Effect of social settings on proxemics during social interactions in real and virtual conditions *

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Abstract. Virtual Reality (VR) offers unlimited possibilities to create virtual populated environments in which a user can be immersed and experience social interactions with virtual humans. A better understanding of these interactions is required to improve the realism of the interactions as well as users' experience. Using an approach based on Interactionist Sociology, we wondered whether the social settings within which the individual interact has an impact on proxemics norms in real conditions and if these norms apply in VR. We conducted an experiment in real and virtual conditions where individuals experienced a transgression of proxemics norms at a train station and in a sports fan zone. Our results suggest that proxemics norms vary according to the subjective relationship of the individual to the social settings. This variation would translate directly into a modulation of bodily sensitivity to the proximity of the body of others. While we were able to show that social norms still exist in VR, our results did not show a main effect of the social settings on participants' sensitivity to the transgression of proxemics norms. We discuss our results in the frame of the cross-fertilization between Sociology and VR.

Keywords: Virtual reality · Proxemics · Social settings.

1 Introduction

Immersion in populated environments is an essential requirement in many Virtual Reality (VR) applications, including entertainment, education, security, but also for the study of human behavior during person-to-person interactions. In this context, social interactions between a user and virtual human characters moving in the same environment need to be better understood to improve the realism of the interactions as well as users' experience. When considering social

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interactions, body norms were shown to be very important metrics [24]. As one of them, proxemics norms can be very influential on bodily interactions especially in the current context of COVID-19 pandemic. The proximity of one body to another may indeed appear excessive and lead to physical displacement even when this proximity is not mechanically constraining.

Proxemics is the study of people's perception and use of space [25]. The exploration of this field of study emerged in the 1960's as an interdisciplinary approach to understanding complex human behaviour in crowds. Proximity was shown to be influenced by cultural aspects [25], as well as by gender [13], behaviour [2] or attractiveness [31]. Among variables that influence proxemics norms, the subjective relationship that the individual maintains with the social setting was rarely considered. However, interactionist sociology showed that body norms vary depending on the subjective relationship with the social setting [29]. The amount and variety of social settings users can be immersed into with VR therefore raises the following questions: does changing the social setting of the environment have an impact on proxemics norms? Do these norms still apply in VR?

To answer these questions, we used a transdisciplinary approach relying on Sociology, Movement Sciences and Computer Sciences. We first aimed at verifying that the same transgression of proxemics norms provokes different reactions in individuals undergoing this transgression in real situations, according to the subjective relationship they have with the social setting in which they are interacting. To manipulate social settings, we used the concept of "non-place", proposed by the anthropologist Marc Augé [4], and which designates excessively standardized places such as shopping malls or stations. In contrast, anthropological places are social settings that make sense for individuals and in which they engage their identities, their affiliations, their tastes, etc. We then compared proxemics norms in a train station where individuals have to stand in front of the departure board to get information about the train (the presence in this specific location is constrained by the need to get information) and a sports fan zone, where individuals stop because they are attracted by an event of interest. Our second objective was to evaluate the ability of VR to study the influence of the subjective relation to social settings on proxemics by replicating the real experiment in a virtual environment. In real conditions, results showed that the subjective relation to social setting has an influence on proxemics, which results in an increased sensitivity to the transgression of proxemics norms in a non-place in comparison to an anthropological place. Proxemics norms still exist in VR, but the difference in sensitivity to social settings was not observed.

2 Related Work

Social rules have a main influence on human behavior during non-verbal interactions. In that context, interactionist sociology offers a reading framework that can help understanding norms. This section presents related work in this field, as well as studies exploring proxemics norms in VR.

