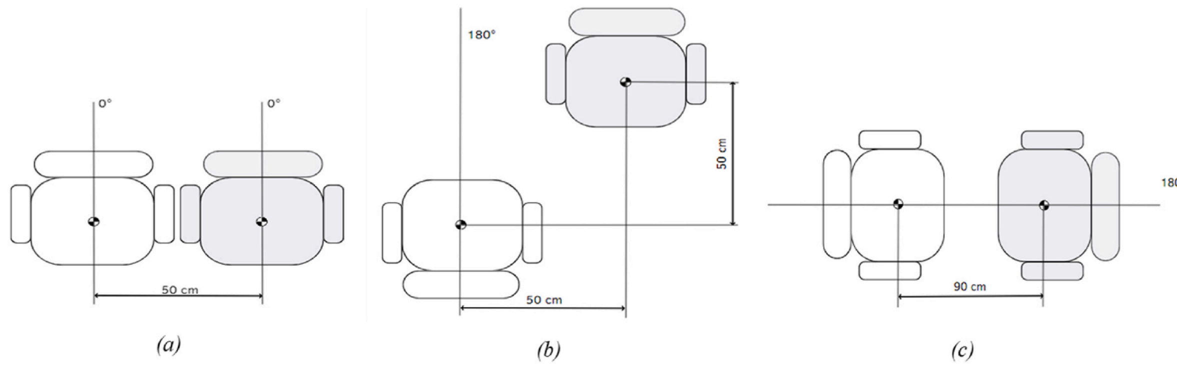

Fig. 5. Experimental setup: a) Alfa setup, b) Beta setup, c) Gamma setup.

randomly chosen at the University of Delft, where the research took place. Most of these are master's students, PhD students, and employees of the Industrial Design Engineering faculty.

Table 1 in Appendix 1 shows the anthropometric data of the participants related to the human body depicted in Fig. 5 in Appendix 2.

There is a great diversity in the nationality of the sample analysed. The geographical distribution of the sample that was analysed can be seen in Fig. 6 in Appendix 2.

The exact number of participants for each country is shown in table 2 in Appendix 1.

2.6. *Protocols*

Before starting the experiment, each participant was required to carefully read and sign an informed consent form. An identification number was assigned to each participant so that all data was collected anonymously. In order to subsequently verify that the AR tests had been performed correctly, each participant's experience was recorded with an external camera and with that of Hololens 2.

Each participant performed 5 tests as levels of an interactive AR game. The game begins by asking the participant to put on the lenses. Each level of the game begins by asking the participant to move around the room looking for the yellow number corresponding to the level to be performed. Once the number has been found, the participant will approach it and interface with a virtual mannequin sitting on a chair. The participant is then asked to sit on the empty chair, to imagine having a conversation with the interlocutor and to select one of five distances from the interlocutor that would make him/her feel more comfortable, first pretending that he/she was an acquaintance and then that he/she was a friend.

In the first 4 levels, the participant will choose the most comfortable distance for him/her by positioning the chair on the red sphere and moving further and further away from the mannequin following the direction of the white arrow. The participant will communicate the most comfortable distance, identifying it with the colour of the corresponding sphere. In the fifth level, however, the participant will be asked to place the chair on one of the white spheres and move freely.

After having performed the first 5 levels, the participant was asked to communicate his/her preferred one, taking into account the setup used and direction of movement, focusing not on the person he/she is talking to, but on his/her physical comfort.

After completing the AR game, a questionnaire was given to each participant. If objective data (distances) are obtained from the execution of the tests, subjective data are obtained from the questionnaire. The subjective data are important to understand what factors influence the choice of interpersonal distance during a conversation.

Finally, participants' anthropometric data measurements were taken and collected with the aim of investigating how much a participant's body size influenced their need for space.

2.6.1. *Level 1*

In the following test the participant used the Alpha setup. The participant finds the most comfortable position by moving only in the transverse direction (Fig. 7 in Appendix 2). The lower and upper limits of 50 and 130 cm were chosen taking into account the ranges delimiting the Hall zones. Hall's interpersonal zones of interest for the experiment are those of Personal Distance and Social Distance. The Personal Distance range for interactions between good friends or family was 1.5 - 4 ft (46 cm - 122 cm), while the Social Distance range for interactions between acquaintances was 4 - 12 ft (122 - 366 cm).

In order to evaluate the impact that the activity of conversing has on the need for interpersonal space, the first level was repeated twice: the first time asking the participant to pretend not to have a conversation with the interlocutor and the second time pretending to talk to him/her.

2.6.2. *Level 2*

The starting configuration was the Beta setup. The participant could only move in the transverse direction to find the best distance for him/her. The participant could choose between the following distances: 50 cm, 70 cm, 90 cm, 110 cm and 130 cm (Fig. 8 in Appendix 2).

2.6.3. *Level 3*

The starting configuration of the seat was the Beta setup. However, during this test the allowed movement was sagittal. The distances 50 cm, 70 cm, 90 cm, 110 cm and 130 cm were tested from the transverse axis of the mannequin's chair (Fig. 9 in Appendix 2).

2.6.4. *Level 4*

The face-to-face configuration (Gamma setup) was tested in Level 4. Therefore, the chairs were placed in opposite directions and with parallel and coincident sagittal axes. Only sagittal direction motion of the chair was permitted. The dimensions from which the participant could choose were: 90 cm, 110 cm, 130 cm, 150 cm, 170 cm (Fig. 10 in Appendix 2).

