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SPECIAL ISSUE PAPER

Perceptually plausible formations for virtual conversers

Cathy Ennis[1,2]* and Carol O'Sullivan[1]

[1] Graphics, Vision and Visualisation Group, Trinity College Dublin, Dublin, Ireland
[2] Games, Media and Agent Technology Group, University of Utrecht, Utrecht, Netherlands

ABSTRACT

Recent progress in real-time simulations has led to a higher demand for believability from virtual characters. Background characters are becoming a more integral part of games, with emphasis being placed in particular on interactions between them. Conversing groups can play a significant role in adding plausibility, or a sense of presence, to a real-time simulation. However, it is not obvious how best to generate and vary these kinds of groups. In this paper, using anthropological standards for interacting distances and formations, we conduct a series of experiments to examine how these parameters inherent in human conversation are perceived for virtual characters. Our results show that, although participants were sensitive to both distance and orientation changes between talkers and listeners in a virtual conversation, they were not as sensitive to anomalous gesturing behaviours across different distances. Copyright © 2012 John Wiley & Sons, Ltd.

KEYWORDS
perception; virtual social groups

***Correspondence**
Cathy Ennis, Games, Media and Agent Technology Group, University of Utrecht, Utrecht, Netherlands.
E-mail: c.ennis@uu.nl

1. INTRODUCTION

Non-hero characters are beginning to play a more integral role in games, where they interact with each other and with the player's avatar. Games like Assassin's Creed use bespoke artificial intelligence systems for their background characters, who react to the decisions the player makes and thereby change the mood of the scene [1]. As these characters become more important to the gameplay, they are expected to exhibit more plausible behaviours and reactions. One way of achieving this added realism is to include social behaviours such as conversing groups. Often, however, priority is not given to producing expensive artificial intelligence behaviours, and groups are composed of random or repeated formations. This can result in a less realistic environment, so a plausible but computationally efficient solution would be very desirable.

Our goal is to guide the automatic generation of varied conversing groups. Ennis *et al.* [2] identified perceptually plausible pseudo-random combinations of motions and audio for virtual conversers. They found that ensuring the appropriateness of talker/listener roles within a group was the best way to generate new conversations from a limited data set (Figure 1). However, their conversers maintained the same formations throughout, thereby limiting variation. Additionally, when combining together body motions from separate conversations, there will inevitably be unintentional modifications to the group structure. What effects do these modifications have on the sense of interactivity between the characters? If these effects exist, then how do we manage them to create believable new group formations? We build on the results of Ennis *et al.* and conduct a set of perceptual experiments to identify perceptually plausible variations to the positions and orientations of individuals within a virtual conversing group.

We apply two conversational behaviour theories from anthropology to the simulation of groups of conversing characters. Firstly, we focus on the variation of distance between the characters [3]. Is there a distance between two virtual characters that is more or less conducive or disruptive to the perception of communication between them? If characters are to be positioned at different distances, are there limits on the types of motions that they can exhibit? If a motion can be used for multiple conversations over a range of interpersonal distances, then this could simplify the capture process and eliminate the need for a large capture space.

Secondly, we test a theory based on orientation of characters around a focal point in the conversation space [4]. We investigate if it is possible to modify the orientation of

Figure 1. Applying animations to conversing groups as advised by Ennis *et al.*

individuals within a group and whether any negative effects of these modifications can be masked by redirecting the attentional focus of the character.

Results from our perceptual experiments show that near and mid offsets improve the realism of communication from the talker, and at these distances, any body motions can be used. Furthermore, when characters are mis-orientated, modifying the gaze direction to focus on the talker can significantly enhance the perceived engagement of listening characters. Participants were not sensitive to gesture differences for conversations at different interpersonal distances; this means that any body motion can be interchanged across several different character offsets.

2. RELATED WORK

The positions of two or more people in a conversation give a good indication of the relationship between them and the nature of the conversation. Hall's proxemic theory [3] suggests four levels of distance between two people and the types of communication they are associated with. These range from an intimate distance, which is only entered into when people are extremely familiar with each other, to a public distance, for more formal forums such as a classroom environment.