2.1 Social norms as a determinant of the individual behavior

In populated environments, individuals form a coherent whole that makes them interdependent with one another [19, 20]. This implies behaving according to the norms, which are the basis of the process of civilization [19, 20]. A norm is defined here as a tacit rule which is constantly regulated in the course of daily life interactions [24] and is part of the socialization process during which each individual incorporates the normative behaviours of the social group to which he or she belongs to [12]. Any deviation to the norm is anticipated by the individual and, if necessary, sanctioned by consequences that can range from mere reprobation to exclusion. According to Goffman [24], the reason why the collective disapproves individuals' deviance from the norm is twofold: deviant behaviours challenge the norms that regulate the foundations of the course of interactions, and it makes the collective lose face insofar as it highlights the unnatural character of socially constructed reality. This is why each interactor has to play his or her role correctly.

2.2 The body proximity as a social norm

Proxemics norms require the interactants to maintain interpersonal distance [25]. They can be considered as determinants of individuals' motor conduct during unfocused interaction. This interaction refers to a co-presence of the interactors, without direct contact but while still influencing each other normatively [28, 24]. Individuals' non-verbal reactions in terms of body posture, motion, interpersonal distance as well as gaze behaviour in such an interaction were extensively studied in the literature (see [26] for a review).

Proxemics studies identified 3 types of distances: intimate, personal and extra-personal ones [25]. Transgressing personal distance is a deviant behaviour that causes significant discomfort. The individual who transgresses is, in this case, doubly at fault: he or she does not respect the minimum distance imposed by the situation and he or she does not correctly practice socially constructed norms [24].

Social distances vary according to cultures [16, 37], speed of movement and density [40], lighting condition [1], indoor or outdoor locations [17], obstacle movements [23] as well as gender and age [37, 34]. Studies also investigated social distances by people's perception of crowding. McClelland and Auslander [33] found that crowdedness is associated with both the number of persons, as well as the social setting and the amount of space available. Social density was found to be more positive in specific settings, such as bars and discos, which are associated with pleasant, hedonic experiences, whereas density was negative in utilitarian settings [8]. Interestingly, the same settings can be perceived differently by individuals. Baker and Wakefield [7] found that shoppers with higher need for control tend to perceive social density in shopping malls as stressful, while shoppers with a higher need for intimacy, perceived density as exciting. Despite the amount of work on that topic, little is known about the influence of the subjective interpretation of social settings. For example, socially acceptable

uses of the body are not the same in a football stadium, on a beach or in a railway station hall [18] and Interactionist Sociology showed that body norms vary by the subjective relationship to social settings [29]. Body would act as a sensory barometer of social status [30]. This is precisely why the transgression of proxemics norms causes a feeling of discomfort even when it does not mechanically limit movement. But could this discomfort, linked to excessive proximity, vary according to the subjective relationship to the social settings?

2.3 Subjective relationship to social settings: non-place and anthropological place

The subjective relationship between one individual and the place where he or she evolves is infinitely variable. According to Augé [4] we can however identify two main types of places according to their level of symbolization and sociality, namely "anthropological places" and "non-places".

An "anthropological place" is highly charged with symbols, such as a football stadium. Colours, individual placement, behaviour, clothing, words and songs are all symbols that manifest the identities, affiliations, antagonisms and history of the place. Interactions are focused [24] and individuals have expectations which act as foundations of the collective experience in which they come to participate. Other places are poorly charged with symbols, such as shopping malls or train station halls, which have been highly standardised by urbanisation to the extent that they all look alike and their utilitarian function overwhelms their social dimension. These places are called "non-places" [4]: individuals remain more anonymous and solitary. The subjective relationship that individuals maintain with these non-places is marked by distances and constraints. Interactions in such a non-place correspond to a logic of necessity to which everyone is accustomed. The distinction between non-place and anthropological places is not systematic and exists in the subjective representation made by individuals as well as the task they have to perform. For example, an individual can perceive the station in a very positive way if it reminds a happy encounter. Conversely, a professional steward will have a more functional and constrained relationship with the stadium. Moreover, we can wonder whether that distinction between theses two main sensitive and subjective social settings still apply in VR.

