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Probing Social Aspects of Human-Robot Group Interaction in a Collaborative Game

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ABSTRACT

We present an experimental testbed for probing social aspects of human-robot group interaction using a collaborative game. Our testbed, *Sheep and Wolves*, allows a human user to play as a game piece, with a group of robots as peers, all engaged in collaborative gameplay on a large physical game board, using mixed reality and cartoon art-based techniques to communicate and discuss moves.

The paper argues the importance of controlled experimental testbeds in the development of future social human-robot interfaces, and motivates the research goal of understanding group effects within a collaborative group composed of humans and robots. The paper then discusses the design and implementation of the second iteration our testbed, *Sheep and Wolves*, and its successful use in an extensive user study. The paper concludes with the current preliminary analysis of our experimental results, and our planned future work on *Sheep and Wolves*.

Categories and Subject Descriptors

H.5.2 [Information Interfaces and Presentation]: User Interfaces—*Interaction Styles*; H.5.1 [Information Interfaces and Presentation]: Multimedia Information Systems—*Artificial, augmented, and virtual realities*

Keywords

Human-robot interaction, group effects, mixed reality, physical interaction, electronic entertainment

1. INTRODUCTION

As robots become increasingly intelligent and ubiquitous, it is worth while to consider the potential roles robots can have in society and their relationship with humans. Some feel robots should be "tools", performing only tasks requested by human operators. Others feel robots would become "masters", taking charge of completing tasks by themselves without human intervention [9]. However, a more symmetri-

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Figure 1: *Sheep and Wolves* collaborative Human-Robot Interaction testbed

cal human-computer relationship is advocated by *The Media Equation* [11], suggesting humans and computers should work together as equal peers. It argues: "Being on the same team encourages people to think that the computer is more likable and effective, and it also promotes cooperation and better performance." The notion of robots as teammates is gaining awareness within the human-robot interaction (HRI) community both as recognition for practical applications such as search and rescue and as part of the optimistic outlook toward the integration of robots into society. Future human-robot teams will be both necessary and beneficial since the interdependence between humans and computers has steadily increased in modern society.

Working in teams is a natural human behaviour. It can offer many benefits such as mutual support, skill sharing, and error checking. However, the process of team work is often complex, and the resulting effect is much more than simply a sum of all team members. Interaction within teams also depends on the group effects which arise when team members collaborate. Research in psychology has shown that when humans work together, simply being part of a team alters the behaviours and attitudes of individual team members. Both positive and negative group effects can have significant impact on the operations of teams. For example, humans tend to think they are more similar to their team members, resulting in admiration and respect for each other. How-

ever, humans also tend to yield more often and more readily to team members, leading to potentially dangerous decision making effects such as group-think. It is critical to understand and recognize these group effects to maximize the productivity of teams and minimize potential failures. Collaboration in human-human teams is a well-studied topic, but when considering human-robot teams, the circumstances become more intriguing. Two questions arise from this human-robot relationship. Can humans view robots as legitimate team members and naturally engage in collaborative work with them? Will the group effects present in human-human teams transfer to human-robot teams and alter the attitudes and behaviours of human team members in similar ways?

These challenging social issues of HRI are difficult to investigate. Unlike the familiar concept of human-human teams which can be designated easily, human-robot teams and the required collaborative relationships are still a novelty and require more effort to construct. To explore group effects, a realistic collaborative experience between humans and robots is necessary to evaluate the interaction process. One approach to provide opportunities for investigation is to piggy back experimentation on an existing real world application involving human-robot teams such as space exploration. However, for the purpose of investigating group effects and other social aspects of collaboration, this is a fairly high fidelity approach if there isn't a suitable application to begin with. Also, real world tasks take place in real world environments where the challenging physical aspects of interaction can be both tricky for implementation, difficult to control, and distracting for the target investigation. It would be ideal to create an HRI testbed which is simple yet valid, focused on investigating the social aspects of human-robot teams, and representative of the interactive qualities of realistic human-robot collaborative experiences.

