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ORIGINAL ARTICLE

New proxemics in new space: proxemics in VR

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Abstract
With the development of computer technology, it is possible to design virtual reality (VR) media that provides services to multiple users. Hall's proxemics theory, which holds that the distance varies depending on the relationship between people, has been applied when designing VR in such media. However, this concept was usually applied to designs without criticism and without confirming whether proxemic distances established in physical space are equally valid in VR. This study investigated how proxemics in VR activate differently from those in a physical space. We measured the distance and the number of instances of direct contact between people, with 69 participants from Korea and Turkiye. As a result, a proxemics pattern similar to that of a physical space appeared in VR. However, the average distance between participants in the VR was about 160% greater than in the physical space. Also, we could observe direct contact up to 260% more in the VR than in the physical space. We analyzed the collected data using Bayesian ANOVA and t-tests. We could clarify the difference between the two proxemics in physical space and VR, but the reason for the phenomenon has yet to be discovered. However, this study is meaningful because any industry designing VR, such as those in digital games, can directly apply the findings to manipulate multiple users' emotions and experiences more efficiently. Additionally, this study provides directions for any future studies discussing VR design.

Keywords VR · Virtual space · Proxemics · Human-computer interaction

1 Background

The development of computer technology has made it possible to implement a virtual reality (VR) that can provide a higher degree of immersion. Accordingly, we often see attempts to implement a virtual landscape that designs users' experience beyond VR, simply a visually sophisticated space. These developments include several games or other types of content that induce collaboration among multiple users in VR and lead to the creation of various experiences that occur independently.

Looking at contents that utilize VR to accommodate multiple users or examples of related studies, most have Hall's proxemics theory as the basis for their design (Hall 1966). This theory explains how the distance between multiple people varies according to their social relationships. If the people in question are in a romantic relationship, they will maintain a close distance of less than 50 cm; if they are friends, they will keep a distance of more than that, and if they are in a public relationship, they will keep a distance of more than 2 ms.

If VR uses these figures, an ideal design that accommodates multiple users becomes possible. However, the problem is that Hall's theory and figures are typically calculated in physical spaces. Hall established proxemics theory as an anthropologist by observing the behavior of various animals and people in physical spaces. However, he could not study how his theory would work in non-physical spaces such as VR. Additionally, not enough research has investigated how the concepts associated with proxemics work in VR thus far. We have been habitually using his theory without criticism, assuming it applies in VR.

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For example, Williamson et al. (2022) ran a study comparing proxemics between head-mounted displays (HMD) and monitor users. The pattern and results are clear, but the research has been conducted based on the assumption that users will share the same volume of proxemics in VR as in physical space. McCall et al. (2009) adopted the concept of proxemics to measure the aggression of individuals. Still, the research was also conducted under the premise that proxemics was the same between the physical space and VR. Same for Kolkmeier's research (Kolkmeier et al. 2016). The researcher adopted the concept of proxemics to understand the interaction between non-playable characters but adopted the concept without criticism. As listed, research with proxemics uses the theory, assuming it works similarly in VR.

Therefore, we must understand whether Hall's proxemics theory works equally well in VR. Suppose his theory requires values or ratios different from those in physical spaces. Then, we can expect the same effect of the proxemics as in physical space only if we apply it to VR designs based on such differences.

For this reason, this study aims to understand whether the proxemics is equally applicable in VR. With the results of this study, we can create interactive activities between multiple users more naturally in VR. In addition, the results here will be valuable as a starting point for those who study users' social behavior in non-physical VR (Hasler and Friedman 2012).

2 Proxemics

The anthropologist Edward Hall proposed the concept of proxemics, defining it as the interrelated observations and theories of humans' use of space as a specialized elaboration of culture (Hall 1966).

According to his theory, a person defines the relationship between another person and oneself by integrating various forms of information from senses, such as hearing, smell, and touch, as well as the sense of sight and related memories. With the collected information, the person creates an invisible bubble around oneself according to that relationship. This concept is similar to an animal's territorial behavior.

According to observations by Hall, proxemics is a phenomenon common to all humans worldwide. In addition, Hall argued that the distance between people affected by the size of the bubble could be classified into four types: intimate, personal, social, and public (Hall 1966). Figure 1 presents the concept of proxemics.

The intimate distance is the closest distance within proxemics, at 0 to 46 cm (0 to 1.5 ft). At this distance, intimate 'skinship' behaviors, such as hugging and touching, naturally occur between close people, and they typically whisper

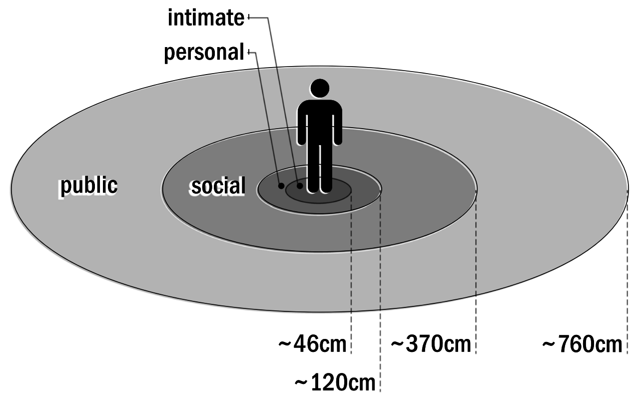

Fig. 1 The concept and the distance of proxemics

to each other. It is a distance between lovers or family members, and one can feel the other's heat and breath and sense their scent. Next, the personal distance is between 46 to 1.2 m (1.5 to 4 ft), the distance one interacts with friends. Social distance is an official distance between 1.2 to 3.7 m (4 to 12 ft). It is the distance at which social interactions occur, for example, between employers and employees or students and a professor. Interactions between senses other than sight and hearing do not occur at these distances. Finally, the public distance is between 3.7 to 7.6 m (12 to 25 ft), which is the distance associated with speaking in public. At this distance, voices become louder, and eye contact with others decreases.

Hall proposed proxemics after years of observation and discussed how each distance ratio of proxemics differs depending on culture and ethnicity. This difference affects architecture and urban planning and influences the shapes of spaces based on their ethnic and geographic locations. For example, in warm regions near the equator, interactions between people occur at a shorter distance than in regions in the northern or southern hemispheres. This indicates that people's non-verbal communication is a spatial element, directly impacting the designs of spaces.