2.4 Virtual Reality and social interactions

VR is a powerful tool to study human social interactions [36]. VR offers new experimental perspectives since it enables experimental control while preserving a high ecological fidelity [10, 32, 36] which is an important challenge when considering interactions between individuals. In addition, a main advantage is to enable to manipulate any characteristics of the virtual environment the user is interacting with and to then design new experimental contexts [36]. The growing interest of Social Sciences for VR can be illustrated by the recent surveys about methodological guidelines for using VR and its benefits and drawbacks in this context [21, 36, 38, 43, 44].

The persistence of proxemics norms in VR in comparison to real conditions has been extensively evaluated. Bailenson et al. [5] designed a task where users have to approach a virtual human to find some elements on its clothes. In such a condition, users always preserve a distance threshold (40cm) with the virtual human. As previously demonstrated in real conditions, this study also demonstrated that users maintained a larger distance when the virtual human was engaged in a constant mutual gaze. They also highlighted that users left more distance when approaching a virtual human from the front than from the back. Observing the behaviour of users' avatar playing the Second life game, Yee et al. [45] showed that male-male dyads maintain larger interpersonal distances than female-female dyads. They also reported a preservation of the Equilibrium Theory [3, 6] where mutual gaze was inversely correlated with interpersonal distance. They concluded that social interactions in such a virtual environment follow the same social norms than in the physical world. Iachini et al. [27] used a paradigm where users have to press a button as soon as they feel uncomfortable with the interpersonal distance between them and a virtual human (interpersonal space), or as soon as they can reach the virtual human with their hands (peripersonal space). They performed this task while walking towards the virtual human (active) or standing and observing the virtual human walking towards them (passive). The gender and the age of the virtual human was manipulated. They also replicated the experiment in real conditions. Their results showed a similar effect of factors manipulated in both environments: the interpersonal distance was larger in passive than in active conditions, interpersonal and peripersonal spaces were similar in the active condition but interpersonal space was larger than peripersonal space in the passive condition. Both in real and virtual conditions, the distances were larger when participants formed a dyad with a male than with a female and larger when a young adult interacted with an older adult in comparison to a young adult or a child. Finally several studies used a collision avoidance paradigm where a user has to avoid a virtual human while walking. Collision avoidance consists in regulating the interpersonal crossing distance, which is not only a contact distance but includes social norms too. In line with this idea, Gérin-Lajoie et al. [22] showed that the elliptical shape of personal space demonstrated in real conditions is preserved in VR, even if its dimensions are slightly increased. An increase of the crossing distance but a preservation of the main characteristics of the avoidance behaviour have also been reported in several studies either while walking with a HMD [9, 14] or using various locomotion interfaces and control laws [35]. Similar effects were also demonstrated for both environments regarding the effect of interacting with an anthropomorphic obstacle (i.e., a human) as opposed to inanimate objects as well as the effect of anthropomorphic obstacle orientation [39].

All these studies, while using different approaches, converge to the same conclusion that social norms are preserved in VR, even though quantitative differences sometimes exist. This is an important result which encourages researchers to consider VR as a relevant tool to study human social behaviour but also to consider social rules when designing virtual populated environments. While

many factors were investigated in VR such as the influence of age and gender [27], gender and attractiveness of motion [46], emotion [11], interpersonal attitude [15], there was no investigation of the effect of the subjective meaning of the virtual social setting on proxemics norms.

3 Experimental design

3.1 Objectives

This study had two main objectives. First, we were interested in evaluating the effect of the subjective meaning of social settings on proxemics. Specifically, we investigated whether a similar transgression of proximity norms implies similar body reactions depending on the subjective relation the individual undergoing the transgression has with the social settings. To this end, we compared two types of spaces: a "non-place" (a train station) and an "anthropological place" (a sports fan zone). Secondly, we evaluated the persistence of these results in VR by replicating this experiment with participants immersed in a virtual environment. From an applicative point of view, the aim is both to grasp the extent to which virtual reality preserved the bodily sensitivity involved in social interactions, and to understand to which extent VR must integrate the social dimensions of the space when designing virtual crowded environment.

