Investigation of the perception of openness of a small group formation with varying head rotations in VR

Qinbai
baiq@kth.se
KTH Royal Institute of Technology
Stockholm, Sweden

Christian Lindberg
ckkli@kth.se
KTH Royal Institute of Technology
Stockholm, Sweden

Mohamad Harits Nur Fauzan
mhnf@kth.se
KTH Royal Institute of Technology
Stockholm, Sweden

Ólafur Konráð Albertsson
okalb@kth.se
KTH Royal Institute of Technology
Stockholm, Sweden

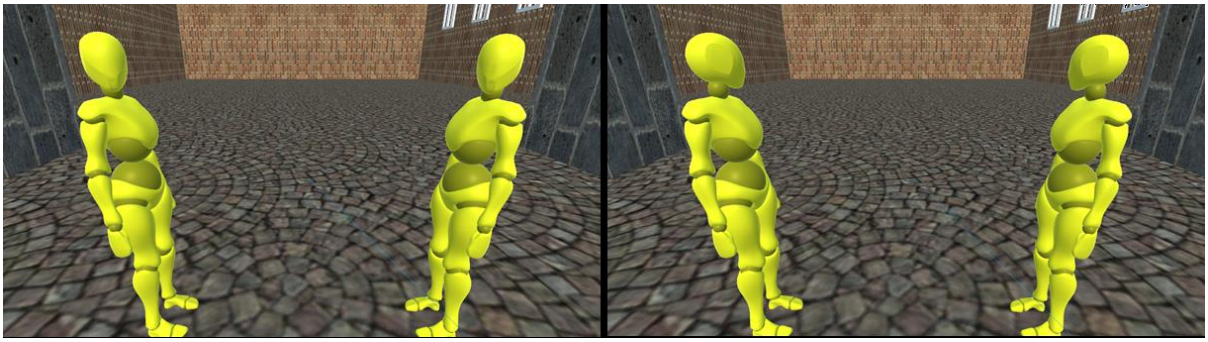

Figure 1 *Two of the stimuli used during the report to investigate the perception of openness of a group.* ***Left*** *being when both virtual agent's heads are rotated to face the participant; the* ***right****, both heads are facing away from the participant. The camera being the participant.*

ABSTRACT

How group and crowds are perceived have been intriguing topics for researchers. Previous studies show that body rotations have an impact on peoples' perception of small group formations. However, the perception of solely the head rotation seems untested. This paper investigates the effect of virtual agents' various head rotation angles have on the perceived openness in small group formations in a VR environment. The Unity game engine was used to build a setting of students meeting outside KTH campus, with an Oculus Quest 2 to display the scene and a controller to choose answers for our in-built rating form. Two static virtual agents in yellow were placed in front of the camera with different head rotations, and 12 participants each experienced 18 scenes, with 9 different stimuli shown twice in a pseudorandom order. The participants rated their perception of openness of the group in the VR setting after each stimulus was shown for 5 seconds. The results showed a significant link between the head rotations of virtual agents and the participants' perception of openness of the group. The more the virtual agents' head turned towards the participants, the higher their perceptions of openness of the group were. This report suggests that head rotation does have a significant impact on the perceived openness of the group.

Keywords

Perception of Openness, Virtual Reality, Head Rotation

INTRODUCTION

Modern technology has enabled us to create virtual environments where people can interact with virtual agents. Interactions in virtual environments can be similar to interactions in the real world. Humans interacting with virtual agents have been shown to even imitate some human-human behavior in a relatable manner (de Borst & de Gelder, 2015). These interactions can be seen in the implementations of simulations for media such as movies, tv and video games.

These simulated interactions imitate the communication between individuals, one of them being non-verbal communication. E.g., how the gaze, head and body are orientated. These orientations can affect the perception of attention one is granting others. I.e., affect the display of interest or "openness" towards onlookers (Peters, 2005; Zojaji et al., 2020).

Not only are simulations trying to imitate the non-verbal communication of one individual but also the collective behavior of individuals in groups. These group behaviors can be complex and how they are perceived by others trickier still. Even so, how groups and crowds are perceived has been researched and factors such as perceived politeness of groups shine a light on how people experience the group dynamic in certain circumstances (Zojaji et al., 2020).

The interplay between orientation of the body and the perception of groups caught our attention when reading the report made by earlier students that investigated the perception of small group formations with varying full-body rotations (Vestberg et al., n.d.). In the previous research studied, however, the interplay of solely the orientation of the head does not seem to have been investigated. Hence, we decided to investigate the interplay between the two.