2.6.5. *Level 5*

All distances reported in the first four levels were combined in this level, to permit the participant to have fewer limitations in determining the most comfortable configuration for him/her, from a human-centred perspective. In this case the allowed movement of the chair was both sagittal and transverse. To ensure consistency, the configurations at a transverse distance of 25 cm from the mannequin have been added (Fig. 11 in Appendix 2).

2.6.6. *AR games*

Four scenarios in AR games have been created and are represented in Fig. 6.

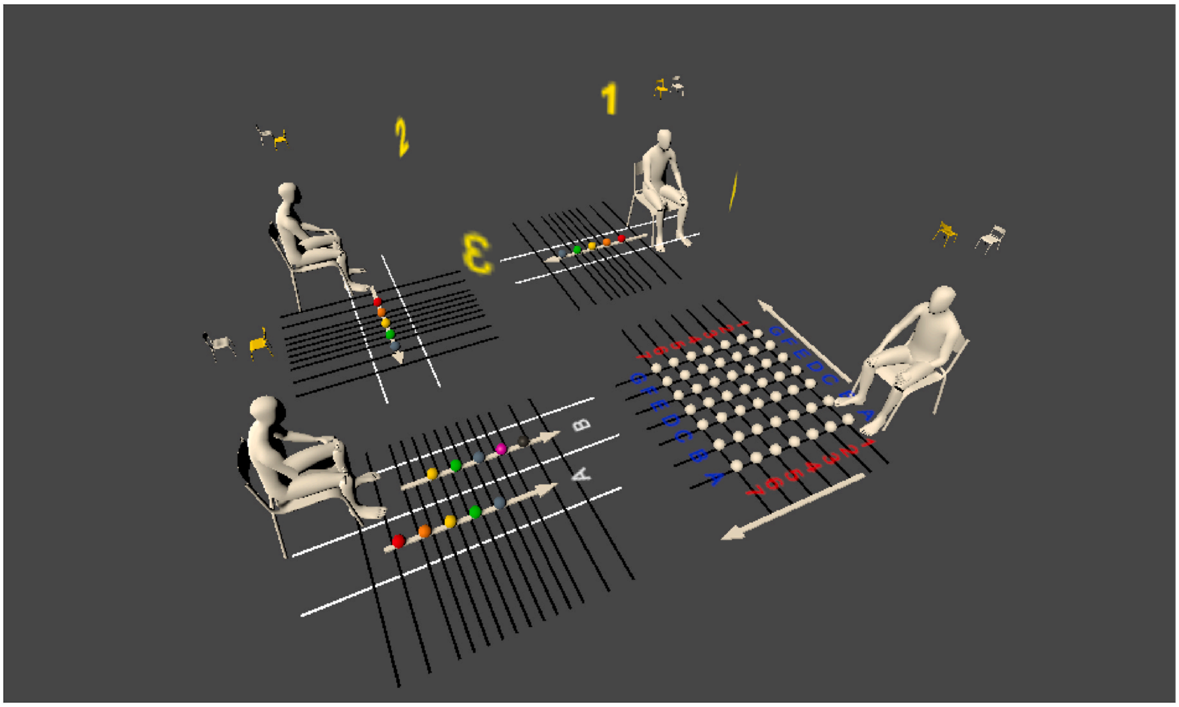

Fig. 6. AR scenario.

3. Subjective data analysis

This chapter explores participants' perceived comfort across different seating configurations. It examines how personal factors—such as the interlocutor's gender, stature, and level of familiarity—influence interpersonal space needs and seating preferences in conversation scenarios.

3.1. Preferred level

To the question "Regardless of the person you are interacting with, what is the level in which you felt most comfortable?", the participants responded as shown in Table 3 in Appendix 1.

Participants have reported that conversing in the first two levels were extremely uncomfortable due to excessive neck rotation. The face-to-face configuration allows for a 0° head rotation, which is the most comfortable (Naddeo, 2017). However, this configuration provides less legroom and requires individuals to maintain a greater distance, which can negatively impact the quality of conversation. Moreover, many individuals have expressed a preference for avoiding direct eye contact with their conversation partner throughout the entire conversation because they feel awkward. Setup and movement used in level 3 represent an excellent compromise. As the distance increases, head rotation decreases (see Table 4 in Appendix 1), and there are no obstacles in front of the seat, allowing passengers to stretch their legs freely. This might suggest that participants opted for the maximum allowable distance, but it's important to note that as this distance increases, conversation quality decreases. The next paragraph will identify the optimal distance for the participants.

3.2. Influence of Interlocutor's gender on interpersonal space needs

Through the online questionnaire each participant was asked to answer the following question: “During the game you related to a genderless mannequin. To what extent do you think the gender of your interlocutor influences your need for interpersonal space?”. Participants could respond by assigning a score from 1 to 5, where 1 stands for "Not at all" and 5 for "Totally". Table 5 shows the participants' responses. 73% of participants indicated that the interlocutor's gender has at least some influence on their perception of personal space, although only 8% (3 participants) voted "Totally". Those who indicated that the gender of their conversation partner affects their need for personal space were subsequently asked the following question: “Would you sit closer to someone of your own gender, or would you sit closer to someone of the opposite gender?”. The majority of participants (23 out of 27, or 85%) reported that they would prefer to sit closer to someone of the same gender, while only 4 participants (15%) expressed a preference for sitting closer to someone of the opposite gender.

3.3. Influence of Interlocutor's stature on interpersonal space needs

Participants were asked to answer the question: “To what extent do you think the stature height of your interlocutor influences your need for interpersonal space?” using a scale from 1 to 5, where 1 meant “For nothing” and 5 meant “Totally”. The majority of participants gave low scores, with 59.5% indicating that the stature of their conversation partner does influence, at least to some extent, their personal space needs (i.e., rating from 2 to 4). However, none of the participants rated the influence as total (score 5). Among those who acknowledged an influence, 95.5% stated they would prefer to sit next to or in front of a shorter person, suggesting that perceived height can subtly shape interpersonal spatial preferences.