3.2 Social Settings

We considered two social environments, both in real and virtual conditions (cf. Figure 1), that differ in term of the subjective relation they can infer to individuals:

- **An anthropological place**: A symbolized and social place where people choose to come to interact and share an experience with others. A place around a soccer game was chosen, where people observe others playing for pleasure.
- **A non-place**: A very common place that cannot be defined as identity, relational or historical and which is often transitory [4]. For this purpose, we chose a train station hall, as it is a transitory space where the individuals' presence is constrained by the obligation to wait for the necessary information to be displayed on a screen.

These two environments share similar physical properties: the density is close, individuals stand still to get an information displayed on a screen or to watch a soccer game, their position is determined by the screen being the only common focal point.

The four environmental conditions were then the followings:

- **Real "non-place"**: a train station hall where individuals are constrained to wait in front of the train display board (Figure 1.top-left).

Fig. 1. Illustration of the four social environments used in the experiment.

- **Real "anthropological place"**: a stand in a fan zone in front of the soccer stadium on match days, where individuals watch other people having fun (Figure 1.top-right).
- **Virtual "non-place"**: a train station hall where individuals are constrained to wait in front of the train display notice board (Figure 1.bottom-left).
- **Virtual "anthropological place"**: a giant screen broadcasting a football match in a fan zone (Figure 1.bottom-right).

We then formulated two hypotheses:

- **H1**: the transgression of proximity norms induces less discomfort in a highly symbolized and social place (i.e. an anthropological place), such as a sport event where individuals come to spend a good time, than in a non-place, such as a train station where presence is constrained. In particular, we expect larger reactions in the non-place condition. According to [4], we hypothesize that individuals will feel more at ease in anthropological places and then tolerate more easily a transgression of proxemics norms.
- **H2**: In line with the results of the studies presented in Section 2.4, we hypothesize that the transgression of proximity norms in VR induces similar reactions than in real conditions.

3.3 Participants

In order to minimize confounding individual factors, since it has been previously shown that proxemics is influenced by gender and age [37], inclusion criteria

have been defined. Individuals had to be male, aged between 20 to 40 years, and their self-reported blood alcohol concentration below the legal limit for driving, since it is known that alcohol affects social behavior [42]. In real conditions, 17 subjects meeting these criteria from the post-experiment discussion were studied at the station and 13 in the fan zone. In virtual conditions, the experiment involved 22 participants in the fan zone and 22 participants in the station. In virtual conditions, we conducted experiments at the Sports Sciences University: participants were all in their twenties and male students in their 2^{nd} year of Sport sciences bachelor's degree. They had no previous experience with VR.

3.4 Task

We designed a between-subjects experiment, which involved different participants in the four conditions considered (non-place vs. anthropological place $\times$ real vs. virtual environments).

In real conditions, a male confederate identified an unknown and uninformed male individual within a crowd of people. He then approached him and stood excessively close ($15cm$ away) in front of him in the same direction during 10s (cf. Figure 2). The confederate tried not to obstruct the subject's view of the screen to ensure that the reactions caused were not due to a mechanical impediment.

Fig. 2. Illustration of the proxemics norms transgression task used in this study: a confederate (red) approaches an individual (blue) and stops just in front of him at a very close distance so as not to occlude his view of the screen he is looking at.

In virtual conditions, male participants were immersed in the virtual environment using a FOVE HMD (70Hz, 100° field of view). A soundtrack specific to each space was played through headphones. Participants were able to move in a $2m \times 2m$ space. In the train station condition, they had to stand and look

at a screen until the track of the train going to a specific destination *(Dourdain-La-Forêt)* would appear. In the fan zone condition, participants stood in front of a screen where a soccer game was displayed, but were not given any specific instruction. We voluntarily provided participants with different instructions in the two virtual environments to reproduce the situation observed in real conditions: the constrained task of waiting for the information to be displayed on a screen in a train station versus a non-constrained task of watching at will a football game in a fan zone. In both virtual conditions, 30s after the beginning of the immersion, a virtual human moved towards them, then stood in front of the participant, in order to reproduce the same stimuli as in the real conditions. In each environment, we made sure that the transgressor did not interfere with the subject's vision (by a slightly shifted position in front of him) in order to ensure that the transgressor's potential movement was related to a normative and not a visual disturbance.