How people orientate themselves within a conversation is also a subconscious, but structured, process. Kendon's F-formation [4] system describes the structure and properties of an interacting group in relation to spatial positioning and orientation. The F-formation is mainly described by the positioning of the lower bodies of the members that gives each group member equal access to the centre of the conversation space (Figure 2). Although differences have been noted with respect to proxemics across different cultures, the F-formation system has been noted across many cultures and seems to be a widely used social system [5].

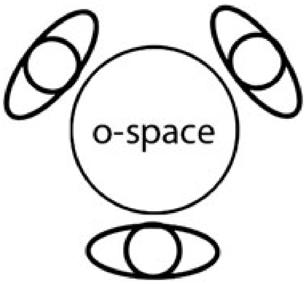

Figure 2. Example of an F-formation for a three-person conversation.

Thompson *et al.* [6] investigated human interpersonal distance preferences and found that participants preferred, and found more appropriate, intermediate over extremely close or far offsets. However, they experienced some ordering effects, which highlight the subjectivity of the perception of conversational behaviour. Aiello *et al.* [7] identified participants' preferences for interpersonal distances and found that physiological reactions (e.g. stress levels) to crowding can vary depending on such preferences. However, despite individual differences with respect to interpersonal distances, they all had similar standards for crowding distances.

The distance between individuals in a conversing group is an integral part of conversational behaviour and can affect other aspects of conversational style. Links have been found with the amount of conversational eye contact between them [8] and different group sizes [9]. Results from this study show that the distance between participants in a conversation decreased as the group went from a dyadic (two-person) conversation to a multiparty conversation. So such preferences are dynamic and not static over all conditions.

Proxemics are important considerations for virtual characters in immersive virtual environments and human–computer interaction applications. It has been shown that people treat these virtual agents similarly to how they treat other humans and afford them similar personal space bubbles [10]. However, this is only true for virtual characters that represent avatars and not for autonomous agents. This implies that how we perceive virtual characters varies on the basis of their function. It has also been found that humans react differently to the proximity of a single character than to a group of characters [11].

Pedica and Vilhjálmsson [12,13] presented a platform based on Kendon's F-formation system that produces realistic reactive behaviours for virtual characters participating in group conversations. A pilot evaluation of this technology implies that the addition of territorial behaviours can increase the believability of non-humanoid virtual conversers in some cases. Jan and Traum [14] defined a similar model for maintaining virtual group formations based on forces, for example, an attraction force towards the speaker or a repulsive force away from outside noise.

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Although it has been found that standards for group formations and offsets are commonplace in communicative encounters between humans (and are expected during interaction with virtual characters), they can be subject to external factors, such as crowding or group size. However, it is not known how tolerant people are of subtle anomalies in distance/gesture matching or orientation modification. We examine the effects of such modifications (investigating distance using dyadic conversations and orientation using triadic conversations) that can be inadvertently introduced by the combination of different animations or deliberately to create variation, to guide their use for virtual conversers.

3. STIMULI CREATION

We conducted two motion-capture sessions to create the stimuli for our experiments. Each session consisted of a number of two-person and three-person conversations. In the first session, we captured male actors aged between 27 and 31 years. In the second, we captured female actors aged between 23 and 28 years. For both sessions, we captured dyadic conversations where both actors wore full-body motion-capture suits. We also captured triadic conversations where a listener was added to the group with 10 body markers to allow us to capture position and orientation information of the two listeners.

We captured the actors' motions using a 13-camera Vicon optical system, with 52 markers per actor (Figure 3). We did not capture face motion as we wished to focus on body motions, positions and orientations in this study. Each conversation consisted of a talker and either one or two listeners. Although we did not capture finger motion, we placed a marker on the forefinger and little finger of the speaker, which allowed us to interpolate basic finger motions. A microphone was placed in front of the speaker to record the conversations. For both sessions, the actors were well known to each other and had time to become familiar with the motion-capture setup, thus enabling natural conversation.