Therefore, space-design experts such as architects, urban planners, and landscape architects actively adopt the proxemics concept in their design processes. Cheong Yin Mei, Buai Chin, Taib (2017) studied the layout of classroom furniture, the placement of students' seats, and the teacher's movement in the classroom in relation to proxemics and the influence of these concepts of learning ability. Aydoğan and Şalgamcioğlu 2017 traced customer pedestrian flows in a shopping mall to understand the relationship between the density of customers and the characteristics of commercial items. According to these studies, the interactions between people and spaces directly affect the layout and characteristics of the spaces.

Proxemics has been applied not only to physical spaces but also to VR. Mueller et al. (2014) designed VR content

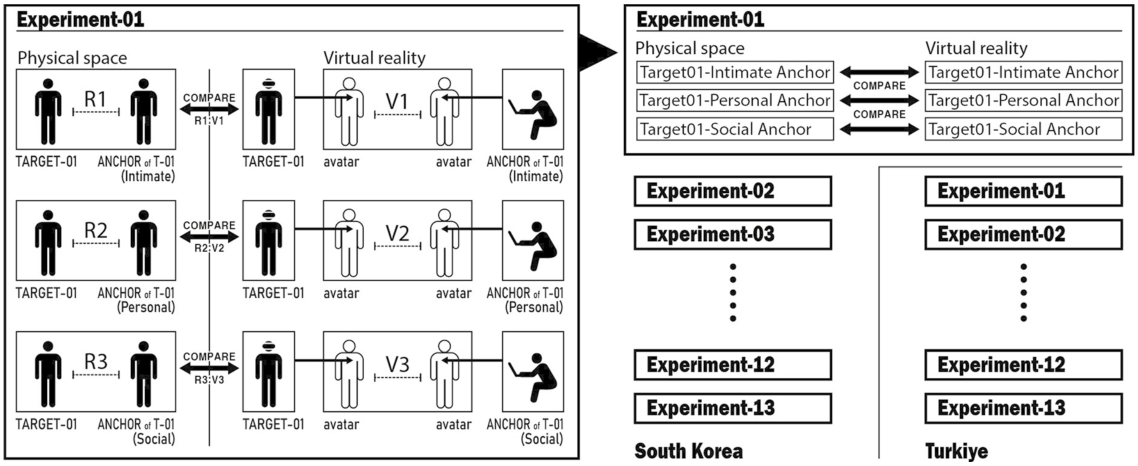

Fig. 2 The experiment structure

that multiple players can enjoy cooperatively based on proxemics theory. Merritt et al. (2017) studied how to induce more active interactions between players based on the theory of proxemics. Likewise, in the digital game industry or in human-computer interactions (HCI), a space of a specific size was proposed based on proxemics theory to induce more active conflicts or cooperation between multiple users.

It is common to find studies and projects adopting the proxemics theory to accommodate multiple users efficiently in VR and induce specific emotions or actions.

However, research on how exactly proxemics work in VR has yet to be conducted. It is challenging to find a study on the differences between VR and physical spaces in relation to this theory. Most studies or projects adopt proxemics while assuming they work similarly in VR. Li et al. (2019) found that people utilized the same proxemics in VR as in physical spaces while examining the differences between humans and robots. Work by Llobera et al. (2010a) revealed that people maintain different proxemics distances depending on how similar the game object in question is to a person in the VR. However, their study is also based on the assumption that proxemics work similarly to how they function in physical spaces.

3 Methodology

The present study concentrates on three types of distances: intimate, personal, and social, to examine whether Hall's proxemics theory works similarly in physical spaces and VR. The study removed the public distance from the scope because interactions in public places or situations do not often include physical contact or visible interactions.

Most proxemics studies also exclude public distance. Sorokowska et al. (2017) conducted experiments with 8943 participants from 42 countries, studying proxemics by assigning the intimate distance to those who are close to an individual, the personal distance to acquaintances, and the social distance to strangers, omitting the public distance. It is limited to finding any proxemics reference focused on the public scale, including Sorokoska's study (Sorokowska et al. 2017). Most of the research studying proxemics mainly removes the public. We can assume that it is because the last type of proxemics, the public, is relatively rare in our daily lives, and it is challenging to design an experiment to investigate it. This study also removed the public proxemics with the same logic and focused on the rest of the types.

A series of comparative experiments in this study observes distances between participants, and the frequency of direct contact between individuals is compared. Here, direct contact refers to any contact between participants in a physical space and VR. Additionally, this study does not define the characteristics of each type of direct contact, with only the number of these instances counted. Figure 2 presents the overall structure of the experiment.

Hall created the theory based on observations of various countries and cultures to minimize errors and provide the most general findings, so this study conducted experiments in Korea and Turkiye.

Based on the study by Hofstede (1984) and study by Onder and Nyadera (2020), the culture in Turkiye is slightly more masculine and collectivist than in Korea. However, both are at the same level of uncertainty avoidance and low individualism. Therefore, we assumed it would be easy to find any similar patterns between the two countries' results, and if the research finds any significant differences between the two, tracking the reason for the phenomenon would be efficient. Additionally, because each research member of this study was located in both countries, running a series of synchronized experiments was ideal.

Table 1 Participants in experiments

Title	Detail	Movement	Participation
Target	Target of each experiment	Target can move freely	Target can participate in other targets' experiments as personal or social anchors However, he or she can participate in another's experiment after his or her experiment as a target
Anchor 1 (intimate)	Anchor in an intimate relationship with the target	Anchor cannot move	Intimate anchors only can participate experiment once as an intimate anchor
Anchor 2 (personal)	Anchor in a personal relationship with the target	Anchor cannot move	Personal anchors can participate in other targets' experiments as personal or social anchors
Anchor 3 (social)	Anchor in a social relationship with the target	Anchor cannot move	Social anchors can participate in other targets' experiments as personal or social anchors

13 participants from each country participated in the experiment as targets, and 23 from Korea and 20 from Turkiye participated as anchors. As anchors couldn't move in the experiment to affect the distance value, anchors could participate repeatedly in different targets' experiments. Therefore, a total of 69 participants participated in the experiments. Detailed information about each step of the experiment is presented in Fig. 2, and the detailed condition of the participants is described in Table 1.

The purpose of the experiment conducted in this paper is to observe the distance values generated by the target for different types of anchors and to understand how the distance values appear differently in physical space and VR. We observed three distance values in physical space and three in VR for each target. Six values of direct contact were collected for each target using the same procedure.

Targets can move freely in physical space and VR, but anchors cannot. This is to measure the distance efficiently. Targets can participate in other targets' experiments as anchors but can only participate after joining their experiment as a target. Anchors can participate in other targets' experiments. This repeated participation doesn't affect the result, as anchors cannot move during experiments.