To attempt to answer some of the important questions raised about human-robot teams and group effects, we have developed the *Sheep and Wolves* HRI testbed [13] which is currently in its second iteration of development. Our contribution for this paper is two-fold. First, we introduce the new iteration of the testbed design which supports a collaborative physical board game played with a human-robot team. This testbed utilizes a handheld mixed reality interface for communicating with robots, allowing humans and robots to play within a shared physical setting and incorporates elements of cartoon art to help human team members better anthropomorphize robot team members as valid peers (Figure 1). Second, we make use of the new *Sheep and Wolves* testbed to perform a user study exploring group effects within human-robot teams, and we offer our preliminary analysis of the results as insight for designing further studies and future human-robot teams.

2. RELATED WORK

In this section, examples of real world human-robot teams will be provided as motivation for our investigation, and other efforts exploring the social aspects of human-robot collaboration will be presented to support the validity of our work. Research directly related to exploring human attitudes and behaviours when collaborating with robots or computers will also be considered, and several simple approaches on constructing human-robot teams are discussed. Also, a brief survey of various HRI testbeds is outlined to support our testbed approach for investigating group effects

in human-robot teams.

2.1 Human-Robot Teams

Although currently most robots are designed as tools to be controlled by humans, it is not unfathomable to have more intelligent and capable robots which engage in interaction with humans as partners. One program focused on this concept is NASA's vision for space exploration [6]. The goal is to establish a sustained human presence in space which will require a large amount of robot support. Therefore, emphasis is placed on the development of human-robot teams which can leverage the capabilities of humans and robots for the appropriate tasks. Robots of varying autonomy will provide infrastructure support such as repairing loose fixtures, offer contingency life support by responding to medical emergencies, and perform field studies. Some HRI challenges which accompany these ambitious plans are the ability for human-robot teams to communicate clearly about their goals, abilities, plans, and achievements. Most importantly, the teams must also collaborate to solve problems in situations which exceed autonomous capabilities. Another real world application which represents the canonical HRI problem is urban search and rescue (USAR) [4]. This is a field application where robots must operate within unpredictable and obstacle-filled environments. This interaction setting is interesting because sometimes humans cannot conduct search and rescue in certain areas due to hazardous physical constraints and must rely on robots to gather information and perform tasks, and current mobile robot technology is not advanced enough for fully autonomous rescue robots. Human-robot collaboration is even more important in such circumstances because of the highly interdependent nature of human and robotic team members, and the use of robots must also fit into the existing task and personnel hierarchy.

2.2 Social Aspects of Collaboration

Real world applications such as the aforementioned examples have sparked research in various aspects of human-robot teams from control mechanisms to robot behaviours. Social aspects of collaboration are also considered. Hoffman and Breazeal [8] investigated the effect of adaptive anticipatory action on the efficiency and fluency of human-robot teams, suggesting that an adaptive action selection mechanism can improve task efficiency and fluency compared to a purely reactive approach. They performed a user study with a simulated factory assembly task where humans and robots are in charge of building carts by using the appropriate tools to put together the corresponding parts. The results show significant improvements in task efficiency for anticipatory actions over the purely reactive approach, and the perception of the robots within the team in terms of commitment and contribution to the team's success is also greatly affected. *The Media Equation* [11] raised the question of whether teams composed of both humans and new media (i.e. computers or robots) exhibit the same group effects as teams of only humans, and outlined a simple user study where two teams composed of both humans and computers were evaluated when completing a ranking task. Two human-computer teams were formed, differing only by the human participant's perceived relationship of computer team members. In one team, the computer is made to appear more like a team member to the human participants. To manipu-

late this variable, the two key factors of group identity and group interdependence from social psychology experiments are used. In one team, the computer is decorated with the same color as the wristbands worn by its human team members, and human team members are told that they will be evaluated based on the work of both the computer and themselves. On the other team, the computer is decorated with a different color than its team members, and human team members are told that they will be evaluated only based on their own work, and the computer is just there for help. Based on these simple perceptual manipulations of group identity and group interdependence, the results showed that participants on the team where the computer is made to appear more like a team member feels that the computer is more like themselves, solves problems in a style similar to themselves, and even agrees more with their own opinions. This is consistent with psychology research in human-human collaboration and indicates that group effects present in human-human teams can also appear in teams of humans and new media. In our paper, the exploration of group effects in new media will be extended to human-robot teams. As far as we are aware, this is one of the first investigations of group effects for human-robot collaboration.

