You are the Mind of a Robot

Tele-existence for Adults and Children

Vladimir Estivill-Castro and Vladimir Sukhov

School of Information and Communication Technology
Griffith University
Nathan Campus, Brisbane, 4111, QLD, Australia
Email: v.estivill-castro@griffith.edu.au vladimir.sukhov@griffithuni.edu.au

***Abstract*—We carried two experiments of tele-existence. We provide a real-time illusion to humans that they exist in another place. The other place is the real world, although now their new body is a robot. In our experiments, we used virtual-reality to transport the subject to the body of a soccer-playing robot. In this new visions of human-computer interaction, we differentiate the experience between that experimented by adults and that experimented by children. We observed that the experience radically changes the adults' views regarding tele-existence and robotics. On the other hand, children become rapidly transported to the body of the robot.**

***Keywords*–Human-robot interaction; mixed-reality; tele-existence; experiments and applications; virtual reality; immersive environments.**

I. INTRODUCTION

Minsky introduced the term *tele-presence* [1] emphasising the importance of high-quality sensory feedback and suggesting that in the future, human perception and action will be no different from those transferred as from those interacting with the technologies. Since the first robotic-assisted remote tele-presence surgery, its application continues to grow [2]. The iRobot AVA 500 has been heralded now for several years as the first ever self-driving business collaboration robot [3]. The market of robots that can automate or assist in a range of environments, from offices to clinics has seen several companies emerge, such as Anybots, Double Robotics, Mantaro, Revolve Robotics, Vecna, Awabot, Inbot Technology and iRobot. For office work, robots that resemble a tilt-able tablet on wheels are gaining popularity; for example, the products by Amy Robotics, AXYN Robotique, MantaroBot, Suitable Technologies, Double Robotics and Ava Robotics offer video conference and mobility. In 2017, the market value for 2016 was estimated at $1.6 billion [4]. However, how much of these tools create the transportation effect originally suggested by Minsky? Many scholars [5] have pointed out that tele-presence raises fundamental issues about the nature of existence. In particular, one definition of *presence* is

> "*the perceptual illusion of non-mediation [6].*"

Thus, Minsky's tele-presence should be indistinguishable with presence; and the quality of tele-presence is related to the ability to deceive our perceptual system to take for "real" what is not there.

We are interested in how humans consider the possibility of *tele-existence* [7] [8]. There are pioneering studies on how humans attribute social and ethical stance to robots [9] [10]. However, Kahn et al. [9] found the attitude towards robots is fundamentally linked to the anthropomorphism of the robot. Our research here is concerned with the person's simulated immersion in the body of the robot and the effect of this immersion on the person's understanding of possibilities for tele-existence. Moreover, we propose here to explore in children the attribution and transportation of one's body to the body of the robot: the departure of one's own body and accept the body of the robot as our interaction with the world. We suggest this happens remarkably fast when the child is immersed in the environment and controls the body of the robot via mixed reality. Such tele-presence results in children rapidly adopting not only control but a dialogue where children abandon in their language anything related to their own physical body, and they formulate sentences and actions with a semantics that is now grounded in the body of the robot. Note that research in cognitive sciences has revealed language influences thinking and experience and body influence the resolution of ambiguous terms in abstract thought [11].

Although some early work suggested that in a child's world there could be some confusion between reality and fantasy [12], with *tele-existence*, there is nothing more real than the mixed-reality environment and, we argue that their new robotic body is authentic. Our study with adults departs from most tele-presence studies which aim at understanding how to improve tele-presence systems [13]. The dominant approach to facilitate social interaction between humans is Mobile Robotic Tele-Presence Systems (MRTPS) [13]. Typically, such MRTPS could be considered a tablet on wheels; they enable the technologies of computer tele-conference with some mobility. However, the robot (and its pilot) can hardly influence the environment. If the robot is a tele-android system [14], its primary goal is human-to-human reproduction of realistic face-to-face human communication. If the robot has arms [15], the main purpose is gesturing to reinforce human-to-human gesticulation. Here, our robots are Nao robots (humanoids) in the environment of the RoboCup Standard Platform League. Their pilot can navigate them following a ball or to a position in the soccer field. They can kick the ball with a choice of leg and a choice of kick (we ask the reader to reflect on what could "they" stand for, the robots, or the pilots: while the robots physically kick the ball, the pilots command when and how such kick happens). Moreover, our pilots (a person who remotely connects to the robot via a computer interface) have a significantly immersive interface (as opposed to MRTPS). For our pilots, our interface consists of a virtual reality headset and room size tracking technology, giving the pilot an opportunity to experience a simulated environment.

Copyright (c) IARIA, 2019.