Observation and interview For each condition, an experimenter observed the scene from a distant point of view and reported participants' reaction over the invasion of their interpersonal space. Then a post-observational interview was conducted at the end of the experiment to find out the degree of awareness expressed by subjects regarding the transgression of the proxemics norms that just occurred, their feelings, as well as the reasons that pushed them to react when they did. This explanation interview completed the observations performed by the experimenter and allowed each individual to verbalize their reactions. The interview also enabled us to confirm the subjective relationship (constrained/desired) of the individual to the social setting.

4 Analysis

We used an ethnographic method, often used in Interactionist Sociology, to describe the individuals' behaviour following the transgression of proxemics norms both in real and virtual conditions. Additionally, in virtual conditions, we recorded participant and virtual humans positions. At the end of all observations, an explanatory interview was also performed.

4.1 Ethnographic data

Using an ethnographic approach, i.e. an observational method, we rated individuals' non verbal reactions to the transgression of proxemics norms using a 7-point scale from 1-None, 3-Minimal, 5-Moderate to 7-Frank. This rating was based on 3 indicators that were shown to be important when considering interpersonal interactions and proxemics namely, gaze, body posture and movement [26]. A minimal reaction corresponds, for example, to an increased surveillance on the confederate through the gaze, a straightening of the chest, a small displacement. A moderate reaction corresponds to a transfer of body weight from one foot

to the other or micro-displacements both creating distance, accompanied by visual surveillance. Finally, a frank reaction results in a displacement increasing interpersonal distance.

4.2 Position data in virtual reality

We studied the interaction as the time period in which participant's proxemics norms were violated, starting when the virtual confederate stood in front of the individual (T0) and ending when the confederate left. We computed the interpersonal distance (IPD) between the participants and the virtual confederate (center to center distance) at T0 to control the initial conditions of the interaction. We also computed the maximum IPD and the time to reach this distance during the interaction. It represents the IPD reached by participants after (more or less) motion adaptation in response to the transgression of proxemics norms.

4.3 Statistical analysis

The statistical tests were performed using R software and the significance threshold was set at 0.05. The normality of data distribution for IPD and time variables in VR was assessed using the Shapiro-Wilk test. We evaluated the effect of the social settings using a Mann-Whitney test since data did not follow a normal distribution. Regarding ethnographic data, because our sample size was small to conduct a χ^2 test of association, we reported only descriptive statistics.

5 Results

5.1 Real conditions

Results of the ethnographic analysis in real condition are reported in Figure 3 in plain colours (train station in blue and stadium in green). In the train station, 47% of the individuals (8/17) had a frank embarrassed reaction to the obstruction of the proxemics standards, such as a displacement, and only 12% (2/17) did not exhibit any embarrassment-related reaction. At the stadium fan zone, 8% of the individuals (1/13) had a frank embarrassed reaction and 38.5% (5/13) did not show any embarrassment. The other intermediate reactions between those two extremes, like eye surveillance or weight transfer from one support to another, were observed in similar ranges, as shown in Figure 3.