This report aims to investigate the perception of openness of a group in a virtual environment (see Figure 1) by measuring the self-reported response given to varying head rotations of said group. I.e., the method of constant stimuli. The stimuli entails a scene in which two virtual agents facing with their bodies toward each other, in a *vis-à-vis* formation (Setti et al., 2015), with their heads facing different degrees towards or way from a human participant. A participant-controlled avatar by Virtual Reality goggles is initialized in the r-space of this group. The participants of the study will be asked to rate their perceived openness of which the group seem to have toward their arrival. Figure 2 illustrates the scene and Figure 1 what the participant sees.

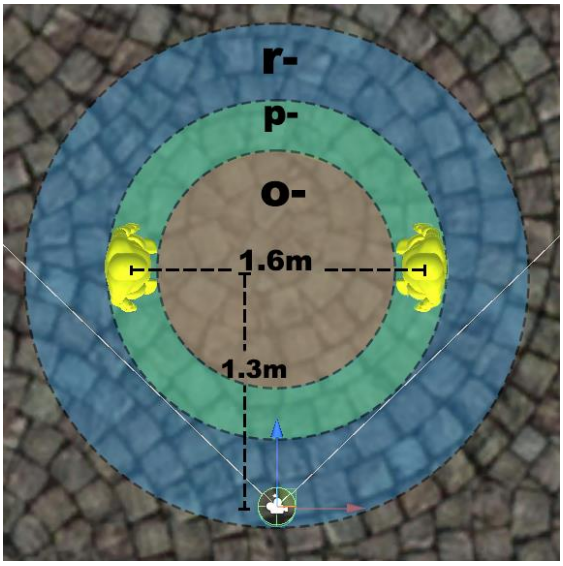

Figure 2 *The group in the virtual environment. A possible f-formation as the yellow virtual agents' heads is turned to face each other. The camera at the bottom representing the human participant.*

The study is guided by the overall research question **RQ**: What is the impact of head rotations on the perceived openness of a group of two agents in a current *vis-a-vis* formation? Three more specific research

questions were formed to help answer this research question.

RQ1: In what combination of head rotations will the user perceive the group as open vs. not open?
RQ2: Is a group with heads turned away from the user perceived as less open compared to when the group has their heads turned towards each other?
RQ3: Does the head rotation of one of the agents have more impact on the perceived openness than the other?

Setti et al. (2015) show that the O-space can be determined by analyzing the feet layout/shoulder orientation and the head orientation; with the direction in which the face is oriented being the strongest determinant. Since being close to the O-space can be seen as being part of a group formation, as described by Setti et al. (2015), two hypotheses were formed:

H_0: The head rotations of the virtual agents do not affect the perceived openness of the group.

H_1: The head rotations of the virtual agents have a significant impact on the perceived openness of the group.

1 BACKGROUND

How we are perceived to allocate our attention is an everyday staple of human communication. This can appear in many ways and not least of them is the orientation of gaze and head.

Orientation of the eyes or gaze is one of the most effective methods of communicating the allocation of attention. When it is not possible to discern gaze, the default of discerning gaze can be appraised from the head's orientation as research has alluded to (Perrett et al., 1992). It is then interesting to think of how applicable it is to not just individuals but groups.

It takes only two people coming together and they form a free conversational group with a social hierarchy that they form between themselves, and these internal relations then decide the group's disposition (Kendon, 1990; Qiu & Hu, 2010).

Relations between groups will behave similarly but with added complexities. Expansion and contractions of groups can cause groups relationships to change collective behavior (Fay et al., 2000).

To reduce complexity, there is a generic model of small static group formations, Kendon (1990) describe the term F-formations where individuals arranged in a circular manner. Kendon further describe f-formation as a grouping of three social spaces: o-space, p-space, and r-space. The o-space is a round empty area surrounded by people who are engaged in a social engagement that is only available to group members. Kendon also describe the p-space as the region around the o-space that contains the group members, whereas the r-space is the area beyond the p-space that is open to the public.

2 METHOD

The study uses the scientific approach of experiment. A pilot test and its brief analysis, and the main trial, will be explained in this section. The dependent variable being the perceived openness during the main trial. The independent variable being the head-rotations of the virtual agents.

2.1 Pilot Test

During the pilot the dependent variable was defined as ‘perceived welcomeness’. After

the pilot it was re-defined as ‘perceived openness’ instead.

The pilot test used a quasi-experimental design, conducted primarily to get insight as to whether the perceived welcomeness did change with altered head rotations of the virtual agents in the VR setup. This also gave a chance to verify any perceived gender of the chosen character model and any inferred emotions. As well as investigating if any other extraneous variables may be influencing the results.