2.3 HRI Testbed

Although working and testing with realistic settings and tasks is a well advocated approach, it is often not practical or feasible with robots due to technological and environmental limitations. Therefore, HRI researchers frequently adopt the testbed approach where much simplistic settings and tasks are constructed to fit the purpose of the research at hand. This approach works well if the purpose of the investigation pertains to high level questions which transcend particular settings and tasks. Bartneck et al. [3] investigates the factors which influence the way people perceive robots as being alive. In their user study, the game of Mastermind is used to create opportunities for human participants to become engaged with simple robots during interaction. The goal of the game is to select the right combination of colours. This task is completed by the robot and the human participant through cooperation and not competition. The robot would make suggestions to the human player as to what colours to pick, and the intelligence and agreeableness of the robot are manipulated for the purpose of the experiment. Although the game is simple and doesn't relate to realistic tasks, it is sufficient for human participants to perceive the robots' intelligence and agreeableness and to act upon this perception. Dickinson and Jenkins [5] take a similar testbed approach with robots and augmented reality games. Their goal is to leverage the popularity of games as a technique to collect human decision making data for the purpose of robot learning. A telepresence interface is used for robot control, allowing multi-player online play, and augmented reality is used to display game elements and show the robots' perceived state. Another game related testbed with a strong physical interactive element is Argall et al.'s work [1] on human-robot teams playing Segway soccer which builds on the Robocup vision. By using autonomous Segway Robotic Mobility Platforms (RMPs) to play soccer alongside humans riding on Segways, this work explores a variety of technical challenges as well as issues which arise in human-robot teams such as team coordination. Our testbed integrates several of the elements and techniques used in the abovementioned HRI projects such

as games, teleoperation, mixed reality, and physical interaction. In the next Section we describe our and its use for investigating the social aspects of human-robot teams.

3. SHEEP AND WOLVES TESTBED

To answer the questions concerning group effects in human-robot teams and the social aspects of human-robot collaboration in general, we have designed and developed the *Sheep and Wolves* testbed. We are currently reporting on its second iteration of implementation and experimentation which makes significant improvements on the first, where a mixed reality and telepresence interface was used to investigate the effects of submissive and assertive robot behaviours [13]. The goal of the testbed is to construct an interactive environment within a controlled laboratory setting, where evaluations can be performed on activities involving teams of humans and robots. Instead of building on a practical real world application such as search and rescue, a simple metaphorical interactive goal-oriented activity is used to engage humans in the interactive process. The inspiration for the testbed design comes from the movie, Harry Potter and the Philosopher Stone, where human players play the game of Wizard's Chess on top of a large chessboard by moving and acting as chess games pieces. Not only does the chess game involve actual physical movement and battles, players also engage in active communication with each other such as using gestures and speech to inform other players to make certain moves. We draw from this idea of a collaborative physical board game to create the *Sheep and Wolves* testbed.

The approach is to use games as a catalyst for interaction. Games are ubiquitous in everyday life. They are common activities for many people and often involve collaboration between multiple players. We see games as promising tools for exploring human-robot teams for several reasons. First, games are flexible. There is a variety of games people play, requiring a wide range of interaction. Games can also be adapted and customized to fit the interests of players or the needs of experimenters. In the *Sheep and Wolves* testbed, a classic board game is adapted to allow team play. The rules of games as well as their complexity can be manipulated based on the target of investigation. For example, in the second iteration of the *Sheep and Wolves* testbed, new game elements and new incentives in gameplay are added to introduce risk taking which is measured in the user study. Second, games are often played in controlled environments governed by a clear set of rules. This simplifies implementation by avoiding complex real world settings and also allows various relationships to be established between players within games. When working with robots, artificial intelligence is a challenge for real world tasks, and robot intelligence is often inferior to humans. However, in restricted domains such as chess and checkers, artificial intelligence can exceed humans. Therefore, robots can take on various social roles such as superior, teammate, or subordinate within games by adapting their intelligence. Finally, games are fun and have many interactive qualities of real world tasks. They are often social activities requiring important interaction such as decision making. Both the game environment and gameplay can be tailored to imitate real world applications. In the first iteration of *Sheep and Wolves*, a telepresence interface was used to simulate the look and feel of a search and rescue application [13].