In the train station, 65% of the individuals (11/17) accompanied their reaction with a demonstration or a body attitude mobilized as a pretext for not revealing the transgression of the norm: turning to the other side of the confederate and pretending to search someone, for example. These "bodily excuses", dissimulating the embarrassment were found in individuals who had 'frank', 'light' and 'minimal' reactions. At the stadium fan zone, only 15% of the individuals (2/13) had this type of behaviour that could be interpreted as diversion strategies, but the interviews revealed that it was not a pretext and that the

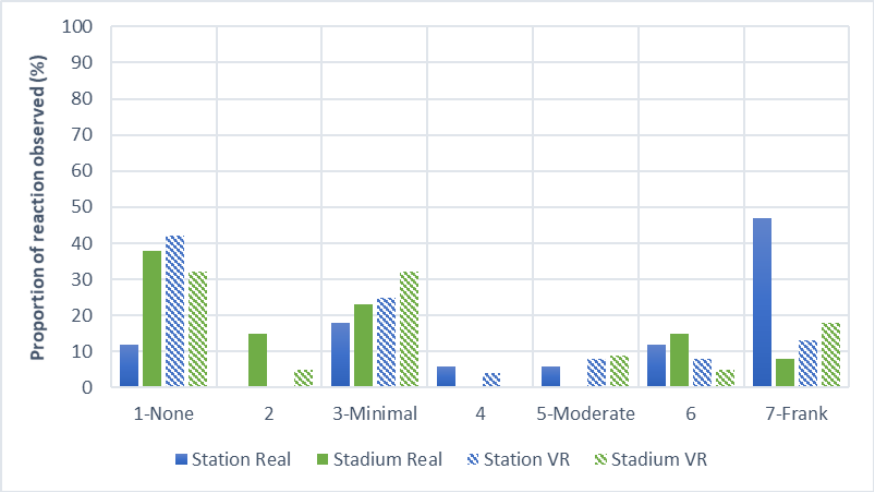

Fig. 3. *Ethnographic observations during transgression of proxemics norms. The figure reports the proportion of bodily reaction and discomfort intensity observed in each conditions.*

bodily attitudes were well justified by a practical reason. On the other hand, the explanatory interviews confirmed these diversion strategies in the train station. The interviews also revealed that 47% of the individuals (8/17) at the station vs. 15% (2/13) at the stadium were aware of the proximity of the experimenter.

5.2 Virtual conditions

Ethnographic observations (hatched colors in Figure 3) showed that only 13.5% (3/22) and 18% (4/22) of the individuals exhibit frank reactions of discomfort when the virtual human invaded their personal space respectively in the train station and in the fan zone. Conversely, 42% (10/22) of the individuals in the train station and 32% (7/22) in the fan zone did not show any reaction. Minimal and moderate reactions were also quite similar between the 2 spaces. Interviews showed that all the individuals in the fan zone (22/22) and 95.5% (21/22) in the station noticed the presence of the virtual human during the experiment. A large part of the reactions to the transgression of proxemics observed in real conditions (body weight transfer, displacement by trampling...) were also observed in VR. Some behaviours were however not observed in real conditions: laughing, trying to touch the virtual human, a strong surprise manifested by a burst.

Distance and time metrics are reported in Figure 4. Initial IPD, i.e., when the virtual human stopped in front of the participants was similar in the train station and in the fan zone ($p=0.96$), which means that participants were exposed to the same initial conditions of proxemics transgression. No effect of the social settings was reported on the maximum IPD value reached by participants during the interaction ($p=0.92$). An effect was however reported for the average time