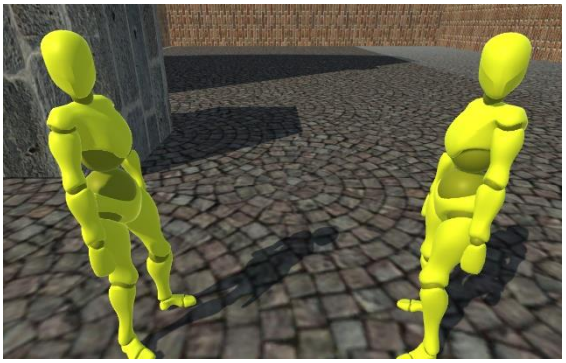

Figure 3 *Example of pilot stimuli, both agents' heads turned towards the participant. The agents had a certain stance and shadows were being cast.*

Six participants were selected out of convenience. The test was explained, and informed consent collected. Care was taken to not reveal what variable was being investigated. Putting on the VR headset they were presented with nine different stimuli (see Figure 3 for example) sorted in a one and the same pre-ordered sequence. The participants were shown each stimulus for 5 seconds. After each stimulus a form for rating the perceived openness in a 5-point Likert scale was presented inside the VR headset, asking “*rate your perceived welcomeness*”, ranging from *Unwelcomed* (1), *Neutral* (3) to *Welcomed* (5). After rating, the process repeated with the next stimulus being shown.

After the 9 stimuli, the participant filled out a physical questionnaire asking about: their perception of the agents’ gender, if there was any inferred expressions or emotions from the agents, if they felt looked at when the heads of the agents were turned towards them, and if the agents color inferred any emotion. There was also a brief verbal discussion about the participants experience with one researcher taking notes.

The results of the rating were presented inside the VR at the end, which was checked by one researcher and manually written into a digital spreadsheet

2.1.1 Results, Analysis, and Conclusions of Pilot

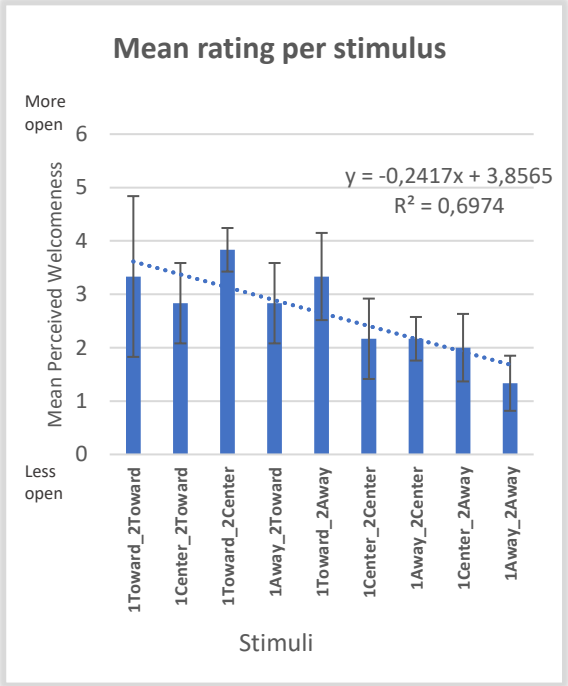

Figure 4 *Mean perceived welcomeness rating per stimulus for the pilot. Trendline $R^2 \approx 0,7$. Error bars = Standard Deviation. Indicating a decrease in perceived welcomeness as the heads turn away from the participant.*

Based on Figure 4 there was a trend of less rated perceived welcomeness as the agents look away from the participants, suggesting it was worthwhile to continue with the experiment. Furthermore, there was a difference when comparing the mean rating

for when each agent's head was facing the participant (mean ± SD) 3.6 ± 0.7 vs. 2.8 ± 0.7. Indicating something might be interfering with the perceived welcomeness of the group, as there theoretically should not be any difference.

Answers in the questionnaires and discussions showed that four participants perceived no gender in the virtual agents. One participant also perceived the agents as being aggressive, while the rest perceived no inferred emotion or expression.

Based on the results, it was identified that several factors may be influencing the perceived welcomeness. Hence, was the following changed moving forward to the main trial: the stance of the agents (the lower body of the agents made completely straight and facing each other equally), all the shadows were removed, the lighting to light up both agents equally and lastly, the background environment was changed to be more symmetrical on the left vs. right side.

2.2 Main Trial

Moving from the pilot, it was decided that perceived 'openness' is a better description for the dependent variable. I.e., no longer referred to as 'perceived welcomeness'.

2.2.1 Participants

For the main trial, participants were also selected out of convenience and the sample size mainly pragmatic with 12, young adult, students of KTH. These were met in a secluded room at KTH one by one, informed about the experiment and their consent collected before beginning.