Aside from the engaging and challenging activity of the

chess game, another important element of Wizard’s Chess is the physicality of the environment and the interaction. This is also important for HRI testbeds because robots are physical entities and exist within the physical world. Instead of using computer agents as proxies for robots and playing games within a purely simulated virtual environment, it is important to involve real robots and allow humans to interact with them in a physical setting. Powers et al.’s comparative study [10] between a computer agent and a humanoid robot shows both behaviour and attitude differences for human participants. In the first iteration of the *Sheep and Wolves* testbed, we also find it is easier to convince human participants that they are engaged in a realistic collaborative experience when real robots are used. Even though the goal is not to mimic real world settings and tasks, the physicality of the environment and the task is a characteristic shared by most robotic applications and should be involved in an effective HRI testbed. Furthermore, robots have the unique capability of being able to both interact in the physical world and perform tasks in the digital world. Therefore, effective HRI testbeds should also capitalized on the physical and digital duality of robots.

Following the inspiration of Wizard’s Chess and the design motivations outlined, our *Sheep and Wolves* testbed also involves the use of a large checkerboard as the physical setting for interaction (Figure 1), but because of the complexity of chess, the game we are playing is the simpler *Sheep and Wolves*. This classic turn-based game is traditionally played on a regular size checkerboard. The game has five game pieces; four of which are the wolves, and one is the sheep. The wolves start on one end of the checkerboard, and the sheep starts on the other. The team of wolves are only allowed to move one wolf forward diagonally by one square during each turn. The team’s objective is to surround the sheep so it cannot make any legal moves. Meanwhile, the sheep is allowed to move forward and backward diagonally by one square during each turn. Its objective is to move from one end of the checkerboard to the other. Obviously, while the sheep is more flexible in its moves, the wolves’ strengths are in their numbers and ability to move as a pack. Originally, *Sheep and Wolves* is played with two players, one playing the sheep and the other playing the team of wolves. To make the game a more interactive and collaborative task we took a similar approach to Wizard’s Chess and separated the team of four wolves into four separate player positions. This way, we can have humans and robots playing as independent wolves and collaborate on how to defeat the sheep as a team. The physicality of the environment and task is established by using real robots which move on the large checkerboard along with the human participants. We also introduce digital entities into the game using mixed reality. This allows us to explore various scenarios where human players need to rely on their robot team members to access the digital aspects of the game. This test bed setup allows us to produce a realistic collaborative experience with potential for investigating a variety of social situations and effects within human-robot teams. By collaborating within the controlled physical game environment instead of complex real world settings, we are able to focus on the social aspects of human-robot collaboration.

4. IMPLEMENTATION

In the following section, the basic elements of the Sheep

and Wolves testbed are briefly described. We outline important improvements made and new features in the current iteration of the testbed and detail how they are implemented.

4.1 Sheep and Wolves Foundation

In the *Sheep and Wolves* testbed, the robotic platform used for the robot wolves is Sony’s AIBO ERS-7 robot dog. These zoomorphic robots are designed for social interaction with a friendly appearance. They are capable of walking, playing sounds, and wireless communication. We make use of the Tekkotsu development library for programming robot behaviours which run onboard the AIBO, allowing us to process video data from the AIBO’s camera and also control its walking in a high level fashion. For the large checkerboard, we have purchased a 264 cm (104 inches) by 264 cm RolaBoardŽ designed for outdoor giant chess. Each square measures 33 cm (13 inches) by 33 cm, providing sufficient room for AIBOs to sit on or humans to stand on. It also comes with the standard black and white checkerboard pattern which is ideal for robots to use for navigation. We use the lines and corners of the checkerboard as cues for correctly orienting the AIBO and moving the AIBO to the desired square on the checkerboard [13].

4.2 Mixed Reality Interface

One of the major changes in the second iteration of the *Sheep and Wolves* testbed is the interface used for playing the game. Unlike the first iteration where human players play the game using a telepresence interface at a remote computer [13], the current iteration features a handheld mixed reality interface which allows human players to stand on top of the checkerboard and collaborate with the robot in the shared physical setting. Mixed reality allows the game to be enhanced by superimposing computer generated graphical elements onto the physical scene while still allowing the human player to maintain awareness of the physical setting. It is also critical for onboard communication with the robots because the game is played with collocated team members rather than teleoperation, making input and output for interaction more difficult. Unlike the first iteration where a keyboard, mouse, and monitor are used as conventional input and output devices, the second iteration requires new interaction modalities to allow the human players, standing on the physical checkerboard, to play with the robots. Output is challenging because the form factor of the AIBO has limited display capabilities, and input has many problems as well. Using mixed reality, these interaction issues can be addressed. The handheld mixed reality interface is constructed using a Toshiba Portege M200 tablet PC. This platform is heavier than preferred but runs our mixed reality application faster than the smaller OQO 02 UMPC which was also tested. To help human players carry the tablet PC during the game, we have attached a supportive strap for them to wear around their neck. A webcam is clipped onto the tablet PC to deliver live video of the physical setting. This allows human players to use the tablet PC as a window or lens in which they can see the physical checkerboard but also other graphical elements we choose to display on top of the live scene. To ensure the graphical elements are displayed at the appropriate places in the scene, visual tracking is used. This is achieved using a set of markers provided by the ARToolKitPlus [12] development library. This library processes video from the webcam and use the markers seen