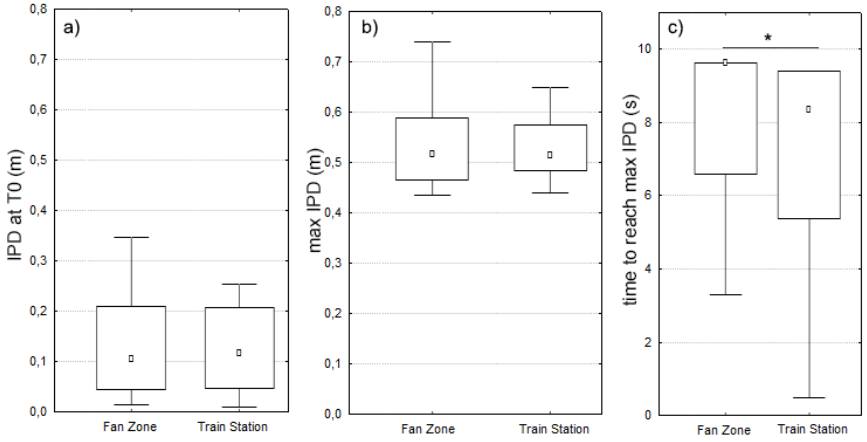

Fig. 4. *Box plots of a) Interpersonal Distance (IPD) between participants and the virtual human at the beginning of the interaction b) maximum value of IPD during the interaction and c) the time to reach maximum IPD depending on the social setting. Significant differences between social settings are highlighted using a * ($p<0.05$).*

to reach the maximum interpersonal distance with the virtual human: it was significantly shorter in the station than in the fan zone (U=168, p=0.032).

6 Discussion

In this paper, we aimed at investigating the effect of the subjective relation individuals have with social settings on proxemics norms. Using an ethnographic method from a conceptual basis offered by interactionist sociology, we studied the effect of transgression of proxemics norms in a non-place and an anthropological place in real conditions. We also replicated this study in virtual conditions to evaluate whether these norms still apply in VR.

6.1 Proxemics in non-place and anthropological place in real conditions

The ethnographic results in real-life situations indicated a tendency for individuals to be more sensitive to the proxemics norms in a constraining and perceived non-place space such as a train station compared to a meaningful anthropological place [4] such as a stadium. These results support our first hypothesis about the influence of the subjective relation between an individual and the social settings on proxemics norms: individuals showed more discomfort and tried to dissimulate more their discomfort in the train station than in the stadium. As suggested by the interviews, individuals would possess a sensitive - more than reflexive - skill in reading and adapting to the normative context of the space in which they interact. The fan zones around the stadium are visited voluntary to

share a collective identity around a local team, wearing jerseys and emblems, or at least a passion for the sport. These elements distinguish the football stadium as an anthropological place where people share the same social codes [4]. At the opposite, the train station can be considered as a transitory and temporary non-place that individuals do not appropriate, isolating them from the others. Individuals do not share an identity community linked to the space they pass through, so they are less inclined to accept the proximity of others. More generally, individuals are also less accommodating towards transgressions of norms and more sensitive to the "theatre of appearances" [24] because they do not share a collective identity.

6.2 Proxemics in non-place and anthropological place in virtual conditions

As previously described in the literature [5, 27, 22], our results showed that social norms exist in VR and the violation of interpersonal space induces discomfort which leads individuals to perform adaptive motions to increase this distance, which is in line with our second hypothesis. We measured male-male interpersonal distances around 50cm, which is consistent with the ones obtained in previous studies [5].

While proxemics norms apply in VR in our experiment, our results did not show main differences in sensitivity to deviance from proxemics norms depending on the social settings, which qualifies our conclusions regarding the validation of hypothesis 2. Nevertheless, we were able to show that the time to reach maximum distance after the invasion of interpersonal space was smaller in the train station than in the fan zone. Individuals reach a comfortable interpersonal distance quicker in the station, which suggests that they tend to be more sensitive to proxemics norms transgression in the virtual non-place than in the virtual anthropological place. Let us note that the dispersion of the timing to reach maximum interpersonal distance between individuals and the virtual human, was large both in the fan zone and the station. This high interindividual variability underlines the highly variable nature of the bodily reactions linked to the transgression of personal space by the virtual human. It also strengthens the interest of a transdisciplinary approach combining Movement Sciences and Social Sciences to fully comprehend the complexity of social interactions.

6.3 Limitations and future works

Several factors may explain the differences observed between real and virtual conditions, where the fundamental difference between anthropological place and non-place was decreased in VR.