2.2.2 Software and Scene Modelling

The VR scene and stimuli were built using Unity 2020.3.18f1. The environmental models and textures were provided by our supervisor at KTH. The environment is a simple model of the main campus of KTH. The character model was downloaded, with a free license, from Adobe Mixamo[1] and altered to not show any fingers since this can be a salient stimulus (C. Peters, personal communication, September 27, 2021)[2]. The color of the model was set to yellow, as this has been shown to be less likely to infer any emotion (Feng et al., 2010). The VR headset used was Oculus Quest 2.

2.2.3 Experimental Setup and Data Collection

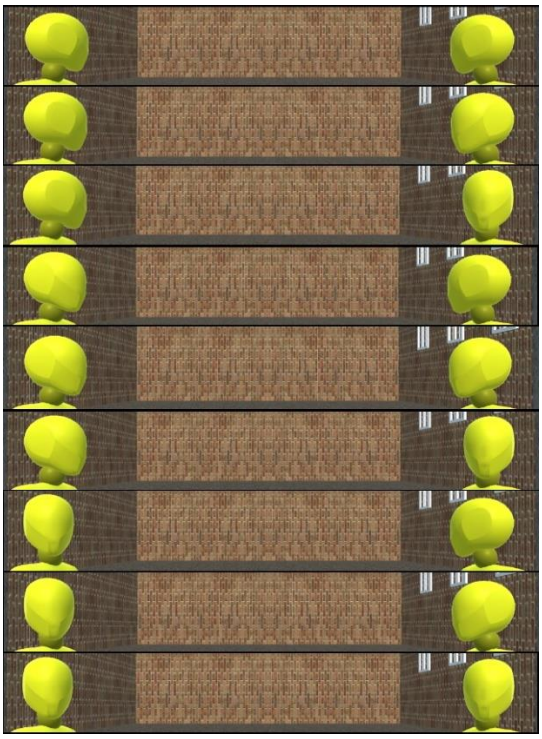

Figure 5 *The 9 stimuli. Ranging top to bottom as Figure 8 x-axis ranges left to right. In Unity the amount of degrees the heads are rotated is 50° left/right, with 0° being facing straight forward.*

[1] www.mixamo.com

[2] https://www.researchgate.net/profile/Christopher-Peters-2

The experiment used a within-subjects design. The experiment had 9 different stimuli (see Figure 5). Each participant saw and rated all the stimuli twice, totaling to 18. The ordering of these nine stimuli was pseudorandomized in two sets, for each participant, using Unity's Random class[3]. I.e., one set of the 9 randomized stimuli was first presented and then the second randomized set of the 9 stimuli.

The participants were shown each stimulus for 5 seconds and after each stimulus a form for rating the perceived openness in a 7-point Likert scale was presented inside the VR headset, asking "*You feel that the group is being open to your presence*", ranging from *Strongly Disagree* (1), *Neutral* (4) to *Strongly agree* (7).

After the total of 18 rated stimuli, the participant filled out a physical questionnaire asking about: their perception of the agents' gender, if there was any inferred expressions or emotions from the agents, if they felt looked at when the heads of the agents were turned towards them, and if the agents color inferred any emotion. There was also a brief discussion about the participants experience with one researcher taking notes.

2.2.4 Data Processing

After each participant had finished with the experiment, the result data was displayed inside the VR scene which was screen-captured and then manually written into a spreadsheet. Continuing, the head rotation of the two agents were split apart to allow processing the head rotations individually. A CSV file was formed that consisted of three columns: head rotation of the left (first) agent, head rotation of the right (second) agent, and the perceived openness of the stimuli, with each row containing the result for each stimulus. The data was then processed and analyzed using R version 4.1.1 and R Studio 2021.09.0 Build 351.

3 RESULTS

3.1 Naming of the Stimuli

Each stimulus is named by how each agent's head was turned. The First (i.e., left) agent was named 1 and the Second (i.e., right) was named 2. When an agent's head was turned towards the participant it was called *Toward*, when the head was turned towards the other agent it was called *Center* and when the head was turned away from both the participant and the other agent it was called *Away*. E.g., the stimulus 1Toward_2Center is when the First agent's head was turned towards the participant and the Second agent's head turned to face the first agent.

3.2 Results from Main Trial

3.2.1 Descriptive Statistics

In this section, data from the main trial are presented in form of tables and figures.