Figure 2: Human player interacting with robot teammates using a handheld mixed reality interface

to relate the position and orientation of the webcam to the markers by providing OpenGL projection and modelview matrices for proper rendering. Multiple markers are used to obtain stable tracking and to deal with partial occlusion of the checkerboard by human or robot players. Since all the game pieces can only move diagonally in the game, they can only occupy squares of the same colour. For example, if the game starts with the *Sheep and Wolves* on the white squares of the checkerboard, then they can never make a legal move onto the black squares. Therefore, we have chosen to place sixteen markers on only the black squares of the checkerboard and play the game always on the white squares. This gives an even coverage of the checkerboard, and tracking works well regardless of where human players are looking at on the checkerboard. Stable tracking allows human players to freely move around and explore the checkerboard, making the fusion of the physical and digital worlds appear natural.

4.3 Human-Robot Communication

In the game, we have three autonomous AIBOs and one human player playing as wolves. The team of one human and three robot wolves play against a digital computer sheep visualized by the human player using the mixed reality interface. Similar to the first iteration, decision making for the team of wolves is achieved through voting where every member of the team has only one vote to voice their opinion about the preferred move for the team to make. A decision is finalized through a majority vote. However, in the current iteration, we force the team of wolves to go through two distinct phases of decision making. The first phase is the suggestion phase where every member of the team is expected to contribute a suggestion on the best move for the team to make. After the suggestion phase comes the voting phase, where every team member then casts a vote for one of the suggestions presented in the suggestion phase. This procedure ensures that no one is left out of the decision making process and also presents the opportunity for team members to change their opinion in the voting phase based on the suggestions presented by other team members in the suggestion phase.

For the robot team members to communicate or share

their suggestion and vote with the rest of the team, graphical speech bubbles are used which contains text of the robots' dialogue (Figure 2). These cartoon art elements are readily recognized and help to increase the human-likeness of the robots [14]. Although more natural techniques for communication can be used such as speech and gestures, we feel our simplistic approach is appropriate for the mixed physical and digital environment in which the game takes place. When a robot team member speaks, a speech bubble containing the text of what has been spoken pops up above the robot's head and is seen by the human player through the mixed reality interface. This speech bubble then slowly fades out after a short delay. Furthermore, if a suggestion or vote is voiced by the robots, this information is also displayed as a mixed reality arrow which points from one of the wolves to a destination square, indicating the suggested move (Figure 3). Each wolf is assigned a player colour at the start of the game, and the arrows displayed are coloured to identify the wolf that made the suggestion or vote. If two or more suggestions or votes are the same, then the arrows are displayed in a fan, and different transparencies are used to show the order in which the suggestions or votes are given. This maintains a visual history of the suggestions and votes to help the human player keep track of other team member's opinions since the speech bubbles are not persistent and require time for the human player to read the text.

For the human player to make suggestions or cast votes, a more direct approach is taken. Unlike the first iteration where human players can use the keyboard to type votes to the rest of the team in a text chat interface [13], the handheld mix reality interface is not practical for typing since the tablet PC must be supported by the human player using one hand. Therefore, a click and drag interaction technique is used, where in order to make a suggestion or cast a vote, the human player can click on the square occupied by one of the wolves displayed on the screen of the tablet PC and then drag a mixed reality representation of the physical wolf to the destination square with the pen (Figure 2). This selection in 3D is achieved by inverse projecting 2D pen movements into 3D movements on the plane representing the checkerboard in 3D space, since the position and



Figure 3: Human player looking at robot suggestions while surveying the mixed reality game environment

orientation of the webcam relative to the checkerboard is known using the set of markers. Visual feedback is provided during dragging in the form of circular auras indicating the selected target and the intended destination and a flashing arrow showing the potential suggestion or vote. When the click is released and the dragging completes, the flashing arrow turns solid to indicate the committed suggestion or vote. Visual feedback for dragging is only provided for valid moves, so the human player is bound by the interface to make only legal suggestions or votes.