3.1 Subject recruitment

In the process of recruiting the experimental subjects, we kept the exact purpose of the research a secret to minimize contamination of the participants. We only reported that the research seeks to understand interactions between people in VR. Within the recruitment procedure, we announced that participants with romantic relationships (Anchor 1 as intimate) and friends (Anchor 2 as personal) could also participate in the experiment.

Every participant was a university student, and researchers could designate Anchor 3 (social), which could consist of researchers or professors at their school. The research team was also included in the Anchor 3 group. This participation was deemed feasible; although the researchers participated in the experiment, this participation did not directly affect the outcome, and contamination was impossible.

For 102 subjects, 61 university students between the ages of 23 and 28 attending universities in Turkiye and 41 with the same conditions at universities in Korea volunteered for the experiment. We collected their contact information and provided information about the third anchor who would participate in the experiment and a survey.

Table 2 Survey items and answers

Survey items	Answer style
Digital games familiarity	5 point Likert scale
HMD experience	Yes/No
Impression about digital contents	5 point Likert scale
HMD ownership	Yes/No
Interested in VR	5 point Likert scale
Game play time per week	Description
Self consideration as a gamer	5 point Likert scale

3.2 Survey and subjects selection

The survey collected each participant's basic, personal information, their familiarity with contents and technology such as VR, HMD, and digital games, and the depth of the relationship with the anchors who would also participate with them. Table 2 presents collected survey items. The survey was conducted remotely through Google Forms. The following link contains the survey questionnaires.[1]

Through the questionnaire, we excluded individuals unsuitable for the experiment. These were persons who had maintained a relationship with the first anchor for less than six months and couples when the gender of the first anchor and the target were the same. These individuals were excluded given the likelihood that couples whose

[1] https://www.virtuallandscape-ik.com.

Table 3 The number of participants in the experiments

Nationality	Recruited	Selected	Participants	
			Target	Anchor
Korea	41	36	13	23
Turkiye	61	33	13	20
Total	102	69	26	43

relationship has not been maintained for more than six months will not have established a deep enough relationship.

Additionally, we did not find a reference holding those proxemics between intimate couples of the same gender work identically to that between heterosexual couples. As a result, we recruited 102 participants and selected 69 for the experiment throughout the screening based on the survey. The detailed number is presented in Table 3.

3.3 Pilot test

We ran two pilot tests separately, both in Korea and Turkiye. We found through the pilot tests that measuring the exact distance with 50 cm grids on the floor in a physical space is challenging. Therefore, we reduced the size of the grid spacing from 50 to 25 cm.

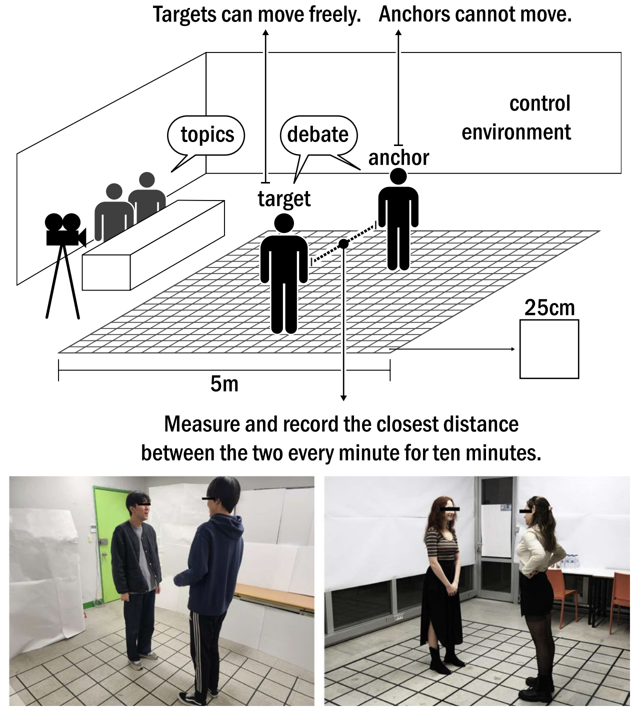

Fig. 3 Physical experiment environment

3.4 Experiments and data collection in physical space

As this experiment was conducted in two different countries, we attempted to provide the same experimental environment to the subjects to minimize any noise in the results. We established the space in the following steps.

First, a space measuring 25 square meters was selected to let participants move while conversing. Second, we created a grid with 25 cm spacing distances on the space floor. This grid served to measure the distances between participants. Third, all windows, doors, furniture, and clocks in the experimental space were removed or covered with white paper to block subjects from noise or unnecessary stimuli so that the subjects could concentrate on the experiment.

In each experiment, two researchers participated. One conducted the overall process of the experiment, and the other recorded the overall process and the necessary information. Figure 3 presents the physical experiment spaces.

Additionally, the order of participants in the experiment was randomized. Targets could meet intimate or personal, or social anchors in random order. This random order was to minimize any possible influence on the experiment.

Experiments in physical spaces were conducted in the following order. First, the researchers guided one target and one anchor to enter the experiment space. Second, a researcher delivers safety guidelines to the target and anchor. This safety guidance includes the fact that the participants can stop the experiment immediately if feeling uncomfortable.

Third, the anchor was ordered not to move during the experiment. The instructions were delivered by calling the anchor out of the test space so the target could not perceive it. Additionally, the researchers instructed the anchors not to share this guidance with the target until the next experiment in VR. This instruction prevented any effect on the experiment if the target recognized that the anchor could not move.

Fourth, the researcher provides a topic of conversation to let the target and the anchor share and discuss the topic. As conversation mediates human-to-human interaction and induces space (Gurevitch 1989), proxemics can be expected to be expressed more clearly through proper conversation. The topics of the conversation are designed to let the target and the anchor naturally continue the conversation for ten minutes and in three categories.

First, an ice-breaking theme is presented to ease the awkwardness and tension of the subjects before full-fledged communication (Inaguma et al. 2016; Chao and Fan 2020; Eggleston and Smith 2004). The ice-breaking topics are casual topics that do not require one's personal opinion. The second conversational topic group requires the expression of personal views. The third conversation topic actively requires personal opinions. They are designed to induce active discussion between the target and the anchor.