3.4. Influence of Interlocutor's familiarity on interpersonal space needs

In this section, we investigated how participants' need for interpersonal space varied depending on their level of familiarity with the interlocutor. To explore this, participants were asked: “To what extent do you believe that how much you know a person influences your need for interpersonal space?”. Responses were given on a scale from 1 (“For nothing”) to 5 (“Totally”). The vast majority of participants indicated a strong influence of familiarity on their spatial preferences: 33 out of 37 participants (89%) rated this influence as 4 or 5, with more than half (21 participants) selecting the highest value. Only one participant reported no influence at all. The average score is 4.405. We expect statistically different results from the social distancing and personal distancing experiments.

4. Objective data analysis

This chapter analyses the actual distances chosen by participants during the experiments. Through statistical comparisons and distribution analyses, it identifies preferred interpersonal distances in different setups, highlighting behavioural patterns in both social and personal space contexts.

4.1. Statistical comparison of personal and social distances

In the following paragraph we want to investigate the difference, where existing, between personal distance and social distance data. The data used are those obtained from each level performed in AR. The probability distribution functions of the experiments are shown in Fig. 12 in Appendix 2. In each graph, the blue curve refers to the personal distance experiment while the grey curve refers to the social distance experiment.

The distributions are non-normal discrete and the two experiments were performed in succession by the same participants, therefore it was opted for the Wilcoxon signed-rank test to study if there is a statistical difference between the data. Data were analysed using IBM SPSS Statistics software. For each level, the Wilcoxon test revealed that distances measured for a friend and those measured for an acquaintance differed significantly, with all p-values below 0.05. To control for Type I error (α) due to multiple comparisons across the four levels, a Bonferroni correction was applied, resulting in a corrected significance threshold of $\alpha = 0.05/4 = 0.0125$. Even after this correction, all p-values remained below the adjusted alpha, confirming statistically significant differences between the conditions. Wilcoxon test results are shown in Table 5 in Appendix 1.

In order to quantify the magnitude of the observed differences and assess statistical power, effect sizes were calculated as $r = |Z|/\sqrt{N}$, where N is the number of non-zero paired differences. According to conventional interpretation, r values of 0.1 indicate a small effect, 0.3 a medium effect, and 0.5 or higher a large effect. As shown in Table 6 in Appendix 1, all levels exhibit large to very large effects ($r = 0.60–0.95$), demonstrating that the differences between conditions are substantial and practically meaningful, and providing an assessment of statistical power, thereby helping to control for Type II error (β), despite the relatively small sample size ($n = 37$).

Since a significant statistical difference was found between the participant's behaviour towards a friend and an acquaintance. The social and personal zones will be examined separately in this article, and the most comfortable distance for passengers will be determined for each of them.

4.2. Preferred distance for each setup

The purpose of this paragraph is to explore the preferred distance for participants to keep from their friends or acquaintances during a conversation.

4.2.1. Level 1

As shown in the histogram in Fig. 13 in Appendix 2, the majority of participants prefer to maintain a distance of 70 cm (chosen by 51.4% of all participants) from a friend and a distance of 90 cm (chosen by 51.4% of all participants) from an acquaintance.

Since the distribution is not symmetrical, it is useful to specify that the average value of the social distance is 94 cm while the average value of the personal distance is 79 cm (as shown in Table 7 in Appendix 1).

4.2.2. Level 2

The social distance chosen by the majority of participants (54.1% of the population) is 70 cm. This value is also the most chosen for personal distance (preferred by 54.1% of participants). In this scenario, participants positioned themselves at a closer distance to the mannequin because, as the length increased, the angle of the neck's inclination also increased, resulting in increased physical discomfort. The 50 cm distance was not preferred by many participants in the experiment involving interaction with an acquaintance, as it resulted in uncomfortably close contact between the two individuals. Conversely, it was chosen by 37.8% of participants for interactions with friends (See Fig. 13 in Appendix 2 and Table 7 in Appendix 1).

We can conclude that the distance of 70 cm appears to be optimal for both studies, although the two distributions show a significant statistical difference.

4.2.3. Level 3

Participants had more varied opinions. This was due to the fact that, in this case, three factors influenced their choice: the need for interpersonal space, the need to converse without hearing difficulties, and the physical comfort associated with less neck rotation. Additionally, in the following configuration, Beta setup, the seats are not aligned. This means that when choosing the best configuration, participants must identify the space they need, considering both the longitudinal and transverse distance from their interlocutor. Therefore, in this configuration, the anthropometric data of the participants significantly influence their need for space (See Fig. 13 in Appendix 2 and Table 7 in Appendix 1).

The most voted distance, both for having a conversation with a friend and an acquaintance, is the one at 90 cm from the interlocutor.

4.2.4. Level 4

In the face-to-face configuration, the participants chose an intermediate distance that allows both sufficient legroom and clear conversation without listening difficulties. The optimal distance for conversing with a friend was 110 cm (chosen by 51.4% of the population), while for conversing with an acquaintance, participants preferred a distance of 130 cm (indicated by 48.6% of the participants) (See Fig. 13 in Appendix 2 and Table 7 in Appendix 1).