4.4 Gameplay

To add depth and interest to the simple *Sheep and Wolves* gameplay, we have introduced a secondary objective for the wolves in the current iteration of the testbed. In addition to winning the game, wolves can now collect mixed reality coins which appear on the physical checkerboard as an extra incentive. To collect a coin, the team of wolves needs to move one team member onto the square occupied by the coin. With this alternative motivation for moving on the checkerboard, we are hoping to create situations where the primary objective of winning conflicts with the secondary objective of collecting coins. This will make the decision making process more complex, allowing us to explore issues such as conformity and risk taking.

During an actual game, the human wolf stands on the checkerboard with the robot wolves, looking at the physical setting through the handheld mixed reality interface (Figure 3). Each robot wolf is named, and their name is superimposed via mixed reality on their body in their assigned colour to identify them in the game. The human player can move the tablet PC around to get a more complete survey of the checkerboard, since certain elements of the game such as coins may not appear immediately within the field of view of the webcam. Audio feedback is provided to make the human player aware of changes that occur during the game such as when a coin appears or disappears on the board or when a robot team member "speaks". For each turn, the team of wolves engages in two phases of decision making. In the suggestion phase, suggestions are presented by each team member and can be seen as four coloured arrows on the checkerboard. The robot team members also verbalize their suggestions using the speech bubbles, making relatively neutral comments such as "Well, in my opinion Mike should move right." The robots also recognize suggestions made by other team members and incorporate this information into their response to give the human player a sense of team cooperation. For example, if a robot team member is making the same suggestion as the one made by another robot team member, Mike, it may respond with "I agree with Mike." After the four suggestions are collected, one of the robot team members makes a summarizing statement such as "Let's vote on this." The four coloured arrows are then cleared from the checkerboard, and a similar process for voting begins. When a majority vote is achieved, one of the robots makes another summarizing statement, reviewing the move that have just been decided upon. For example, it might say, "I guess the decision is Raphy moving to the left. Make the move please, Raphy." The coloured arrows representing the votes clear, and a flashing arrow appears indicating the move to be made. The robots are programmed to make the move automatically, and the human players must follow the dictation of the game and move willingly when they are voted

to move.

Compared with the first iteration of the testbed, we believe the current *Sheep and Wolves* design makes significant improvements in terms of providing a realistic, fun, and engaging experience for human-robot collaboration. The added physicality of the game by allowing human players to stand on the checkerboard and play with the robot peers makes the interaction more intimate and valid, and the mixed reality interface with the cartoon art elements attempts to make the robots more personable. The overall gameplay of the current testbed is also more dynamic, involving risk taking and more complex decision making.

5. GROUP EFFECTS USER STUDY

With the updated *Sheep and Wolves* testbed able to generate a believable human-robot collaboration experience within a controlled laboratory setting, we can now attempt to answer the questions raised earlier about human-robot teams and group effects. The concept of social influence relating to the way people directly or indirectly alter the attitudes and behaviours of other people is a well-studied subject. It is known that social interaction affects individual behaviour in profound ways, and when people collaborate in groups, their social interaction is often more striking. For example, in Solomon Asch's classic study on conformity [2], participants made decisions inline with their peers even though these decisions were obviously wrong. It is interesting to find out if robots can also change the attitudes and behaviours of humans in similar ways.

Social interaction within teams can be rather complex and is often affected by many variables such as the type of interaction involved and the makeup of the group. With the current setup of the *Sheep and Wolves* testbed, our investigation is targeted toward task interaction which is focused on work and achieving goals rather than relationship interaction which is focused more on interpersonal group life [7]. Similarly, the testbed is also more appropriate for evaluating secondary groups, where relationships between members are impersonal and goal-oriented rather than primary groups where members share personal and enduring relationships over a long period of time. Because of the style of gameplay currently in place, we are particularly interested in group effects associated with the process of group decision making such as conformity, group polarization, and social loafing.