3.1. Dyadic Conversations

For two-person conversations, we used the theory of proxemics to guide our formations. According to Hall [3], there are four different spaces we use for different interactions:

- Intimate space: 0–0.46 m
- Personal space: 0.46–1.2 m
- Social space: 1.2–3.7 m
- Public space: 3.7+ m

Intimate distance is only associated with significant familiarity between the part-takers. Personal distance is the most widely used for general conversations. This indicates a close relationship, where touch is still in reach, but personal space is maintained. After this, we communicate at

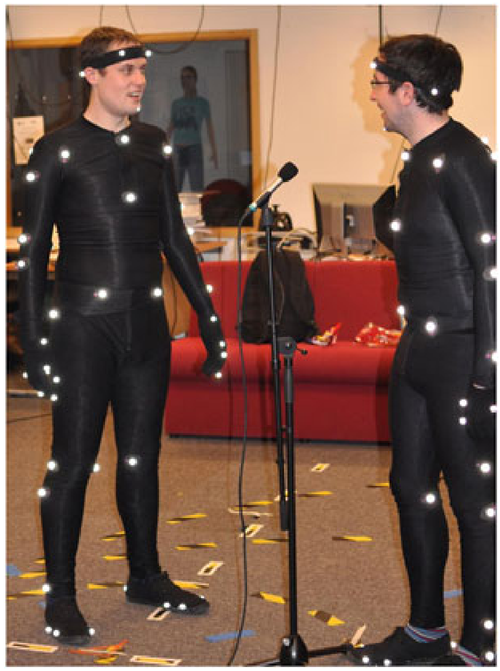

Figure 3. Audio-capture and motion-capture setup with two male actors.

the social distance, which is more impersonal and allows for easier disengagement from the conversation. Finally, public distance is used for formal gatherings such as in lecture theatres. At this distance, there is little personal connection between the participants, until the situation calls for a closer formation.

With these distances as a guideline, we placed markers on the ground for our actors. We asked them to use the markers as a guide, but to move as necessary to maintain a natural style of conversation. We wanted the actors to focus more on the interaction with each other, rather than enforcing specific feet placement. Thus, we captured conversations at three distances from each of our four actors (two men and two women):

- Near (representing intimate distance): 0.4–0.5 m (average: 0.46 m)
- Mid (average of personal and social distances): 1.65–2.1 m (average: 1.78 m)
- Far (representing public distance): 7 m

Each actor was assigned a virtual character used to represent their motions throughout all of our experiments (Figure 4). The characters were chosen to approximately match the actors in age, weight and height to minimise re-targeting errors.

For the near and mid distances, we were able to capture the exact position of both actors, as they were both inside our motion-capture zone. However, for the far distance, we captured the motion of the speaker only. We measured 7 m from where the speaker was positioned and asked the

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Figure 4. Examples of stimuli used in our triadic experiment: 60° orientation offset with original (left) and modified head looks (right). The modified character is highlighted in red.