4.2.5. Level 5

During this test, participants could freely choose where to position their chair among 49 positions. The matrix in Fig. 14 in Appendix 2 indicates for each position the number of participants who chose it in the social distancing experiment. 38% of the population chose the positions corresponding to the face-to-face configuration. The first columns of the matrix (distance of 130 cm and 110 cm) and the first rows of the matrix (distance of 50 cm and distance of 70 cm) have null values.

The matrix in Fig. 15 in Appendix 2 reports the number of votes, for each position, for the personal distance experiment. 46% of participants chose to position themselves in front of their interlocutor. Also, in this case the transverse distances of 130 cm and 110 cm did not have any votes. The sagittal distance of 50 cm was also not chosen by any participant.

To determine passengers' preferred sagittal and transverse distances, we created two histograms: one showing the percentage of votes for each sagittal distance and the other showing the percentage of votes for each transverse distance (Fig. 16 in Appendix 2).

4.3. Statistical comparison of data obtained during and without a conversation

Wilcoxon signed-rank test did not detect a statistical difference between the data collected by asking the participant to talk to his interlocutor and those collected without an interaction between the two. In fact, for both the personal distance study ($Z = -1.124$; $p = 0.267$) and the social distance study ($Z = -0.698$; $p = 0.557$), the p-value is greater than 0.05. The Alfa setup is used for this comparison (Fig. 7).

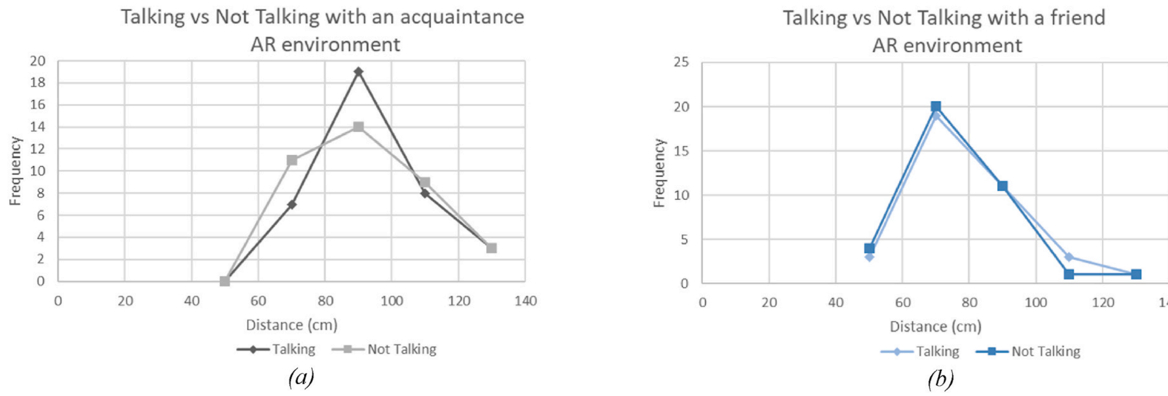

Fig. 7. Comparison of data while conversing and not conversing in: a) social experiment, b) personal experiment.

5. Cluster analysis

This chapter presents a clustering approach based on participants' gender and nationality. The aim is to identify common spatial behaviour patterns within these groups and understand how demographic variables influence interpersonal distance preferences.

5.1. Analysis by nationality

This section examines how participants' cultural backgrounds influence spatial behaviour. By comparing distance preferences across nationalities, the analysis highlights potential cultural factors shaping comfort zones in social interactions.

5.1.1. Anthropometric dimensions

The ethnic heterogeneity of the population also made it possible to carry out a study by nationality. Therefore, the two samples European and Asian were identified. 18 participants are European, while 17 are Asian. Table 8 in Appendix 1 shows the anthropometric values of the two samples.

In order to investigate whether anthropometric differences existed between participants of different nationalities, the Mann–Whitney *U* test was applied to the anthropometric variables (Table 9 in Appendix 1). This non-parametric test was selected because the two nationality groups were independent and the data did not follow a normal distribution.

The analysis revealed statistically significant differences between nationalities for Weight ($Z = -2.345$; p-value $= 0.019$), Stature Height ($Z = -2.042$; p-value $= 0.041$), Hip Breadth ($Z = -3.482$; p-value $= 0.000$) and Sitting Height ($Z = -2.479$; p-value $= 0.013$).

No statistically significant differences were observed for Popliteal Height ($Z = -0.754$; p-value $= 0.463$) and Buttock–Popliteal Height ($Z = -1.407$; p-value $= 0.163$).

5.1.2. Objective data analysis

Although statistically significant anthropometric differences were found between Asian and European participants, the Mann–Whitney *U* test did not reveal any statistically significant differences in the distance choices (social distancing reported in Table 10 in Appendix 1 and personal distancing reported in Table 10 in Appendix 1) made by the two samples across all tests. Since 8 comparisons were performed (4 levels × 2 types of distance: social and personal), a Bonferroni correction was applied ($\alpha = 0.05/8 = 0.006$) to control for Type I error. After applying this correction, none of the p-values fell below the adjusted alpha, confirming that there were no statistically significant differences between the samples.

To further support the robustness of these findings and assess the adequacy of the sample size, effect sizes (r) were calculated for each test level, providing an assessment of statistical power and helping to control for Type II error (β).

For the European sample ($N = 18$), very large effect sizes were observed across all levels ($r = 0.96$ at Level 1, $r = 0.93$ at Level 2, $r = 0.90$ at Level 3, and $r = 0.93$ at Level 4). Similarly, the Asian sample showed consistently high effect size values, with $r = 0.95$ at Level 1, $r = 0.95$ at Level 2, $r = 0.94$ at Level 3, and $r = 0.93$ at Level 4.