[3] https://docs.unity3d.com/ScriptReference/Random.html

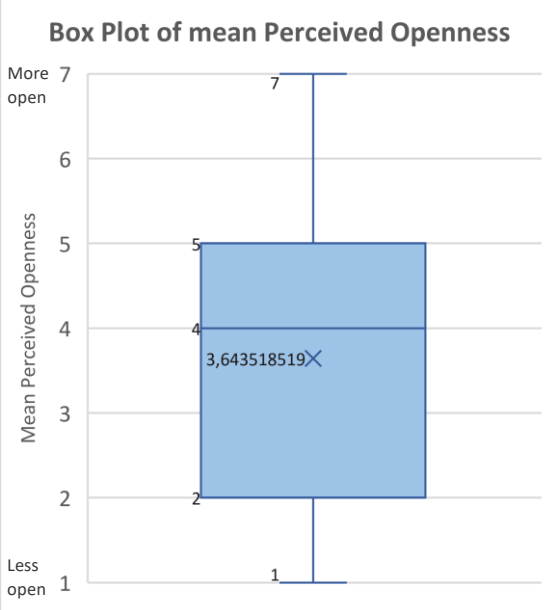

Figure 6 *Box plot of the perceived openness.*

The experiment resulted in a total of 216 datapoints of rated perceived openness. As illustrated in Figure 6, the perceived openness has a mean (mean ± SD) of 3.64 ± 1.48 and a median of 4. The result has a range of 6, starting from 1 (less perceived openness) to 7 (more perceived openness) with 4 representing a neutrality.

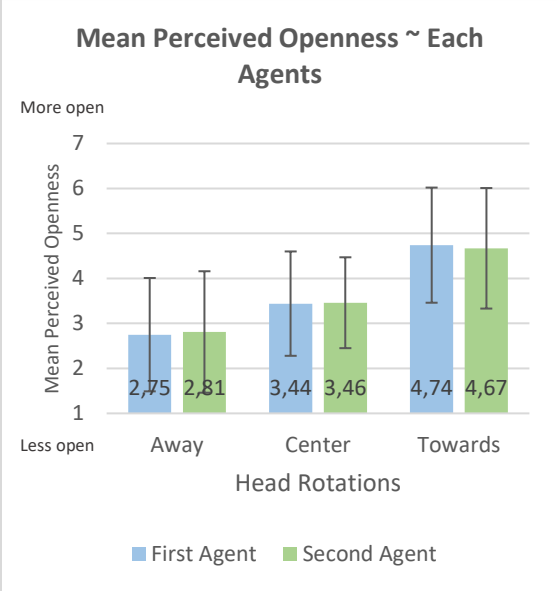

Figure 7 *Bar plot of the mean perceived openness between both agents. The x-axis represents the different head rotations, and the y-axis represents the mean of the perceived openness. Error Bars = Standard Deviation.*

Figure 7 above presents the mean perceived openness in relation to each head rotation for each agent. Comparing the two, we can see that there is no significant difference between the agents (more in detail will be presented in Section 3.2.3.) I.e., both have a similar mean perceived openness for each head rotation. In greater detail, when the agents looked away from the participants, the mean perceived openness (± SD) of the first vs. second agent was 2.75 ± 1.26 vs. 2.81 ± 1.35. When the agents looked towards each other, the mean was 3.44 ± 1.16 vs. 3.46 ± 1.1. Finally, when both agents' heads faced the participant, the mean was the highest with 4.74 ± 1.27 vs. 4.67 ± 1.34.

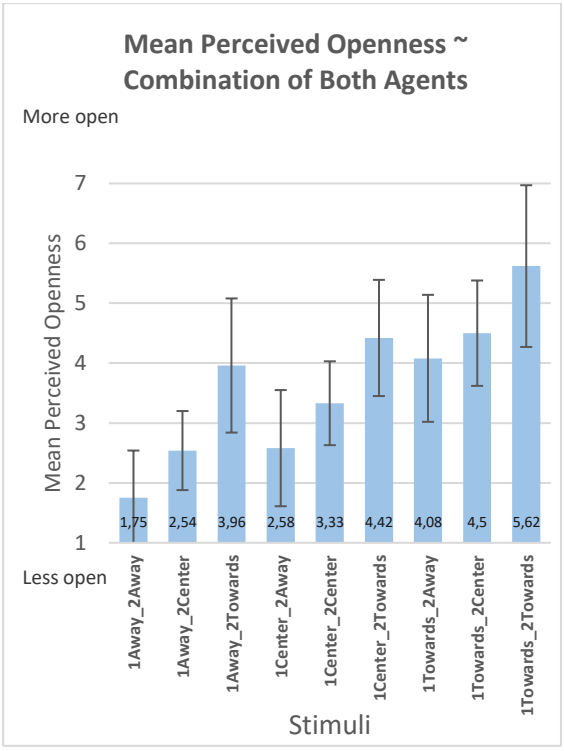

Figure 8 *Bar plot of the mean perceived openness of each stimulus. The x-axis represents the stimuli, and the y-axis represents the mean perceived openness. Error Bars = Standard Deviation.*

In Figure 8, we observe the mean and the standard deviation of the perceived

openness in relation to each stimulus. In our 7-point Likert scale, the scale of 4 represents neutrality. Looking at the figure above, we can see that there are four stimuli that have a mean of perceived openness above the neutral 4-level, which are 1Center_2Towards, 1Towards_2Away, 1Towards_2Center, and 1Towards_2Towards. While the other stimuli have a mean of perceived openness below the neutral 4-level with various degrees.