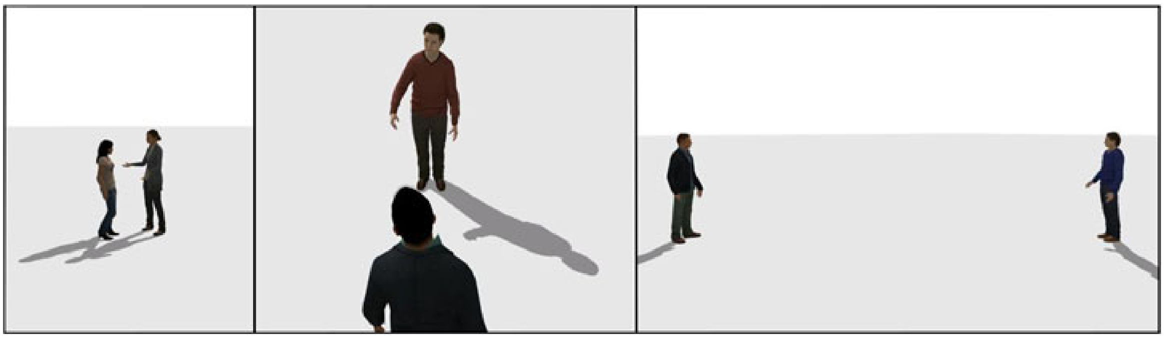

Figure 5. Examples of stimuli presented to participants in our dyadic experiments showing (from left to right) near, mid and far distances from two different viewpoints.

listener to stand at that position, which was outside the capture zone. For the virtual representation of these formations, we positioned the listener to face the speaker at a distance of 7 m (for examples, see Figure 5). For each conversation, two 7-second segments were chosen from each actor's conversations. One of these segments was then chosen at random when the conversation was played at each trial. Because we did not have synchronised conversations for each distance, when a talker conversation was selected, a different, random listener motion was chosen. Following results from Ennis *et al.*, we ensured that the audio was matched to the talker and used random listener motions. The audio track was played from the talker's position in 3D space. We did not alter the audio track in any way as we were focussing on visual conditions in this experiment.

3.2. Triadic Conversations

For our triadic conversations, we tested Kendon's F-formation system [4]. He described the space between a group of conversers as an o-space and described the formation surrounding that as an F-formation. The idea that each member of the group works to maintain this o-space with the positioning of their bodies is at the core of the F-formation system. We investigated the effects of body and head orientations on the perception of good communication between virtual conversers.

The speaker in these conversations stood inside the capture zone, and we then asked the two listeners to walk towards the speaker and initiate conversation. The actors formed natural positions and orientations and always maintained an F-formation without explicit instruction. We captured two conversations of this type for each actor. We captured the full-body motion of the talker for these conversations and the positions and orientations only for both listeners.

We then created synthetic replicas of both conversations using listener motions captured during the dyadic conversations. Each listener was given a different motion and positioned and orientated using the data from the triadic capture session.

To investigate participants' sensitivity to body orientations, we altered these motions, introducing orientation modifications to the listeners. We created variations of the original conversations, where one listener's full body was rotated 30° or 60° away from the speaker (away from the conversation space). To examine whether these anomalies could be rectified with the appearance of directed attention to the talker, two further variations of these were created, layering a head look on the animation to ensure that the listener's head was facing towards the speaker (for examples, see Figure 4). As in the dyadic conversations, two 7-second segments were chosen from each conversation, and these were presented as stimuli to the participants.

4. DYADIC CONVERSATION DISTANCE EXPERIMENTS

Our first set of experiments studied conversing pairs. The first experiment focussed on body motion alone. The second included both body motion and audio as stimuli under the same experimental conditions.

The objective of these experiments is to examine human sensitivity to variations in interpersonal distances for two virtual conversers. We set out to determine if there are interpersonal distances that are particularly implausible for virtual conversers, that is, would participants find communication to be worse over far or extremely close interpersonal distances? We also wished to find participants sensitivity to gesture emulation relative to proximity between characters. For instance, if an actor's gestures were captured when he/she was speaking to someone in close proximity, is it appropriate to use this for much further interpersonal distance? Finally, we investigated the effect of the presence or absence of audio on the perception of virtual conversations? If the correct audio is matched to the talker, will the listener automatically appear to be more engaged in the conversation?

To answer these questions, we tested two conditions in our experiment: the formation of the group, that is, whether the positions of the characters were at the near, mid or far distances described previously, and the gestures of the speaker that is, whether their gestures were emulated at a near, mid or far distance from the listener.

We used motions and audio from each of the four actors to allow for any differences in conversation style, counterbalanced between two different viewpoints.