These consistently large effect sizes indicate that the analyses were sufficiently sensitive, confirming that Type II error (β) is unlikely to have affected the results, and supporting the interpretation that the lack of statistically significant differences in distance choices is not attributable to limited statistical power.

5.1.3. Subjective data analysis

There is a notable disparity in the preferences for the setup between the two samples. This statistical difference was detected with the Mann–Whitney *U* test with a p-value of 0.041.

The results show that only 22% of the European population preferred the face-to-face configuration, whereas the majority of Asians (59%) favoured the face-to-face setup. The preferred configuration among Europeans was that of Level 3, which was chosen by 78% of the population.

5.2. Analysis by gender

This section investigates how male and female participants differ in their management of interpersonal space. It highlights gender-based tendencies in preferred distances and spatial comfort during interaction scenarios.

5.2.1. Anthropometric dimensions

Using the same statistical approach described in the previous section for the nationality-based analysis, the Mann–Whitney *U* test was also applied to compare anthropometric measurements (Table 9 in Appendix 1) between female and male participants. The results indicated statistically significant differences for Height ($Z = -3.513$; p-value $= 0.000$) and Sitting Height ($Z = -2.246$; p-value $= 0.025$).

Table 11 in Appendix 1 presents the mean, mode, and SD values for each anthropometric measurement in both the Female and Male samples.

5.2.2. Objective data analysis

Once it was obtained that the samples present anthropometric differences, it was investigated how this difference affected the distances chosen by the participants. Therefore, Mann–Whitney U was performed for each test, both for social distance and personal distance data. The results of the Mann–Whitney U tests are shown in Table 12 in Appendix 1. Initial analysis suggested statistically significant differences in the second and third test, in which Beta setup is used.

However, to control for Type I error (α) due to multiple comparisons across 8 tests, Bonferroni correction was applied. The corrected significance threshold was calculated as α = 0.05/8 = 0.006. After applying this correction, none of the p-values fell below the corrected alpha, indicating that there is no statistically significant difference between the two samples when accounting for multiple comparison.

As in the previous analysis, effect sizes (r) were calculated for each test level. For the male sample (N = 21), very large effect sizes were observed across all levels (r = 0.97, 0.92, 0.93, and 0.92 for Levels 1–4, respectively). Similarly, the female sample (N = 16) showed consistently high effect sizes (r = 0.94, 0.97, 0.90, and 0.95). These results indicate that the patterns observed in distance selection are supported by robust effect sizes and are unlikely to be due to insufficient statistical power.

In order to compare the frequency distribution curves of the two samples, which have different sizes, their values have been indicated in percentage terms. From the graphs in Fig. 8, it is evident that the female sample consistently moved towards shorter distances in every configuration. The behavioural difference between the two samples was particularly evident in the results of the experiments conducted in levels 2 and 3 (see Fig. 9). In level 2, females preferred to maintain a distance of 70 cm from an acquaintance, while males chose a distance of 90 cm. From a friend, the females preferred to maintain a distance of 50 cm, while the males chose 70 cm. Regarding level 3, females preferred a distance of 90 cm from an acquaintance. The same distance was the most favoured choice for males, although their behaviour was more varied. females provided more varied responses in the personal distance experiment, with distances of 50 cm and 70 cm being preferred. The majority of males, on the other hand, chose to position themselves at a distance of 90 cm from a friend.

5.2.3. Subjective data analysis

No significant statistical difference was highlighted between the two samples regarding the preferred level.

It is interesting to see the different behaviour that the two samples had when faced with the questionnaire query: "Would you sit closer to someone of your own gender or would you sit closer to someone of the opposite gender?". As shown in Table 13 in Appendix 1 and in Fig. 9, in fact, the majority of females (81%) declare that they need greater interpersonal distance from a person of the opposite gender.

6. Discussion

6.1. Research findings

Participants' interpersonal space preferences varied notably across seating configurations, social relationships, and individual characteristics. No significant differences emerged between distances chosen while conversing or not, suggesting that verbal interaction alone does not strongly impact perceived comfort distance. The same finding was reported in (Wang et al., 2023) for standing people, in a VR Scenario, while interacting in different ways in a confined environment, so, this finding is completely new because no papers have already investigated this aspect of interaction while seated (especially inside an AV) and the statistical analysis was done on the entire sample of 37 participants; this number is able to create a valid and robust statistical analyses, being doubled than the sample used by Barbut et al. (Ferrier-et al., 2018) for investigating Level5 AVs interaction with a VR scenario, and wider than the sample used in Peng et al. (2025) for assessing comfort/naturalness rating while evaluating proxemics inside a Level 4+ AV riding in a VR scenario.

Familiarity played a major role: participants consistently maintained greater distances from colleagues than from friends, a difference that was statistically significant. This finding is in line with the results of Hall Theory (Hall, 1966) and confirm the results of Evans et al. (2007) about the effect of proximity with unknown people. Also, in (Ive et al., 2015) the preference of staying closer to friends and farer to stranger has been assessed (even if it was done without a statistical correlation). Also, in