3.2.2 Testing Significance of Head Rotations on Perceived Openness

Two-way ANOVA (Analysis of Variance) was used to test the significance of the independent variables (head rotations of the First agent and head rotations of the Second agent) towards the dependent variable (perceived openness).

According to the two-way ANOVA test, the head angle of both agents have a statistically significant difference on the perceived openness, with $F(2) = 78.1$, $p < 0.001$ for the first agent and $F(2) = 68.5$, $p < 0.001$ for the second agent. However, there is no interaction between the head angles of the first and second agent ($p = 0.528$), making each variable a completely independent variable. The interaction graph between the independent variables and the dependent variables is presented in Figure 9 below, showing no intersecting lines, illustrating the lack of interaction between the independent variables.

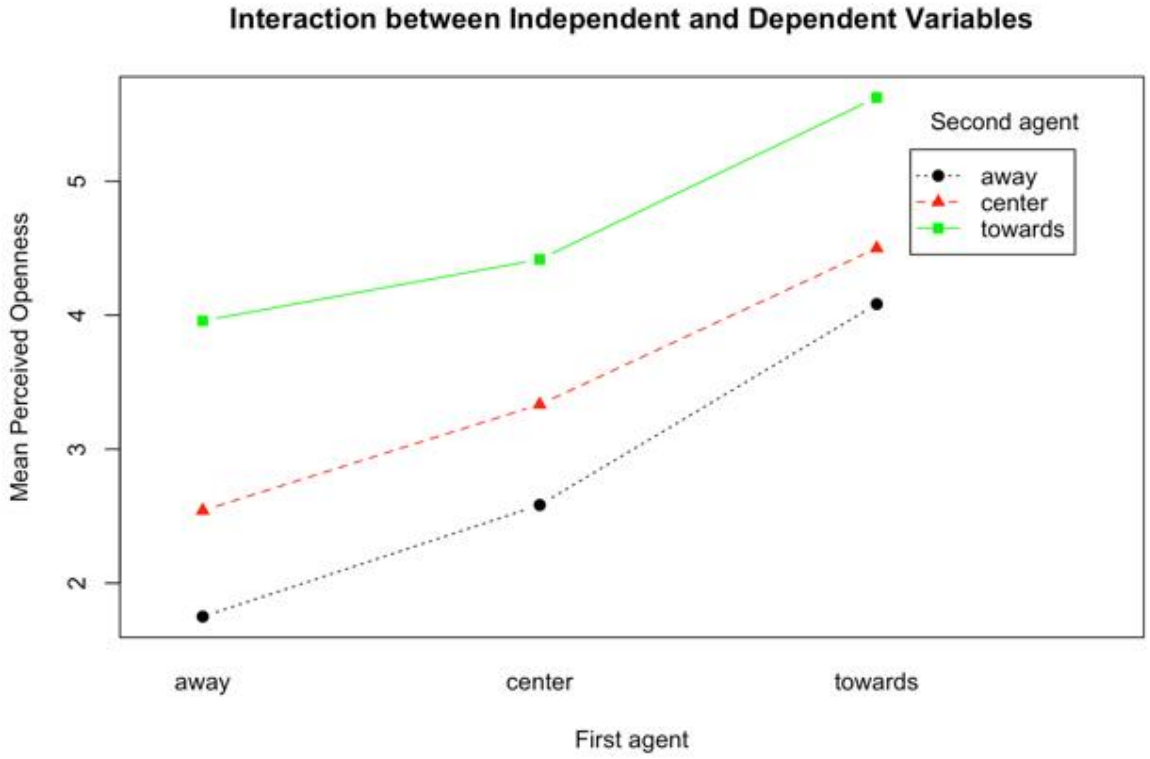

Figure 9 *Interaction plot of the First agent's head rotations (x-axis), Second agent's head rotations (lines) and the mean perceived openness (y-axis).*

3.2.3 Statistical Significance Between Each Head Rotation

Tukey HSD test was conducted to see the statistical differences between each head rotation of the agents. According to the test, all rotations in the first agent are statistically different between each other ($p < 0.001$). The average perceived openness of the rotation Towards is 1.3 points higher than the rotation Center, and 2 points higher than the rotation Away. While the average perceived openness of the rotation Center is 0.7 points higher than the rotation Away.