Table 4 Collected data from physical space

set No	EXP No	TARGET CODE	ANCHOR CODE	ANCHOR TYPE	Imza	Date	Time	Distance (cm) / physical contact in red											Contact	Average (m)
								0m	1m	2m	3m	4m	5m	6m	7m	8m	9m	10m		
1	1	K02	K04	1	YY	0817	1737	10	20	15	10	40	50	0	30	120	30	60	2	35.00
	2	K02	K03	2	YY	0817	2102	50	40	45	50	50	70	55	50	60	50	55	0	52.27
	3	K02	K01	3	YY	0817	2142	70	75	65	120	45	60	50	90	90	120	90	0	79.55
2	4	K05	K06	1	YY	0907	1901	90	90	60	60	75	60	50	70	30	45	60	2	62.73
	5	K05	K07	2	YY	0913	2002	140	120	120	120	115	125	130	130	125	130	130	0	125.91
	6	K05	K01	3	YY	0915	2158	220	175	170	180	180	175	195	195	190	195	190	0	187.73
…																				
13	39	K41	K42	1	YY	1204	2021	60	60	45	90	90	75	45	80	80	80	55	0	69.09
	38	K41	K39	2	YY	1204	1940	100	80	90	105	110	115	90	110	100	100	105	0	100.45
	36	K41	K01	3	YY	1204	1847	200	200	210	220	210	230	230	240	240	240	225	0	222.27

The researchers selected and provided appropriate topics from three conversation topic pools so that the subjects could naturally continue and gradually focus on the conversation. These conversation topics are discussed in (Inaguma et al. 2016; Chao and Fan 2020; Eggleston and Smith 2004). The following link contains the conversation topic pool.[2]

We video-recorded and photo-recorded every process during the experiment. After the experiment, the data were used for verification by comparing them with the data entered during the experiment.

The researchers collected two data types during a ten-minute conversation between the target and the anchor. The first is the distance between them, and the second is the number of instances of direct contact between them. The distance value was measured based on the minimum distance between two participants every minute.

We measured the closest distance between the target and the anchor in the photo and video by comparing the image to the grid on the floor. Originally, we planned to use any device with sensors, but the accuracy was not detailed enough and was inefficient for a series of experiments. We also planned to use any deep learning methodology to automatically measure the distance from the video, but the number of cases was not large enough to train AI. Therefore, we measured distance manually.

For each experiment, a total of eleven distance values were measured for ten minutes, including the distance value at the start of the experiment. Direct contact was measured whenever it occurred, and the researchers marked the time when the direct contact occurred. Each data point was measured in real-time as the experiment progressed and entered into Google Sheets. Table 4 is an example of the collected data.

3.5 Experiments and data collection in VR

According to Yaremych and Persky (2019), recording subjects' real-time VR behaviors can facilitate the evaluation of behaviors such as those in a physical space. Therefore, this study designed a VR to compare behaviors to those in a physical space. The designed VR was intended to provide subjects with the same space to minimize errors.

Currently, various services such as VRchat (2014), vTimeXR (2015), and Rec Room (2016) provide VR to the public for gaming or remote meetings. Among these services, this study selected Mozilla Hub (Mozilla Foundation, 2018) as an experimental tool. Mozilla Hub provides a relatively low level of graphics compared to other VR services. The low graphics levels help the service stabilize various devices, such as HMD and mobile devices. In this study, providing a stable environment for the repeatedly conducted experiments as designed here is a critical selection factor. In addition, Mozilla Hub provides simplified avatars compared to other VR services that allow detailed decoration of avatars. These minimally designed avatars will minimize any chance of the avatar's design being a variable in the experiment. Mozilla Hub was also selected because it is more advantageous when creating an experimental environment, as it allows more freedom in customizing the space compared to other services.

With Mozilla Hub, we designed the experimental space with the following conditions. First, the VR was a 10-square-meter platform. As the physical space of the experiment was a space of about 5 ms in terms of width and length, the VR should be the same size. However, it was necessary to create a larger space to prevent collisions and possible accidents among the participants wearing an HMD.

Second, on the platform, a grid with spacing distances of 25 cm in terms of the length and width was positioned in the same format used in the physical space to help researchers to measure distances (see Fig. 4).

Third, the avatars for the target and the anchor subjects were placed in the space. Mozilla Hub offers avatars of various designs, but we selected the one with the most basic shape (see Fig. 5). This selection minimizes the risk that the size and shape of the avatar would act as a variable affecting the experiment. The experiment participants as a target can connect to the VR as an avatar by wearing an HMD and using a handheld controller. Both Korea and Turkiye used

[2] https://www.virtuallandscape-ik.com.

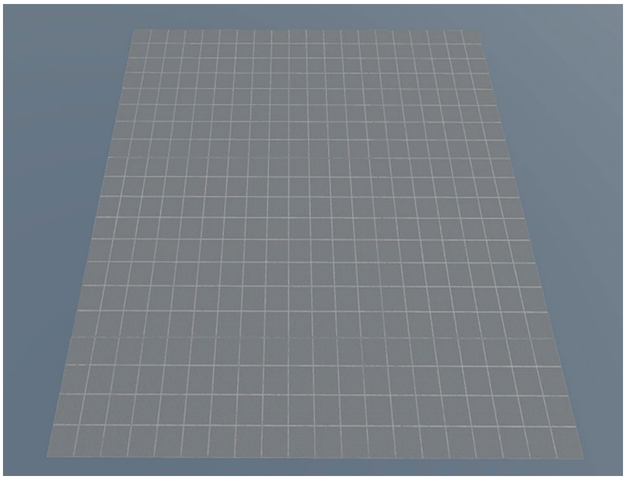

Fig. 4 Grids on the VR platform

Fig. 5 Selected avatars for experiments

the same HMD model, Meta Quest 2, to prevent errors and variables that may occur due to differences in hardware. The Meta Quest 2 model was developed in 2020 by Meta and is equipped with two displays of 1832 × 1920 pixels, providing images from a minimum of 60 Hz to a maximum of 120 Hz.

Fourth, we eliminated every object and façade other than avatars in the VR. Figure 6 presents only the floor with the grid, sky, and avatars placed in the space. This design minimizes the risk that other environmental factors may become variables affecting the experiment. For the same reason, the floor platform and grid colors are monochrome. The light in the space used was ambient light to prevent light and shadows from affecting the experiment. In addition, the amount of light was also designed to be at an inconspicuous level.

Lastly, we designed and placed the avatar as the observer during the VR experiment. To minimize any possibility that the participants realize the observer's existence and behave unnaturally, we selected the most abstractly designed avatar in monochrome color as camouflage. Additionally, this observer's avatar was placed 30 m above the ground platform facing down. Figure 7 presents the avatar's shape and location, and no participants could realize its existence during a series of experiments.