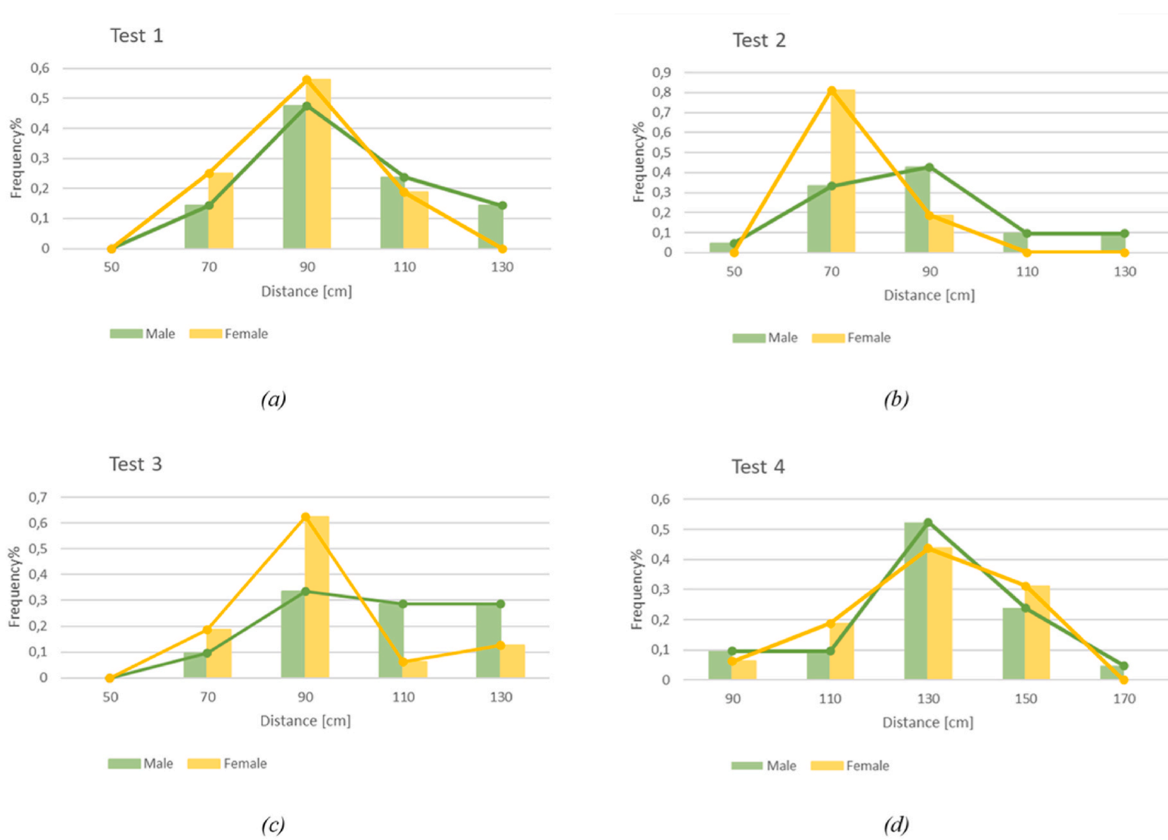

Fig. 8. – Comparison of selected social distances between the Female and Male samples, in: a) Level 1, b) Level 2, c) Level 3, d) Level 4.

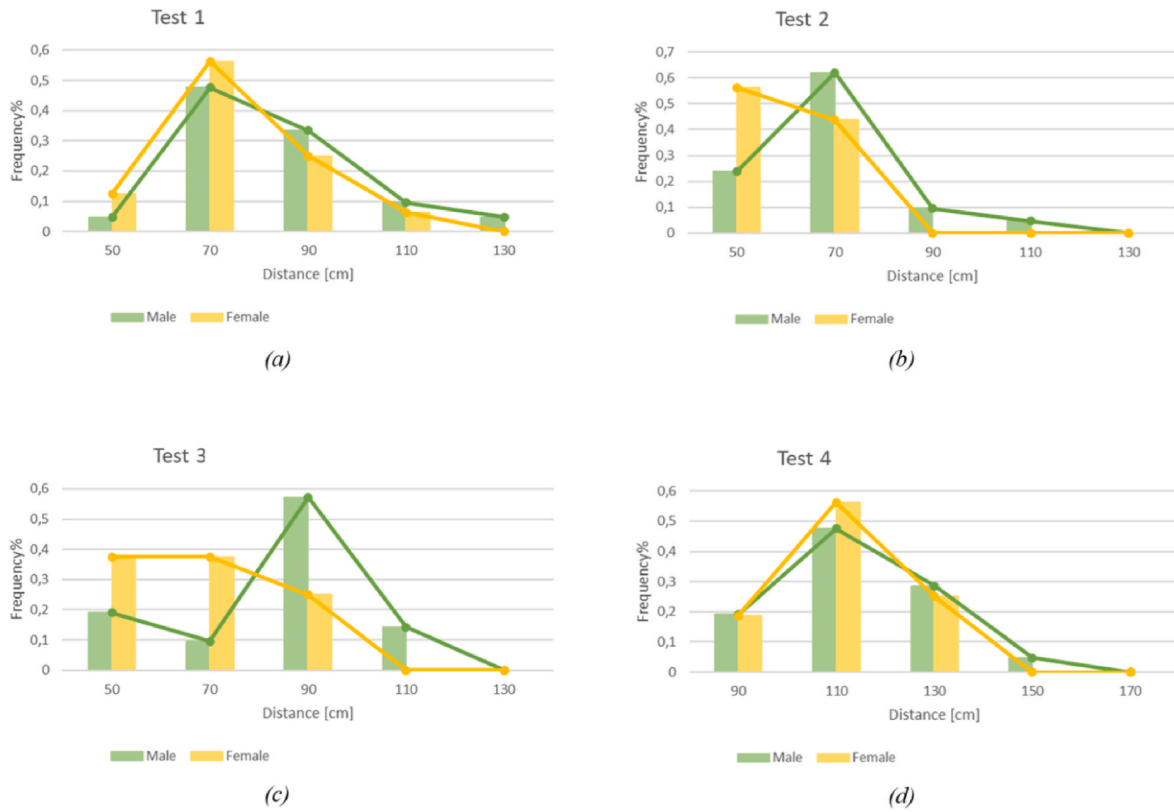

Fig. 9. Comparison of selected personal distances between the Female and Male samples, in: a) Level 1, b) Level 2, c) Level 3, d) Level 4.