Similarly, all angles in the second agent are statistically different between each other ($p < 0.001$). The average perceived openness of the rotation Towards is 1.2 points higher than the rotation Center, and 1.86 points higher than the rotation Away. While the average perceived openness of the rotation Center is 0.65 points higher than the rotation Away.

Table 1 *The mean perceived openness difference and p-value between two alternating group configurations according to Tukey HSD post-hoc test.*

1st Configuration	2nd Configuration	Mean Difference	p-value
1Away_2Center	1Center_2Away	-0.042	1
1Away_2Towards	1Towards_2Away	-0.125	0.99
1Center_2Towards	1Towards_2Center	0.083	0.99

It is interesting to look at the interaction between two alternating group configurations using Tukey HSD post-hoc test to find out whether there was any difference if the head rotation of the agents were switched or not. We can see from Table 1 above that every mirrored head rotation showed no statistically significant difference in the mean perceived openness. All configurations posed a mean difference of no larger than 0.125, where the sign of the mean perceived openness difference indicates which configuration has the higher mean; negative indicating that the second configuration has the higher mean, while positive indicating that the first configuration has the higher mean.

3.3 Questionnaire

Using a 5-point Likert scale, the perceived gender of the virtual agents was probed. Ranging from Male (1), to Gender Neutral (3), and Female (5). With the results being a mean ± SD of 3.42 ± 1.0, indicating that most participants perceived the agents as gender neutral to slightly female.

When asked if the participants perceived some sort of expression or emotion from the virtual agents, six of them answered no, while the other six of them answered yes, noting that the head rotation sometimes makes them feel that the group is open towards them. One participant also commented that when one agent was looking away and the other was watching the other agent, the participant felt that the agents did not want to give the participant attention.

Also, when asked whether the participants feel that the virtual agents were looking at them when their heads were turned towards them, ten answered *yes*, and two answered *sometimes*.

The participants also provided some comments regarding the whole experience of the experiment. One person commented that when the First agent looked at them it felt different than when the Second looked at them, stating that they might give a different rating for these two scenarios. Other participants also commented that it could be confusing to determine the direction of the virtual agents since they did not have a face. Another participant

commented that they felt the most open when the agents were looking directly at them, that they felt ignored when both agents were looking towards each other, and that they felt rejected when the agents looked away from them. One participant also noted that their answer might change depending on how long they stood in the virtual environment. They stated that they felt intimidated when both agents were looking directly towards them but started to feel more comfortable after a certain amount of time.

4 ANALYSIS & DISCUSSION

Here the paper analyzes and discuss the results, and the project is assessed.

4.1 Results Analysis

Firstly, looking at the result of the two-way ANOVA, it is evident that the head angles of the virtual agents made an impact on the perceived openness of the group. The average perceived openness is significantly higher when the virtual agents' heads faced the participants compared to when facing each other, or away from the participants. This supports the alternate hypothesis (H_1) that the head angles of virtual agents did impact the perceived openness of the group and we can reject the null hypothesis (H_0). This result also supports the argument provided by Setti et al. (2015) that transactional segments, the area in front of the body where hearing and sight are most effective, can be determined by the head orientation. Meaning that when the virtual agents were looking away from the participants, it might mean that those agents did not want to form a transactional segment with the participants.

Secondly, looking closely at the mean perceived openness of the group, when combining both agents' head rotations (see Figure 8), we can see an increase in the perceived openness as the agents' head rotate towards the participants. If at least one agent was looking towards the participants, the participants seemed to perceive the group to be more open compared to having no agent looking towards them at all. It is also evident from the data presented in Section 3 that the difference of mean perceived openness between the head angle of *towards* and other head angles was higher compared to any of the other combination of head angles. Since the point of neutrality is 4, therefore, to answer our RQ1, the combination of head rotations that the participants' perceived as open was 1Center_2Towards, 1Towards_2Away, 1Towards_2Center, and 1Towards_2Towards (although it is worth mentioning that 1Away_2Towards scored close to 4, with a mean ± SD perceived openness of 3.96 ± 1.12.)

Thirdly, we can see that when the virtual agents were looking directly towards the participants, the average perceived openness scored the highest, while when both virtual agents were looking away from the participants, the perceived openness scored the lowest. This answers our RQ2, where groups that have the agents' head rotations turned away from the user perceived as less open compared to when the group has their heads turned towards each other.

Lastly, the lack of interaction between the head angles of the first and second agent indicates that changing the head angles did not make an agent more or less open than the other. Furthermore, when observing the interaction presented in the Tukey HSD post-hoc between two alternating group

configurations (i.e., 1Towards_2Center and 1Center_2Towards), we can see that alternating the group configuration did not pose a significant difference towards the perceived openness. This indicates that the head rotation of one agent did not have more impact on the perceived openness compared to the other agent. Hence, providing evidence for answering RQ3.