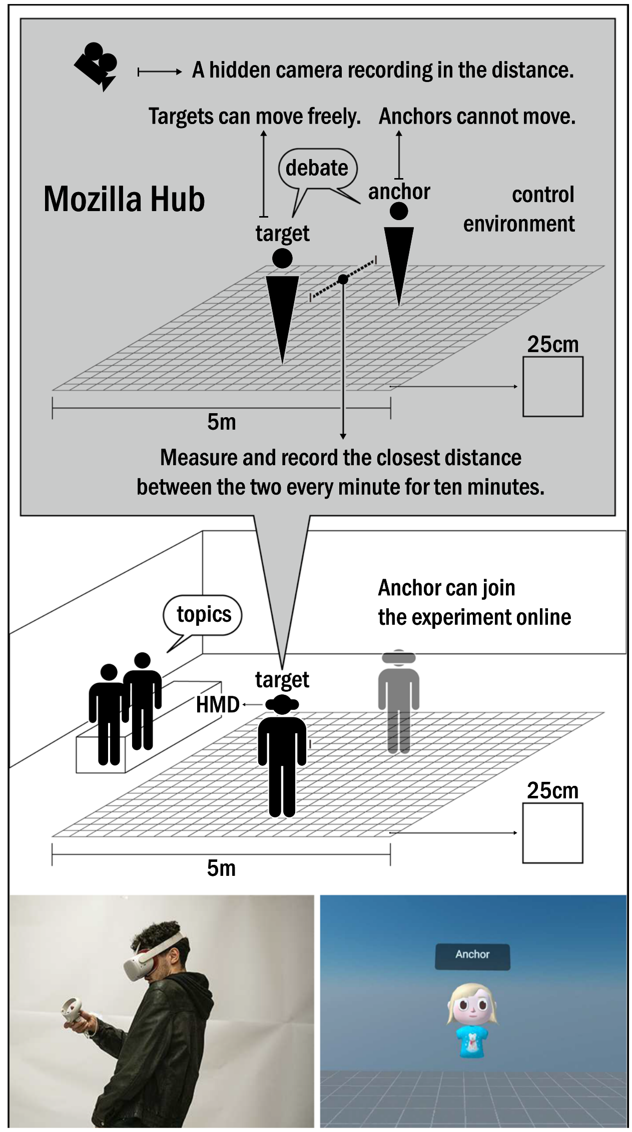

Fig. 6 Experiment environment for VR experiments

The VR experiment was conducted in the following order. First, the target enters the physical experiment space. In the meantime, the researcher delivers the message to the anchor not to move when the experiment begins. The anchor enters another independent experiment space. The anchor can access Mozilla Hub remotely. The researcher explains the safety rules to the target, and the target puts on the HMD. After wearing the equipment, the researcher lets the target move freely for a minute to become accustomed to the equipment. During this process, the experiment was planned to be stopped if the target complained of motion sickness or various abnormal symptoms. However, no participants complained of these symptoms, and no experiment was stopped.

Second, the researcher positions the anchor in the VR platform's center and instructs the target to stand in a

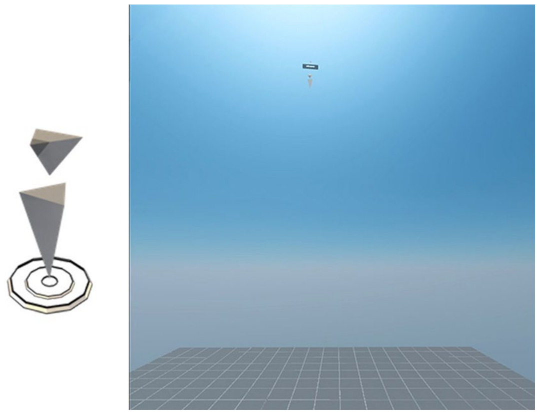

Fig. 7 The shape and the location of the observer

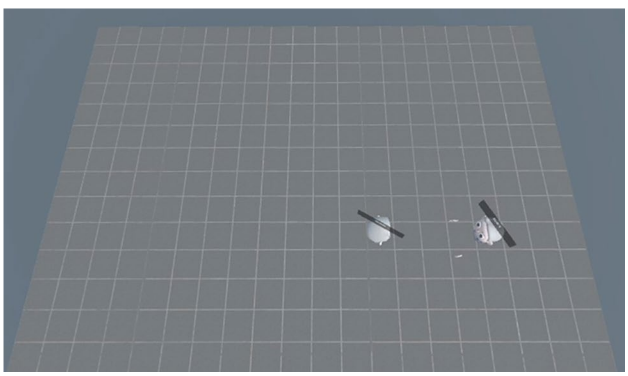

Fig. 8 Observing the experiment in VR

comfortable position. Third, one researcher starts the experiment and records the time for ten minutes, while the other provides a topic of conversation for the target and Anchor. Conversation topics are from the same pool used in the physical space experiment. However, the researchers provided topics different from those in the physical space experiment. The conversation pool is given in the appendix. The researcher measured the time in VR as an avatar, measured the data in flight mode, and put it into Microsoft Excel. Figure 8 presents the scene when observing the experiment in progress.

The observed and recorded data format was identical to that in the physical space experiment. We recorded the minimum distance between the two avatars, and eleven distance values, including the distance value at the start, were measured.

The distance was measured using the same method as in the physical space, manually counting the grid between the closest distances. Similar to measuring the distance in physical space, it was inefficient to adopt any deep learning methodology due to the scale of the data we collected. Additionally, as we used the same absolute matrix scale in VR when we designed and built it, we could calculate the distance in VR as the same in the physical space.

Direct contact was measured eleven times every minute, including at the initial starting point. Video recordings and screen capturing were utilized during the experiment, as in the experiment in the physical space. After the end of the experiment, we used the recorded data for verification through a comparison with the data entered during the experiment.

Additionally, as with the experiment conducted in physical space, the targets participated in the experiment in random order. Targets could face three different types of anchors in random order.

3.6 Data analysis

The collected data was saved in Google Sheets, and statistics were compiled to answer the research question. Does proxemics theory work in VR as it does in a physical space? If any difference arises, how large is the difference? Comparative analyses of the distances and the number of instances of direct contact count between the physical space and VR were conducted, and Bayesian ANOVA. Subsequently, we ran a series of correlation analyses between the survey answers and the experimental result. The following describes the details of the series of analyses.