Wang et al. (2023) the familiarity was investigated in standing position (inside a VR scenario) and a significative statistical difference was detected in preferred distance while interacting with acquaintances and strangers, so confirming the role of familiarity on preferred distances.

While Mann–Whitney tests, performed with Bonferroni correction ($\alpha = 0.006$) and showing large effect sizes ($r = 0.90$–0.97), revealed no statistically significant gender differences in how participants positioned themselves during a conversation with a friend versus an acquaintance, the gender of the interlocutor was found to influence spacing preferences. Seventy-three percent of participants reported adjusting their preferred distance based on the gender of their interlocutor. This result is in line with the findings of Page Ive et al. (2015) and Barbut et al. (Ferrier-et al., 2018). Females generally favoured closer proximity during conversations than males; this result validates previous works studying gender-based effects in proxemics showed in Hecht et al. (2019) based on experiments on a sample of 66 Caucasian people and in Wang et al. (2023); both studies are focused on standing people but the first one is based on a mixed experience (real-vs-VR and real-vs-real) while the second is based only on a VR simulated interaction. The results are also consistent with results obtained by Aiello (1987).

Additionally, sixty percent of participants reported that the interlocutor's physical size influenced how much space they needed to feel comfortable. This finding is in line with results obtained in the experiments by Fiorillo et al. (2021) in which a statistical correlation between the preferred seat configuration (distance) and the interlocutor's height has been highlighted in a confined space representing a Train compartment.

As a secondary result, the analyses revealed a cultural difference in seating arrangements: Asian participants preferred face-to-face configurations, while European participants favoured setups with slight lateral displacement to avoid direct frontal contact. However, Mann–Whitney tests with Bonferroni correction for multiple comparisons, supported by large effect sizes, showed no statistically significant differences in the actual distance between seats across the two cultural groups. This indicates that while seating setups differ culturally, the interpersonal distance itself remains largely similar. These insights underscore the variability in spatial needs based on cultural and personal factors. In (Wang et al., 2023) a low ethnicity effect has been detected in "gaze toward no-speaker" and in "mutual gaze" and also statistical differences have been detected among races and ethnicity towards Gaze in "spatially accommodated conditions"; Wang et al. used a VR scenario and a MR environment that is similar to the one described in this paper but for standing people. Nevertheless, the results are comparable and, even if the clustering produces two small samples (18 European and 17 Caucasian) if compared with the wide sample used by Wang et al. (128 people), the statistical robustness has been validated.

In conclusion, geometric variables that characterize the cabin layout of an AV needs to be adjustable in order to fulfil the different needs of people, based on gender, nationality and familiarity, in order to be comfortable and acceptable by a general user. The right design approach is to provide a flexible seating design archetype whose adjustable feature are:

1) adjustable sagittal distances among not less than three values: 110 cm, 130 cm, and 150 cm;
2) adjustable lateral positioning among not less than three values: 0 cm, 25 cm, and 50 cm.

Obviously, a continuously variable system, like a bidimensional rail system, will allow to accommodate any preferred value.

6.2. Limitations

6.2.1. Sample representativeness

The first and probably the most important limitation of this study is due to the limited number of people that participated to the experiments and to their belonging to a limited social environment (in that case, people from university of Delft). Nevertheless, in recent literature other authors have used a limited number of participants to assess their results. For example, in (Ferrier-et al., 2018), only 19 people, being all students and professors of the same university, were enough for performing a valid statistical analysis (like gender effect), while in (Peng et al., 2025) authors demonstrated several correlations among investigated factors and comfort/naturalness rating, doing a valid statistical analysis on only 14 volunteers. On the other hand, papers dealing with ethnicity, like the (Evans et al., 2007) and nationality, like (Ferrier-et al., 2018) and (Sorokowska et al., 2017) used higher numerosity of the sample for supporting their thesis. For that reason, in order to validate our findings about nationality, a wider sample of participants and a more representative-by-country groups are needed. Despite this, the study applied thorough statistical analyses: distances for interactions with friends versus acquaintances were compared using Wilcoxon tests with Bonferroni correction ($\alpha = 0.0125$), and effect sizes ($r = 0.60–0.95$) were calculated to assess statistical power. These results confirm that the observed differences between personal and social distances are robust and meaningful, even with a limited sample.

6.2.2. *Imposed constraints*

This study aimed to identify the interpersonal distances that people prefer to maintain during a conversation. It focused on only two of the four interpersonal zones identified by Hall: the "social zone" and the "personal zone." However, it would be interesting to repeat the experiment by involving participants interacting with strangers even if the interaction happens inside a closed limited space. Another limitation of the tests conducted was restricting the rotation of the seats to only 0 and 180-degree angles. In a human-centred perspective, it would be beneficial to determine the preferred angles for passengers in each configuration.

6.2.3. *Scenario limitation*

It should be noted that the context in which the tests were conducted, in a large room with desk chairs, may have influenced individuals' perception of space. In order to reproduce, as better as possible, the real scenario (the interior of a Tesla Model 3) some panels have been used to confine the available space. No physical roof was not used both for safety and for experimental needs in order to make the AR device useable and spatially detectable. Fortunately, one of the advantages of augmented reality is the ability to easily modify the scenario used, so it is proposed to repeat the experiments by having participants experience the scenario of a self-driving car. Like in (Ferrier-et al., 2018) and in (Wang et al., 2023) the VR Environment was used for analyse the interaction in a confined space, so the use of AR/VR cannot be considered as a real limitation. Of course, in the future, it will be possible to recreate a real scenario inside a vehicle prototype and perform again the experiments.