4.2 Methodology Critique

In a within-subjects experiment, a truly randomized ordering of the stimuli, or pre-set evenly distributed ordering, is important to avoid any recurring ordering of the test between the participants. Due to time constraints, it was not possible to implement a more complete random ordering, than what the Unity Random class offered, or a create a counterbalance of the ordering with, e.g., Latin Square Design[4]. This might have affected the validity of the results negatively.

When positioning the virtual agents for different head rotations, we only rotated the "head rig" of the model. This was done to isolate the effect of head-turning and further understand the effect of head orientation in groups. But the results from our report do not generally translate into how it would work in tandem with other human posture stimuli as is witnessed in real life. Therefore, more research is needed on other body postures and their effect when combined.

With the results from the pilot, we were able to mitigate the interferences of extraneous variables, we turned off the fog and the shadows of the lights in the scene and set the lighting right behind the participant to light up both agents equally. The stance of the agents was also made stiffer and more equal between the two. It may have reduced the immersion to some extent but evidently helped limit the variable to only what we wanted to investigate, as there was no statistically significant difference in the ratings between the two agents.

4.3 Project Assessment

We scheduled our project progress and had regular group meeting to work together and owing to our prior experience with Unity and data analysis, we were able to finish the project with a decent quality within a limited timeframe. We first began with reading relevant studies done on group formations and brainstormed numerous ideas of how we can continue with the project. There were some confusions about whether we should use the term "welcomeness" or "politeness" when we started our project. We settled with "openness" after conducting a pilot study and consulting with our supervisor and we were able to decide on the number of stimuli we want to show, the amount of time between each stimulus, the posture, stance, and color of the virtual characters.

We had great allocation of work for each group member, with two members working with Unity, and the other two focusing on finding previous research and data analysis. It helped our project a lot in terms of team cooperation and time management. During our cooperation, we used Google Drive, OneDrive and GitHub to work collaboratively and had regular meetings in-person.

There were concerns that our participants might find out what we were experimenting and rate their perception based on "how

[4] https://online.stat.psu.edu/stat503/lesson/4/4.3

they were supposed to choose". However, the experiment went quite smoothly, and the participants mentioned that they choose based on their feelings and intuition.

Lastly, even though we had some innovative thoughts, we learned throughout the project that it was important to limit the variables to only those we want to investigate. We adjusted things during the study based on things we learned and decided not to add any animations or sounds for the project, to rule out other variables that could affect peoples' perception. The result came out satisfying after the experiment and the analyses have helped us in answering the research questions.

4.4 Future Research

This report is far from a complete study of the perceived openness of small groups since research have shown that there are many complex variables involved. When we first started the project, we had thoughts about whether foot rotation could affect peoples' perception of openness of a group, then settled on researching the head rotations. As research states that the feet are the smallest determinant for determining the O-space (Setti et al., 2015). It would be interesting to investigate how much only the rotations of the feet affect the perception of openness. Also, the participants in our report stated in the questionnaires that they felt that the virtual agents were looking at them when their heads were turned towards the participants. We received feedback from our participants that the virtual characters looked aggressive with sharp lines on their face. It is also one thing to consider for future studies on how to make a more natural scene.

5 CONCLUSION

In this report, we investigated the relationship between head rotations of virtual agents and the perceived openness of a group in VR. An experiment using within-subjects design was conducted, measuring the self-reported responses given to random stimuli of a group with varying head rotations. I.e., the method of constant stimuli. The results of the experiment indicated that the virtual group was perceived to be more open when the virtual agents have their heads turned towards the participants, which supported our alternate hypothesis H_1.

Firstly, we answered **RQ1**: *In what combination of head rotations will the user perceive the group as open vs. not open?* from the data analysis that the combinations of head rotations that the participants' perceived as (to some degree) open were 1Center_2Towards, 1Towards_2Away, 1Towards_2Center, and 1Towards_2Towards. Secondly, we found that when agents had their heads turned away from the participants, the group was perceived as less open compared to when the group had their heads turned towards each other, which answers **RQ2**: *Is a group with heads turned away from the user perceived as less open compared to when the group has their heads turned towards each other?* Thirdly, the results showed that the head rotation of one agent did not have more impact on the perceived openness compared to the other agent, answering **RQ3**: *Does the head rotation of one of the agents have more impact on the perceived openness than the other?* Finally, we can conclude that the head rotations of the virtual agents have a significant impact on the perceived openness of the group, answering our general **RQ**: *What is the impact of head rotations on the perceived*

openness of a group of two agents in a current vis-a-vis formation?

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