Firstly, we calculated the average distance in physical space from all participants in the experiment conducted in the physical space and the average distance in VR from all participants in the experiment conducted in VR. Therefore, a total of 78 cases were observed between 13 targets and 39 anchors in Korea and Turkiye.

The second phase of the analysis was to calculate the average distance values collected for each anchor in the physical space. Three anchors provided distance values for each target in the physical space and VR.

Thirdly, we calculated the ratio between the average distance of each anchor in the physical space and the average distance of each anchor in the VR and compared these outcomes. In the previous stage, it was possible to identify the difference in the absolute values by distance. However, the difference in the ratio by distance could be identified in this stage.

Fourth, we compared the total number of instances of direct contact in the physical space and VR. We also compared the average values of direct contact from each anchor in the physical space and VR.

Fifth, we utilized Bayesian ANOVA to analyze whether there is a statistically significant difference in the measured data between physical space and VR. The measured environment was set as the independent variable, and the distance measured in the three relationships was selected as the dependent variable. Bayesian ANOVA is similar to

Table 5 Commonly used thresholds to define the significance of evidence

Bayes factor	Evidence category	Bayes factor	Evidence category	Bayes factor	Evidence category
>100	Extreme evidence for H1	1–3	Anecdotal evidence for H1	1/30-1/10	Strong evidence for H0
30–100	Very strong evidence for H1	1	No evidence	1/100-1/30	Very strong evidence for H0
10–30	Strong evidence for H1	1/3-1	Anecdotal evidence for H0	1/100	Extreme evidence for H0
3–10	Moderate evidence for H1	1/10-1/3	Moderate evidence for H0		

Table 6 The value of survey items by nationality

Survey items	Korea (N = 13)		Turkiye (N = 13)		Total (N = 26)	
	M	S.D.	M	S.D.	M	S.D.
Digital game familiarity	3.00	1.225	3.23	1.641	3.12	1.423
HMD experience	1.62	0.506	1.77	0.439	1.69	0.471
Game positive negative	3.77	0.927	3.77	0.832	3.77	0.863
VR Interest	3.38	0.870	2.62	0.961	3.00	0.980
Game playtime	6.85	11.401	6.23	10.018	6.54	10.519
Self gamer	2.08	1.441	2.31	1.437	2.19	1.415

*M: Mean

*S.D.: Std. Deviation

traditional ANOVA but uses Bayesian statistics to model uncertainty (Kruschke 2010; Cleophas et al. 2018). The Bayes Factor (BF) is a factor that evaluates the significance of evidence between the null hypothesis (H0) and the alternative hypothesis (H1). BF allows us to measure the relative evidence between the two hypotheses. The JZS (Jeffreys-Zellner-Siow) Method was used to derive the BF in this study. IBM[3] defines the significance of evidence for the value of BF as shown in the following Table 5.

Finally, if a statistical difference is observed in the analysis results, we correlated the relationship between the eight variables collected through a survey and the measured values of VR and physical spaces to determine the cause of this difference. We set the nationality and the gender of the participants as dependent variables and the average distance value from six different types as the independent variables to run the independent-sample t-test. This analysis assumes that the cause of any difference was in the subject, i.e., the target. IBM SPSS Statistics 25, widely used in social science research and can efficiently compile and analyze data, was used as a statistical analysis tool (Weinberg and Abramowitz 2002; Kafle 2019).

[3] https://www.ibm.com/docs/en/spss-statistics/saas?topic=statistics-bayesian-one-way-anova.

4 Result

Data collected from the survey with 26 targets is presented in Table 6.

As the average value of the distances integrated from Korea and Turkiye, the average distance between a target and an intimate anchor in the physical space is 92.15 cm, the personal anchor average is 121.15 cm, and the social anchor average is 170.56 cm. These distances indicate that the total average distance in the physical space is 127.95 cm.

As the average value of the distances integrated from Korea and Turkiye, the average distance between a target and an intimate anchor in VR is 133.15 cm, the personal anchor average is 206.91 cm, and the social anchor average is 275.79 cm. These distances indicate the total average distance in VR is 205.28 cm. Figure 9 presents every distance value from both the physical space and VR.

According to Fig. 9, both distance patterns from the physical space and VR follow the pattern of proxemics theory. Whether in physical or VR, the distance becomes smaller between intimate and close relationships, and the distance broadens with a more formal and official relationship.

However, the values of the distances in the pattern present a significant difference between physical space and VR. The average distance value is higher in VR than in physical space.

The ratio between the average distance in the physical space and the average distance in the VR calculated by summing the cases of the two countries is 1:1.60. The distance ratio between the physical space and VR observed for cases

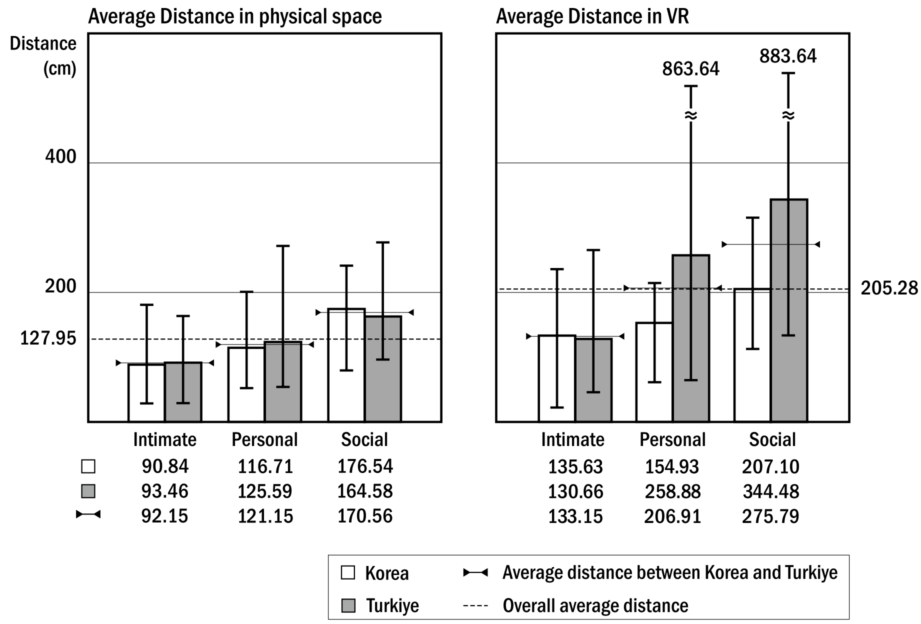

Fig. 9 The average distance from physical space and VR in total and type

Table 7 The ratio of the average distance between physical space and VR

Distance type	Ratio
Physical(overall): VR(overall)	1:1.60
Intimate(physical): Intimate(VR)	1:1.45
Personal(physical): Personal(VR)	1:2.05
Social(physical): Social(VR)	1:1.63

Table 8 The number of Direct contacts between physical space and VR in Korea and Turkiye

Type	Korea		Turkiye	
	Physical	VR	Physical	VR
Intimate	15	27	8	31
Personal	4	11	2	3
Social	0	2	0	1
Total	19	40	10	35

of intimate relationships is 1:1.45, the personal ratio is 1:2.05, and the social ratio is 1:1.63. (see Table 7).