Like in (Wang et al., 2023) the environment simulation neglected completely the comfort aspects related to the level of noise or quietness; it is notable that in a closed environment those factors can alter the quality of a conversation and the need to approach one's interlocutor to understand their words. Nevertheless, this aspect was a little out of our purpose so it has been neglected. Therefore, it is proposed, for future activities, to enrich the scenario by incorporating sounds that we hear when inside a car, such as acceleration noises, sounds of a passing motorcycle etc.

Another limitation can be represented by the use of a standard office chair instead of a Car-seat. In (Ferrier-et al., 2018) the same kind of experiments has been performed using a standard soft office chair in a Virtual scenario and have been considered valid and consistent. Furthermore, in a new design paradigm of car-interiors, t can be imagined that less restrictions on shapes, geometries and layout will be possible.

6.2.4. *Colour blindness*

When creating the scenario for levels 1, 2, 3, and 4 of the AR game, no consideration was given to the possibility that participants might not be able to recognize colours. This limitation of the scenario can be easily overcome by also creating the earlier levels, similar to how the last level was designed. In other words, by distinguishing distances not by the colour of the spheres but by numbering each sphere progressively.

7. Conclusions

This study builds on Hall's proxemic theory by examining how interpersonal distance preferences vary in seated interactions, particularly within autonomous vehicle environments.

The main target of this study was to give an answer to four research questions.

1) Which seating configuration is most comfortable for passengers during a conversation?

No significant difference was observed between distances selected during conversations and those chosen in silence, indicating that verbal interaction alone does not substantially influence comfort distance. So, the results about comfortably distances found by Fiorillo et al. in (Fiorillo et al., 2019) and (Fiorillo et al., 2021) can be applied inside an AV without being affected by the type of interaction.

2) What are the ideal seating distances in each configuration?

The results confirm that the type of social relationship plays a key role in defining preferred spacing: participants consistently maintained greater distances from colleagues than from friends, in line with Hall's distinction between personal and social zones and with findings from Sorokowska et al. (2017) and from Fiorillo et al. in (Fiorillo et al., 2019).

3) How does gender influence interpersonal space requirements?

Participants of different genders did not show statistically significant differences in the distances they chose when interacting with friends or acquaintances. This conclusion is supported by Mann–Whitney U tests, corrected with Bonferroni adjustment to control for Type I error due to multiple comparisons, and by effect size calculations, which confirmed sufficient statistical power and ruled out the possibility that the lack of differences was due to Type II error. Nevertheless, participants reported that the gender of the person they were interacting with influenced their preferred distance. About 73% of respondents indicated that they adjust their spacing depending on whether they were interacting with a male or female interlocutor. Consistent with Aiello (1987) and Ozdemir (2008), females tended to prefer closer proximity, especially in same-gender interactions, while also maintaining greater distance when interacting with males. The perceived physical size of the interlocutor influenced the spatial preferences of 60% of participants, suggesting that visual impressions of body size can affect comfort zones—an aspect still underexplored in proxemic literature. Findings are also consistent with Fiorillo et al. (2021) in which a statistical correlation between the preferred seat configuration (distance) and the interlocutor's height was found.

4) How does ethnicity impact interpersonal space preferences?

Participants from European and Asian backgrounds did not show statistically significant differences in the distances they maintained from friends or acquaintances during the experimental tasks. In other words, the data indicate that both groups behaved similarly in terms of the space they kept during interactions, regardless of the social relationship. This conclusion is supported by Mann–Whitney U tests with Bonferroni correction ($\alpha = 0.006$) for multiple comparisons, which confirmed that none of the differences were statistically significant. Effect size calculations (r = 0.90–0.96) indicated that the tests had sufficient statistical power, suggesting that Type II error is unlikely. However, the analysis revealed that the two groups differed in how they chose to position themselves in a conversation. Asian participants tended to prefer a face-to-face seating arrangement, while European participants favoured a slight lateral displacement. These preferences are consistent with Hall's classification of contact and noncontact cultures, and are supported by observations from Sommer (1962) and Fiorillo et al., 2019, 2021, particularly regarding legroom and head rotation. Even if the sample cannot be considered as well representative of such a wide and different geographic area (European -vs- Asian), results are in line with (Wang et al., 2023) by Wang et al.

As design feature suggestion, this paper allow to affirm that, overall, interpersonal distance appears to be shaped by a dynamic interplay of social, cultural, gender-related, and ergonomic factors. In response to this variability, a flexible seating layout—featuring three sagittal distances (110, 130, 150 cm) and three lateral options (0, 25, 50 cm)—is recommended to support diverse comfort needs and facilitate adaptive, socially sensitive vehicle interiors. Future investigation could take into account also seat rotation and real vehicle features and interactions like complete confined space, vibration and noises.

CRediT authorship contribution statement

Ilaria Chiriani: Data curation, Methodology, Software, Writing – original draft. **Iolanda Fiorillo:** Data curation, Methodology, Resources. **Wolf Yu Song:** Formal analysis, Methodology, Software, Validation. **Peter Vink:** Conceptualization, Project administration, Writing – review & editing. **Alessandro Naddeo:** Conceptualization, Project administration, Supervision, Validation, Writing – review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

The author is an Editorial Board Member/Editor-in-Chief/Associate Editor/Guest Editor for this journal and was not involved in the editorial review or the decision to publish this article.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.apergo.2026.104841.

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