Each experiment described in this paper was run on a workstation with a standard issue sound card and an NVIDIA GeForce 8800GTX graphics card. The stimuli were displayed on a 24-in. widescreen monitor, and participants used stereo headphones for experiments using multisensory stimuli.

We had 72 trials in total: three formations (near, mid and far) × three gestures (from each conversation) × four actors (two men and two women) × two viewpoints (side or behind listener view).

4.1. Body-Motion-Only Dyadic Experiment

To determine if some interpersonal distances were more plausible than others, we conducted an experiment with visual-only stimuli. We hypothesised that conversations with the far interpersonal distances would have a negative effect on the perception of communication. Because our near and mid distances were not extreme, we expected no difference between them. We also tested how sensitive participants were to differences between the distance a gesture was captured at and displayed at. Our hypothesis was that participants would notice incorrect gesture/ distance matching, particularly between the near and far distances.

Nineteen volunteers (13 men and six women) took part in this experiment. It was conducted in a single block with trials displayed in random order.

Participants viewed each trial for 7 seconds and were asked to respond yes or no, using a mouse click, to the question, 'Did the talker communicate well with the listener?' We used this question to find out the effects of our experimental conditions on the plausibility of virtual conversations, without focussing participants' attention to anomalies. We randomly associated the right or left mouse button with the yes response for each participant so as to avoid any bias towards a particular button press. After a participant gave his or her response, a cross was displayed to focus attention on the centre of the screen. Participants were asked to ignore the lack of facial motion as much as possible and to base their answer on their own subjective judgment of good communication.

4.1.1. Results.

A three-way repeated-measures analysis of variance (ANOVA) was carried out on the data, with formation and gesture as within-subjects conditions (after finding no effect of a particular camera viewpoint or actor and so averaging across these). We found a main effect of formation ($F_{2,30} = 67$; $p < 0.005$), where participants found that speakers' communication was perceived to be worse at the far interpersonal distance than at either near or mid distances (Figure 6).

We did not find any effect of gesture, implying that for conversations without audio cues, it is not necessary

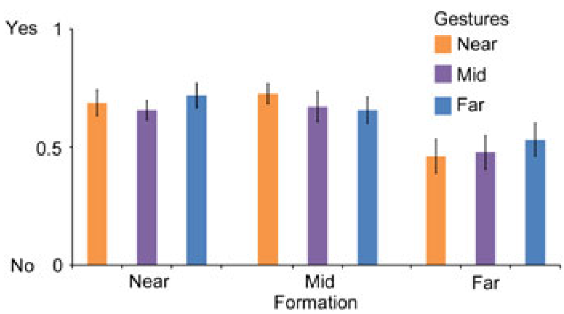

Figure 6. Results from our body motion dyadic experiment. Responses to whether the speaker communicated well with the listener (yes/no) for each formation (*x*-axis) for each gesture type (orange, purple and blue series).

to match a character's gestures to the distance between the conversers.

4.2. Multisensory Dyadic Experiment

Our second experiment was similar to our first but with the addition of an audio cue. Here, we matched the gestures of the speaker to the recorded audio from the capture sessions. We matched the audio to the character's location in the 3D space, to aid participants to locate the talker for each trial. As before, participants were asked to view and listen to each trial for 7 seconds and respond whether they thought the speaker communicated well with the listener or not.

Eighteen (12 men and six women) volunteers took part in this experiment. We asked the same question as before to find out how sensitive participants are to different interpersonal distances. With the addition of audio, we now wished to determine whether it was important to match the gestures to the correct distance.

4.2.1. Results.

As for our body-motion-only experiment, we did not find an effect of actor or camera viewpoint, allowing us to average across these conditions to examine our other factors. Again, we conducted a three-way ANOVA with within-subject variables formation and gesture.

For this experiment, we expected to find similar results as with our body motion stimuli, that is, that participants would find the characters at far distances less communicative. We also hypothesised that with the addition of an audio cue, participants would be exposed to the intonation of the actors' voices and that this would increase their sensitivity to gesture/distance mis-matches.