Regarding direct contact, we observed a total of 40 instances of direct contact in Korean VR: 27 for intimate cases, 11 for personal cases, and 2 for social cases. 19 instances of direct contact in total were observed in the Korean physical space: 15 for intimate cases and 4 for personal cases. We also observed a total of 35 instances of direct contact in the Turkish VR, 31 for intimate cases and 3 for personal cases, and 1 for social cases. A total of 10 instances of direct contact were found in the physical space in Turkiye, 8 for intimate cases and 2 for personal cases. Table 8 presents these data. According to Table 8, for Korea, the frequency of direct contact in the intimate VR increased by 180% compared to that in the physical space, and personal direct contact increased by 275%. social direct contact did not occur in physical space, it happened twice in VR. For Turkiye, direct contact in intimate cases increased by 387.5%, and personal direct contact increased by 150% compared to physical space, in VR. social direct contact did not occur in physical space, it happened once in VR. Overall, the number of instances of direct contact in VR increased by about 210.5% in Korea and about 350% in Turkiye compared to the number of instances of direct contact in the physical space.

Table 9 Summary of the Bayesian ANOVA on Physical Space-VR and Three Measurements

Source	*df*	M.S	B.F
Intimate	1	21848.49	4.965
Personal	1	95594.958	2.752
Social	1	143949.38	11.796

*M.S.: Mean Square

*B.F.: Bayes Factor

Through the distance and ratio calculations, we verified that distances between targets and three types of anchors in VR are larger than in physical space. Also, the frequency of direct contact is higher in VR. We conducted a Bayesian ANOVA analysis on the distances concerning three relationships in two environments to understand the reason for these differences. Table 9 summarizes the Bayesian ANOVA results.

In all three types of relationships—intimate, personal, and social—the two environment groups showed significant values with p-values of 0.006, 0.011, and 0.002 respectively. The Bayes Factor (BF) indicated varying degrees of evidence for the alternative hypothesis (H1) in each case: Moderate Evidence with a BF of 4.965 in the intimate relationship, Anecdotal Evidence with a BF of 2.752 in the personal relationship, and Strong Evidence with a BF of 11.796 in the social relationship. These results support the hypothesis that the distance varies depending on the environment across all relationship types.

Subsequently, we analyzed the correlation between eight survey items, six different distances, and six different direct contacts. Table 10 presents the correlation between them. As none of the participants owned any HMD device, we eliminated the HMD owner section from the correlation item. As an analysis result, it was limited to finding multiple valid correlations. The only valid correlation we found was the relation between Nationality and the distance between Social anchors and targets in VR.

Table 11 is the result of the statistical analysis of the relationship between the nationality of the participants and the distance between participants in physical space and VR. As shown in Table 11, the t-value for the intimate cases in the physical space is −0.158; that for personal cases is −0.446, and that for social cases is 0.669. The difference in the average distance in the physical space was not related to the participants' nationality. In VR, the t-value for the intimate cases is 0.211, that for the personal cases is −1.754, and that for the social cases is −2.398.

Among the three relations in VR, only the social relation showed a significant relationship with the nationality of the participants. In the social relation in VR, the distance between the target and the anchor was 207.10 cm in Korea and 344.48 cm in Turkiye, showing a difference of about 166% by nationality.

Table 12 presents the statistical results when analyzing whether the participants' gender is related to the distance in the physical space and VR. Table 12 presents the t-value of intimate's physical space as −0.143, personal as 0.157, and social as −0.110.

Also, in VR, the t-value for the intimate cases is 0.075, the t-value for the personal cases is −0.891, and the t-value for the social cases is 1.006. Thus, the participants' gender is unrelated to the average distance for both the physical space and the VR.

Therefore, among the collective variables, only the nationality of the participants had a significant relationship with the VR social distance, while the other variables had no significant relationship.

Every data we collected and analyzed through the research can be found in the following link.[4] The link is open to the public.

5 Discussion

Through this research, we found that the proxemics hierarchy in a VR shares the same pattern in a physical space. The distance between intimate and private relationships becomes close, and the distance between formal and official relationships widens.

However, the distance scale differs between physical space and VR. On average, proxemics values are approximately 160% larger in the VR than in the physical space. At the same time, the number of instances of direct contact is 260% larger in VR. We can offer several interpretations of these phenomena.

The first interpretation is that the phenomenon occurred because participants were unfamiliar with VR and the HMD technology used here. They are wary of new environments, but at the same time, they are curious. Hence, it is interpreted that large distance values were found because participants wanted to observe the space by walking around during the conversation. At the same time, direct contact increased because they touched the other participant with curiosity in the form of a character.

However, active movement during the conversation was observed only twice. In addition, if direct contact occurs because the other person's appearance is unfamiliar, the frequency should be concentrated at the beginning of the experiment. However, direct contact occurred continuously without a specific pattern. In addition, according to this interpretation, a significant correlation should be observed between the HMD experience and the degree of interest in VR in the correlation analysis with the survey response, but we could not find any correlation. Therefore, this interpretation may not be logical enough.

The second interpretation is that participants feel anxiety or displeasure at the unfamiliar appearance of the other person, who has turned into an avatar, rather than curiosity, and use a greater distance than in the physical space. However, that interpretation conflicts with the increased frequency of direct contact. Participants should not be willing to touch and make contact with an unpleasant shape.

The third interpretation relates to the differences between incoming senses. People collect information about the space and others using their five senses in a physical space. However, in VR, they can collect information only with a limited number of senses, such as sight and hearing, meaning it takes work to collect enough information. Therefore, participants

[4] https://www.virtuallandscape-ik.com.