5.1 Study Design

To investigate the possible existence of the aforementioned group effects in human-robot teams, we devised a user study which attempts to measure the differences in the decision making practices and attitudes of humans. Participants were asked to make decisions about the game first only by themselves then as a member of a human-robot team. To allow easy comparison of the data, we also decided to script the game so all participants encounter the same decision making circumstances. Scripting was possible because we could always achieve a majority vote with three robots and one human player. To maintain the illusion of realistic collaboration to participants, we masked the scripting by dynamically altering the robot's suggestions, votes, and responses based on the human player's input. For example, if a human player votes in line with the scripted move, then one of the robots can cast a different vote to the scripted move. A majority vote for the scripted move would still

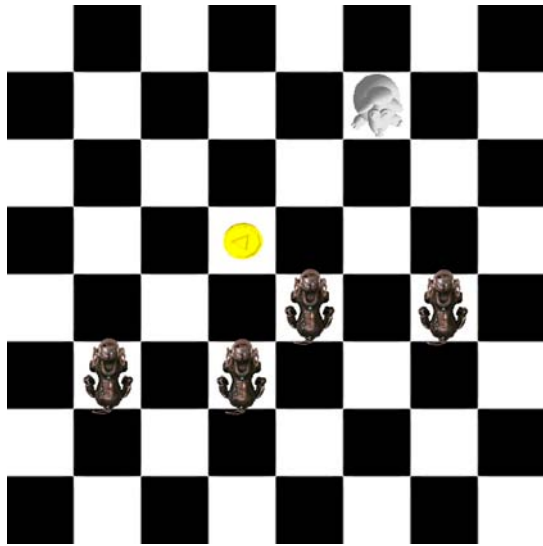


Figure 4: One of the decision making scenarios for participants to consider in the pretest questionnaire

be preserved, but the appearance of a homogeneous robot voting bloc would be broken. The three robots sometimes also made different suggestions to the scripted move in the suggestion phase and change back to the scripted move in the voting phase. This created a sense that the robots can change their mind and may be influenced by the suggestions of their teammates. There were 14 moves for the scripted game, leading eventually to a win for the wolves. Participants first completed a pretest questionnaire which included a scrambled subset of 5 game decision making scenarios from the 14 scripted moves (Figure 4). Then the participants played one scripted game with the robots, where the 5 decision making scenarios reappeared as a natural progression of the game. We limited the number of comparable decision making scenarios to 5 because we wanted to make sure the participants did not notice that they were revisiting previously considered moves. We defined 2 subsets of the scripted decision making scenarios and assigned each to half of the participants. Each scripted comparable move and user decision both in the pretest questionnaire and in collaboration with robots were analyzed to determine whether it was a safe or risky move. Risky moves are defined as ones which sacrificed the defensive strategies of the wolves for the goal of obtaining more coins.

Although studies have shown that certain group effects can occur just by placing humans together in a shared setting [Media Equation], we made explicit attempts to maximize the group cohesion of our human-robot team. Following theories presented in the Media Equation, we established group identity by giving the team a name and having team members dressed in lei as team symbols. We also capitalized on group interdependence by telling human players at the start of the study that they will be evaluated together with the robots as opposed to evaluated only based on their own performance. We are not sure of the effectiveness of these measures when applied to human-robot teams, but we feel they helped to heighten the contrast between the scenarios where participants made decisions by themselves and where they collaborated with the robots.

5.2 Study Methodology

We recruited 22 participants (13 male) from various professions and areas of study (2 out of the 22 participants did not complete the study due to technical problems). We first taught them how to play the game and carefully explained the secondary objective of collecting coins. They were told each collected coin is worth 1000 game points, and winning the game results in an extra 3000 game points. However, they were cautioned that a loss resulted in the forfeit of all their coins. To establish motivation for collecting game points, we offered an exchange for real money. Participants were told evaluation would be performed based on the performance of their team as a whole, and this assessment depended on if the game was won and also the number of coins collected. The pretest questionnaire was administered next, where participants were asked to practice making decisions for 5 game scenarios by "imagining that you are actually encountering the situation playing a game by yourself". Half the participants did the study with one subset of decision making scenarios, and the other half did the study with the other subset. Afterward, participants were ceremoniously initiated into "Team Victorious" with the 3 robots and were given their very own lei to wear as a member of the team (Figure 3). The scripted game with the robots was then run, and participants were asked to fill out a posttest questionnaire and answer some open ended questions for an interview. The posttest questionnaire evaluated the overall collaboration experience of the scripted game as well as players' decision making practices and attitudes using a 7-point Likert scale. All communication between the team members for the suggestion and voting phases were logged, and key information such as differences in the participants' decisions were identified.