There was an effect of formation, as expected ($F_{2,\,32} = 36$; $p < 0.05$). As in our first experiment, participants judged the talker's communication to be worse for the far distance than either the near or mid distances. This suggests that the positioning of conversing characters is an important factor in creating engaging groups, and inappropriate interpersonal distances will result in an implausible experience for the user. Despite the addition of audio, participants still find talkers at a large distance from the listener to be poor communicators.

Although there was no effect of gesture, there was an interaction between gesture and formation ($F_{4,\,64} = 26$; $p < 0.05$). Newman–Keuls *post hoc* analysis showed that this was due to the far gesture being rated better than the near gesture for the near formation and the mid gesture being rated better than the far gesture for the mid formation (Figure 7). This implies some sensitivity to gesture/distance mis-matches but could possibly be due to the gestures themselves. When we recorded the conversations over far distances, our actors reported that they felt that the conversation was more contrived and that their movements were less natural. Observing the movements themselves, the actors appear less animated at this distance.

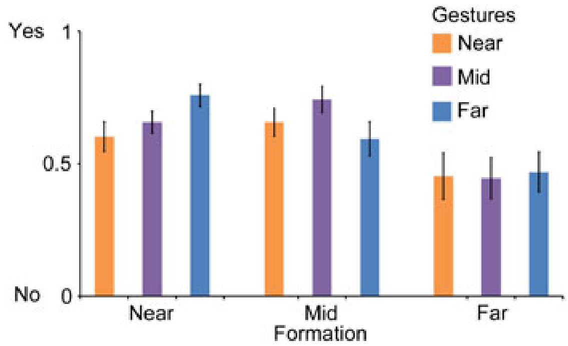

Figure 7. Results from our multisensory dyadic experiment.

Although our results showed that a far interpersonal distance was not appropriate, it is important to note that there was no difference for our near or mid distances. So, the generation of plausible virtual formations can be achieved using gestures recorded at a near or mid distance and characters can be placed between 0.4 and 2.1 m apart, giving scope for a high level of variety in a crowded scene.

4.3. Audio versus No Audio Comparison

To determine the effect of audio on participants' perception of distance in virtual conversations, we compared results across both of our experiments. Each participant had taken part in both experiments, but half of them did the body motion experiment first, and the other half viewed the multisensory stimuli first.

We hypothesised that the presence of an audio cue would have an effect on participants' responses. Because the question was 'Does the speaker communicate well with the listener', it was likely that extra information provided by matching audio and gestures, such as conversation context, would increase the perception of good communication for the conversations.

4.3.1. Results.

To establish whether the presence of audio to body motion would have an effect on participants' perception of interpersonal distance for virtual characters, we conducted two separate ANOVAs with a between-subjects factor of cue (body motion or multisensory) and found no effect.

We then conducted an ANOVA with between-subjects factor of order (whether participants saw the body motion or multisensory stimuli first). We did not find an effect of order, but there was an interaction between experiment order and formation ($F_{2,\,70} = 62$; $p < 0.005$). A possible explanation for this is that participants, remembering the conversation context, found the visual-only stimuli to be enriched by this extra knowledge during the second experiment. Participants who viewed the body-motion-alone experiment first would have had no idea of what the topics or context of the conversations were and could have found it hard to imagine good communication between the characters in the absence of this. So, although there was no effect of audio overall, there was an effect of order, implying that the presence of aural information plays a significant role for judgments of communication between members of virtual groups.

5. TRIADIC CONVERSATION FORMATION EXPERIMENT

Finally, we conducted an experiment using conversing groups consisting of three individuals. From the results of our dyadic experiments, we found that the presence of an audio cue improved the perception of good communication between characters, so we presented the participants with multisensory (audio and visual) stimuli for this experiment.

5.1. Experiment Design

In our final experiment, we wished to investigate participants' sensitivity to manipulations of the conversation space between virtual characters. We wished to determine the level of alteration of conversers' orientations that would be tolerated to maintain the perception of a natural formation. We also wished to investigate if a perceptually unnatural formation could be remedied by correcting the focus of attention of the modified character.