Table 10 Correlation between the measured values and survey items

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1. Nationality	1															
2. Gender	0.00	1														
3. Digital game familiarity	0.08	−0.78**	1													
4. HMD experience	0.17	0.16	−0.18	1												
5. Game positive negative	0.00	−0.68**	0.84**	−0.08	1											
6. VR Interest	−0.40*	−0.25	0.32	−0.43*	0.24	1										
7. Game playtime	−0.03	−0.10	0.42*	−0.30	0.30	0.29	1									
8. Self gamer	0.08	−0.63**	0.78**	−0.09	0.82**	0.14	0.21	1								
9. P intimate	0.03	0.03	0.08	0.18	−0.04	−0.31	−0.13	0.16	1							
10. P personal	0.09	−0.03	0.05	−0.06	−0.28	−0.12	0.11	−0.04	0.47*	1						
11. P social	−0.14	0.03	−0.01	0.21	−0.17	−0.13	−0.08	0.10	0.64**	0.70**	1					
12. P Direct_contact	−0.20	−0.08	0.12	−0.20	0.33	0.16	0.30	0.25	−0.61**	−0.36	−0.37	1				
13. VR intimate	−0.04	−0.02	0.00	−0.09	0.27	0.09	−0.07	0.31	−0.04	−0.15	0.10	0.23	1			
14. VR personal	0.34	0.14	−0.13	0.14	0.01	−0.23	0.00	−0.06	−0.15	−0.10	−0.07	0.09	0.49*	1		
15. VR social	0.44*	−0.20	0.39	0.28	0.27	0.04	0.09	0.38	−0.05	−0.04	0.09	0.07	0.17	0.39*	1	
16. VR Direct_contact	−0.06	−0.08	0.06	0.23	−0.24	−0.10	−0.02	−0.15	−0.05	0.05	−0.12	−0.05	−0.74**	−0.21	0.04	1

**Correlation is significant at the 0.01 level (2-tailed)

*Correlation is significant at the 0.05 level (2-tailed)

Table 11 Average Distance-Nationality t-test

Type	Average Distance (cm)		S.D.		t-value	*p*
	Korea (N = 13)	Turkiye (N = 13)	Korea	Turkiye		
Physical intimate	90.84	93.46	43.64	41.08	−0.158	0.876
Physical personal	116.71	125.60	40.61	59.24	−0.446	0.660
Physical social	176.54	164.58	41.75	49.12	0.669	0.510
VR intimate	135.63	130.66	62.47	57.58	0.211	0.835
VR personal	154.93	258.88	45.18	208.87	−1.754	0.103
VR social	207.10	344.48	53.30	199.56	−2.398	0.031

Table 12 Average distance-gender t-test

Type	Average distance (cm)		S.D.		t-value	*p*
	Male (N = 10)	Female (N = 16)	Male	Female		
Physical intimate	90.45	93.21	55.69	31.83	−0.143	0.889
Physical personal	123.14	119.91	60.68	44.13	0.157	0.877
Physical social	169.09	171.48	64.31	30.05	−0.110	0.914
VR intimate	134.27	132.44	44.71	67.71	0.075	0.940
VR personal	179.14	224.26	26.21	199.92	−0.891	0.386
VR social	315.55	250.94	208.79	120.17	1.006	0.324

attempted to collect more information from their surroundings by maintaining a longer distance between themselves and the anchors so that they could use their peripheral vision. According to this logic, the increase in the number of instances of direct contact can also be interpreted as part of the information collected using the sense of touch. However, the presence of participants who want to move closer to the other anchor and gather more detailed information about them should be observable in the experiment. However, we could not observe such a pattern. Therefore, this interpretation also requires more persuasive evidence.

As such, it is challenging to propose a persuasive interpretation of the findings of this study. Through a questionnaire survey, we attempted to find a relationship between the participant's experience and the experimental results. However, this analysis did not deliver a clear relationship or the reason for our findings. Determining why proxemics works at greater distances than in other studies is also challenging. Hasler and Friedman (2012) pointed out that it is still being determined whether proxemics in physical spaces will be equally observed in VR. However, they could not determine what the cause was. Han (2019) also noted that proxemics differ in physical space and VR, but they also could not determine the cause. The cause of the phenomenon may exist in another domain, such as physiology or brain science, rather than the subject's experience or anthropological background.

6 Conclusion

This research found statistical evidence of the difference between VR and physical space proxemics. Similar to that in a physical space, proxemics in a VR become closer as one is more familiar with another. However, the distance is about 160% larger on average than in a physical space. In more detail, it is about 145% greater for an intimate relationship in VR and about 205% greater for a personal relationship. The distance between socially related persons is about 165% greater in VR than in a physical space.

Conversely, direct contact occurs 260% more often in VR than in a physical space. In more detail, for those in an intimate relationship, the direct contact value was increased by about 250%, and for those in a personal relationship, it increased by 235%. Regarding social relationships, the outcomes were identical at 0%.

Though we could not identify the cause of the phenomenon observed here, this study found that VR activates different proxemics than physical spaces, and we could verify the exact volume of the difference. In the future, if this discovery is applied as a variable in a computational VR design methodology (Kim et al. 2018), it will be possible to design any VR to manipulate multiple users' emotions and actions more efficiently. The findings here can also be applied to an automatic design methodology using machine learning. It will be possible to accommodate and persuade multiple users more efficiently by using the findings of this study as a design variable in AI applications.

This study also has limitations. First, additional experiments with more participants from various nationalities and backgrounds should be conducted to draw more comprehensive results. This study ran experiments with students from two different nations. In future research, we can target various ages of participants from more nations. In such a case, finding more precise patterns will be possible.

Second, a series of studies on which spatial elements of VR affect proxemics outcomes should be conducted in the future. This series of follow-up studies should also include content related to avatars. It will be necessary to ascertain how factors such as the avatar's size, appearance, or voice affect proxemics. Llobera et al. (2010b) noted that the shape and the other conditions of avatars in VR don't affect proxemics in their paper, we still need to evaluate the statement through objective experiments in future research.

Third, as this study did not classify and analyze the nature of direct contact, more detailed follow-up studies are required. We will be able to provide different weights and values to different contacts. In such a case, it will be possible to draw more sophisticated results, leading to new findings.

Finally, as mentioned in the discussion, it is necessary to expand the area of research on the causes of different proxemics to the physiological or medical domain using, for instance, an eye-tracking device or an electroencephalogram measuring device.

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Data availability The datasets generated during and analyzed during the current study are available from the corresponding author on reasonable request.

Declarations

Conflict of interest The authors have no conflicts of interest disclosed.

Human and animal rights We further confirm that any aspect of the work covered in this manuscript that has involved human participants has been conducted with the ethical approval of all relevant bodies and that such approvals are acknowledged within the manuscript.

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