6. RESULTS AND DISCUSSION

In general, the response to the study was positive. Most participants felt the game was fun and engaging, resembling a realistic collaborative task. One computer science graduate mentioned that he thought the robots had different personalities and were running advanced AI algorithms. Some commented on the effectiveness of the physicality of the game with the use of real robots in a physical environment. The measures taken to heighten the group cohesion of the human-robot team also appear to be effective. When asked "How strong was your feeling that the four of you were a team?" on a 7-point Likert scale with 1 labeled as "Very Weak" and 7 labeled as "Very Strong", 16 out of 20 indicated either 6 or 5. These results reaffirm the validity of our *Sheep and Wolves* testbed approach and our experimental design. Even with simple and constrained tasks, we were able to reproduce a realistic collaboration experience for human participants.

In terms of the presence of group effects, our current results are mixed. From the interview notes, 11 out of 20 participants indicated signs of social loafing, the phenomenon that people make less effort to achieve a goal when they collaborate in groups than when they work alone. One participant said she felt that she had less pressure to make the correct move when playing with the robots because she had 3 teammates to fall back on while another participant indicated a feeling of shared responsibility with the robots and said, "If we lost, I can blame them." However, these atti-

tudes did not result in a significant amount of participants willing to take more risks when playing with robots. Most participants indicated that they weren't more comfortable making riskier moves when playing with the robots. This is supported by the logged data as there were only 3 occurrences out of all the participants and comparable moves considered, where participants changed from a safe move suggestion when they thought about the move alone to a risky move suggestion when they played the game with the robots. In fact, there were actually 8 occurrences where participants changed from a risky move suggestion to a safe move suggestion. Two participants indicated they were more comfortable with risky decisions when someone else in the team makes them because they wouldn't be responsible. One participant who made safer move suggestions mentioned that he felt it would be harder to recover from a mistake when playing with the robots because he didn't have complete control of future moves by the team. We believe the lack of a more significant shift to riskier decisions may be because the scripted risky moves were too obviously risky or because the motivation for collecting coins was not strong enough. However, it is encouraging to see the few participants who were more comfortable with risky decisions when working with robots relate their reasons to symptoms of social loafing.

In terms of conformity, 14 out of 20 participants indicated that they didn't feel any strong social pressures to conform to the team's decisions. Most commented on the robots' lack of emotion and communicative abilities. Several participants attributed the lack of social pressures to the fact that they didn't care about what the robots thought of them because the robots "won't say bad things" about them. A few participants also indicated that they felt robots had no morals. These results reveal some of the limitations of our current interface. Although 8 out of 20 participants noted that decision making with a team of robots was more efficient than with a team of humans, 13 out of 20 participants felt a more realistic collaboration experience requires more capabilities for communication. These factors may also contribute to participants not feeling comfortable with riskier decisions. Several participants noted that they would be more comfortable with riskier decisions if they can further discuss the decisions with the robots and perhaps gain insight into the logic behind their decisions.

7. FUTURE WORK AND CONCLUSION

In this paper we motivated the need to explore social and psychological group effects in human-robot interaction. We introduced *Sheep and Wolves*, an experimental testbed we developed in order to facilitate such exploration. *Sheep and Wolves* allows a human user to play with a group of robots as collaborative teammates, providing both a meaningful collaborative task, and a fully controlled experimental environment. The paper details the implementation of the second iteration of *Sheep and Wolves*, where the human player is physically situated on the game board alongside her robotic peers, and uses mixed reality cartoon art-based techniques to chat and communicate moves with her robot teammates. We presented a thorough user study we performed with *Sheep and Wolves*, preliminary analysis of the results, and some of our insights on the capabilities and effectiveness of our testbed.

Future work on *Sheep and Wolves* will include various experimental design settings that will expose the human player

to other, new, social group dynamics and allow us to examine her reactions in more specific ways than we obtained in the current study. We are also considering expanding our testbed to support more elaborate experimental setting, specifically allowing group interaction within a team composed of robots, alongside more than a single human player (that is, two, or more human players).

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