The factors we tested to help us answer these questions were formation and head look. Formation refers to whether each character was at the correct orientation (natural) or modified. Modified formations were those where a listener was orientated away from the group by 30° (offset 1) or 60° (offset 2). Head look refers to whether the head of the modified listener was as originally captured, that is, facing straight ahead or turned to face the talker. We counterbalanced between natural and modified formations and which listener orientation was modified for each talker.

We used two different conversations for four different talkers and also counterbalanced across these to ensure there was no effect of a particular actor, or any gestures associated with a particular conversation. We chose three different camera viewpoints, focussing on one agent while ensuring the others were in clear view, and chose one of these at random for each trial. Participants were asked to respond to the following question via mouse click: 'Were the listeners engaged in the conversation?'

We had 128 trials in total for this experiment. There were 64 repetitions of the natural formations counterbalanced with our modified formations, which were broken down as follows: two head looks (original and towards listener) × two orientation offsets × two listeners × two conversations × four actors.

5.1.1. Results.

We hypothesised that participants would find listeners orientated away from the talker to be less engaged in the conversation. In the absence of eye gaze animation, we postulated that participants could potentially forgive a mis-orientation of 30° in some cases, but not 60°. We also hypothesised that, with the addition of a head look towards the talker for these mis-orientated characters, participants would find them more engaging than when presented with their original head look.

First of all, we wanted to examine whether participants were sensitive overall to synthetic orientations in virtual conversations, compared with real conversations. To do this, we averaged across each of our synthetic orientations (two orientation offsets × two head looks). We conducted a repeated-measures ANOVA. We found an effect of synthetic ($F_{1,\,13} = 211$; $p < 0.005$), where participants found characters in real formations to be more engaged than the modified orientations overall.

Looking at the modified orientations alone, we then conducted a two-way repeated-measures ANOVA with within-subjects factors of orientation offset and head look. We found a main effect of orientation offset, where participants found listeners rotated by an offset of 60° to be less engaged than those at 30°, as hypothesised ($F_{1,\,14} = 459$; $p < 0.0005$). Because there was an absence of facial motion, participants could have mentally visualised an eye gaze at the talker for the smaller offset, whereas for the 60° offset, the listener was unmistakably facing away from the talker.

We also found an effect of head look, where participants found listeners with the original head look and modified orientations to be less engaged than those whose gaze was directed towards the talker ($F_{1,\,14} = 113$; $p < 0.005$). Again, this was an expected result because participants would likely have considered the characters with the modified head look to be looking at the talker and therefore more engaged in the conversation.

Finally, we found an interaction between orientation offset and head look. *Post hoc* analysis showed that this was because participants judged that the modified head look improved the 60° offset more than a 30° one ($F_{1,\,14} = 37.0$; $p < 0.0005$). Figure 8 shows our results from this

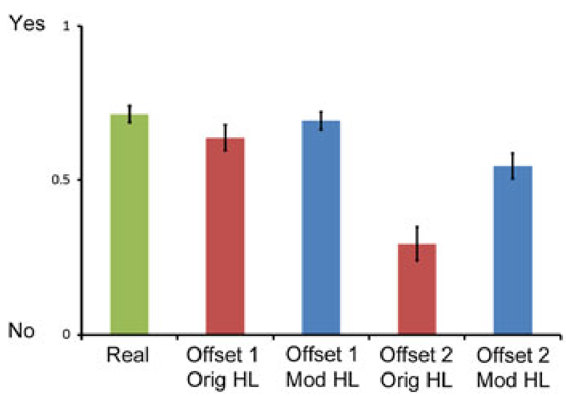

Figure 8. Results from our triadic experiment. Responses to the question of whether the listeners were engaged in the conversation in the real formations (green) for both orientation offsets with or without head-look modification (red/blue).

experiment. A repeated-measures ANOVA showed that participants judged listeners in the real formations to be as engaged as those in the 30° offset formations, regardless of head look. This was followed by the 60° orientation offset formation with the modified head look and lastly the 60° orientation offset with the original head look.