First, individuals knew *a priori* that they are participating in an experiment in VR, which was revealed to individuals *a posteriori* in real conditions. For that reason, their level of awareness but also the control of their behavior was higher than in reality (every participant reported in the interviews the transgression of the virtual human which was not the case in reality). Although the precise

research question was not explained to participants in VR, they knew that they were observed by an experimenter physically present in the same room, which may have modified their spontaneous behaviour. Being in co-presence with the experimenter may have added a constraint (a non-verbal real interaction) that tends to increase the impersonal character of the situation, bringing the two spaces closer together. The virtual interaction with the virtual human is part of a real interaction with the experimenter in the laboratory. This superposition of social settings (real and virtual) may produce two sources of potentially contradictory interactive rules and norms. It would be of interest, when performing experiments in VR related to social settings only, to decrease as much as possible the impact of the real interaction with the experimenter on the sensitive relationship individuals establish with their virtual environment. This could be performed by isolating them in a place with limited interactions with the real setting. Also, designing a distractor task to help enhancing PI and Psi could help to more firmly establish the ecological validity of the depicted social settings to participants prior to the invasion of their personal space by the virtual human. Moreover, for mainly organizational and practical needs, our participants in VR were students in Sports Sciences without any past experience with virtual reality.

Second, immersion in virtual reality, before the appearance of the virtual human, lasted only about thirty seconds, which is perhaps insufficient for the subjects to integrate and adapt to their new context. This possibly too short duration, as well as the discovery of virtual reality experiences, may make individuals feel more in a "virtual reality" situation than in a "station" or "fan-zone" situation. Indeed, several subjects told us in the interview that they did not react because they "were in virtual reality". This finding also highlights the fact that all subjects do not react in the same way to the virtual reality situation, some being fully aware of the fictitious nature of the situation while others show a much higher degree of immersion by going into the interviews to find reasons to justify the virtual human's behaviour. In future works, the level of individual engagement in the virtual environment could be tested by evaluating "Place Illusion" (PI) and "Plausibility" (Psi) [41] to better understand people's responses in virtual reality. It might also be useful to distinguish participants according to their level of familiarity with virtual reality which may affect their level of sensitivity to virtual social settings, and to extend the study with a larger sample size, including the analysis of other variables such as gaze behaviour, which was shown to be an important feature of social interactions.

Third, we acknowledge that, even if we have tried to minimize them (e.g., dedicated soundtrack, situation chosen), some differences exist between the studied conditions. The level of noise, the light or the fact that the movement was more restricted in VR as well as the point of view was more standardized in VR could have impacted participants' reactions. Future work should address the influence of such factors so as to fully understand the effect of social settings.

Lastly, it is obvious that the recent health crisis has upset the standards of proxemics by imposing a preventive distance from the bodies. Although this increased distance has a significant effect on the flow within crowds (in places for

sports shows for example), the most important effect is certainly the transition from a sensitive and physical control of these distances to a reflexive and conscious control. Individuals no longer react only according to the level of perceived discomfort but according to awareness of the health risk assessed in a reflexive manner. It would be of interest to repeat this study in order to compare differences in reaction between the pre- and post-covid19 contexts.

7 Conclusion

Virtual reality offers unlimited possibilities to create virtual populated environments in which a user can be immersed and experience social interactions with virtual humans. Our study confirms the previously established evidence that VR can produce ecologically valid social responses. Furthermore, we presented an example of how VR can be used to study more complex anthropological concepts.

Our approach was based on the combination of Social Sciences and Computer Sciences, which we believe can benefit from each other. Interactionist sociology helps to understand some limitations of virtual reality in restoring the levels of sensitivity to the proxemics norms: it can be assumed that the experimental situation produces a superposition of two interactions (real and virtual) with potentially contradictory rules. Virtual reality offers highly controlled conditions as well as the possibility to measure additional quantitative variables regarding human behaviour during social interactions which is of main interest to study anthropological concepts. Future research is needed to refine the current protocols in VR to allow capturing more subtle effects of factors involved in social interactions.

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