6. DISCUSSION

Results from our first two experiments investigating human proxemics for virtual characters showed that participants are sensitive to interpersonal distances for conversing groups. We found that at a near or mid distance, participants found that the speaker was communicating reasonably well. However, at a far distance, this was not the case. This was true for conversations where body motion alone was visible and multisensory conversations where both visual and aural cues were present. We also found that for these near and mid conversations, communication from the speakers was perceived to be equally effective regardless of the distance the gestures were recorded at.

We also found that when participants were exposed to the audio information, such as the intonation of the voices of characters and the context of the conversation, they were more inclined to perceive the speaker to be a good communicator. Even when they were subsequently viewing visual-only stimuli, it appears that they retained the information and used it to help make their judgments.

A third experiment examined Kendon's theory for orientations of individuals partaking in human conversations for our virtual groups. Here, we found that participants' sense of the characters' engagement in the conversation was not affected by a small offset (30°) of a listener away from the conversation. However, once this offset became larger (60°), this was no longer the case. This reduction in the perception of engagement of the characters can be improved by modifying the listeners animation with the addition of a head look towards the talker. This significantly improves participants' perception of engagement of the characters but does not match the real or less modified characters.

From our results, the following guidelines for the creation of varied synthetic group formations for virtual characters can be proposed:

- When positioning characters, interpersonal distances between 0.4 and 2.1 m are acceptable to give the viewer the impression of good interaction between the characters.
- If possible, an audio cue should be used where the audio is synchronised to the gestures of the talker, as this will increase the perception of interaction.
- If positions are kept within the aforementioned thresholds, gestures recorded from talkers and listeners at any interpersonal distance can be used.
- In triadic conversations, modifications can be made to the orientations of the listeners, at least up to 30°.
- If modifying by 60° or more, altering the animation of the character, by orientating the head so that the listener is looking at the character, will increase realism.

We are exploiting the results of these experiments in a real-time crowd system, where we previously used conversing groups with static formations. We can now add variety to these formations by altering the distance between the individuals within the group and orientations of the listeners. We also note that the addition of head looks not only increases believability of these conversations but also improves variety throughout a large crowd. These observations merit further study. Because Herrera *et al.* [9] found that interpersonal distances change with group size, we also plan to evaluate whether the results for distance and orientation hold when they are applied in combination for different-sized groups.

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AUTHORS' BIOGRAPHIES

Cathy Ennis is a post-doctorate researcher in the Games and Virtual Worlds group in the University of Utrecht. She received a B. Eng. in Electronic Engineering from NUI Maynooth in 2005, and a masters degree in Cognitive Science from University College Dublin in 2007. Following this, she completed a PhD in Computer Science in 2011, while in the Graphics, Vision and Visualisation group in Trinity College Dublin. Her research interests are in the areas of computer animation and the perception of virtual characters.

Carol O'Sullivan is a professor of Visual Computing in the school of Computer Science in Trinity, where she leads the Graphics, Vision and Visualisation group (GV2) and is the director of the newly established Centre for Creative Technologies. After receiving a BA in Mathematics from Trinity College in 1988, she worked for several years as a software engineer in industry (mainly in Germany), and received a masters degree from Dublin City University in 1996 and a PhD in computer graphics from TCD in 1999. She has published over 120 peer-reviewed papers and supervised over 20 PhD students since then. She was elected as the first Irish fellow of the European Association for Computer Graphics (Eurographics) in 2007 and as a fellow of Trinity College in 2003. She is the co-editor-in-chief of the ACM Transactions on Applied Perception and the associate editor-in-chief for Special Issues of IEEE Computer Graphics and Applications. She has chaired several international conferences, including Eurographics 2005, and has been a member of many international program committees, including the SIGGRAPH and Eurographics papers committees.