However, in this simulated environment, a large proportion is the streaming video of the robot's cameras. Therefore, our metaphor is that *what the pilot sees is what the robot sees*. We anticipate this forwarding of vision will transport the pilot to the local environment of the robot, and into the robot's body.

We aim to explore and contrast the thesis that our mixed reality achieves a perceptual illusion of no-mediation, and that the interface pragmatically disappears. Thus, our research is probably best identified with the recent emerging term of *tele-existence* [7]. We follow closely the idea of a master pilot commanding naturally a real-world robot [16]. However, rather than fidelity of reproduction of the human motions with arms and feet, we are interested in immersion by orienting the pilot to achieve tasks. The tele-operated robot is no longer an autonomous robot either. The International Federation of Robotics (IFR) and the Australian Robot Association adopted the ISO standard vocabulary (ISO 8373) to describe 'manipulating industrial robots operated in a manufacturing environment'. We suggest here that the proposed tele-existence blurs further the boundary of the machine relative to human. The fundamental robotic characteristic, that after being programmed, a robot operates automatically, is not entirely true for the mixed-reality tele-existence environment of our experiments. Also, those descriptions of a robot that require a control unit typically composed of a computer and software would not adequately apply as the human pilot is significantly the controller and decision maker in our tele-presence world. However, the pilot is liberated of controlling every joint and motor on the robot by significant autonomous behaviours in the robot (if the robot were to fall, it would autonomously get up).

The next section will provide the details of our methods; in particular, how we secured participants, and how we set the experiment; some of it mandated by requirements for ethical approval. Section III gives some insight on how the visual stream for the robot's cameras was placed on the headset (or visor) and how human participants could pilot the robot. We summarise the results of our experiment in Section IV, and we analyse possible validity threats in Section V. Conclusions terminate the paper.

II. The methods

For our experiments, we applied the following method. The research was performed by a series of demonstrations of autonomous Nao robots (designed initially by Aldebaran and now commercialised by SoftBank robotics)., Nao is a humanoid robot 58 cm tall and weighs 4.3 kg wth 25 degrees of freedom, and a relatively large set of sensors that includes two cameras one above the other in the head, four microphones, sonar, and IR and the V5 offers an atom processor. We performed such demonstration on seven different days. These events were six days of special events where participants visited the campus, and the other two days were public displays associated with Australia's Science Week.

We conducted the activities in South-East Queensland, Australia, with the furthest apart being 90km. The demonstrations were conducted to audiences of children and adults. However, we engaged children and adults in different voluntary experiments. We aim to investigate the attitudes of children and adults to tele-existence. For adults, we collected responses to two questionnaires. These questionnaires were a pre-activity questionnaire and a post-activity questionnaire. For children, we conducted specific directed language and measured specific responses, collecting observational data. Table I summarises the presentations and the involvement of participants (we have far more subjects than the 6 participants in a similar setting [7]). Whenever consent was given, photographs of the session were taken. Presentations were set up for approximately six hours long. Although individual participants engaged with the particular activity for strictly less than 2 minutes (nevertheless, the 180 seconds of our immersion is much higher than approximately 30s [7] or 20s [16] of recent research in a similar setting). That is, all session for all participants immersed in the mixed-reality environment lasted 2 minutes. Displays about the activity were available for the full opening hours of the demonstration. There was no reward or any other incentive except the unique opportunity to experience tele-existence (mixed reality, where the human mind drives somehow the body of a robot). No advertisement or fliers were used. The off-campus displays were mostly promotional events on programs and courses offered by Griffith University. Having visitors on campus is part of Griffith University's open doors programs and also the STEM (Science, Technology, Engineering, Mathematics) engagement programs with many local high-schools. These students visit and are involved in educational experiences on campus. All children subjects were 12 years old or older when participating in our experiments.

TABLE I. EXPERIMENT SUMMARY.

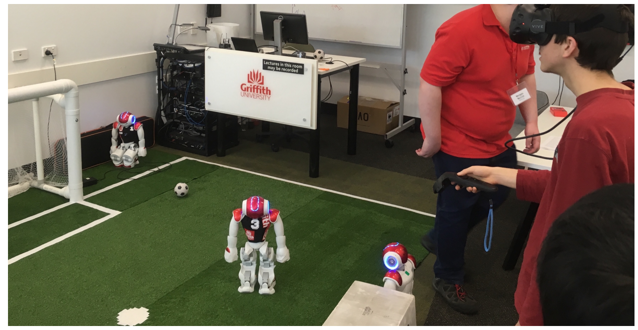
Event	*Adult Participants*	*Children Participants*
STEM-6 Day One	0	22
STEM-6 Day Two	0	25
Open Day	23	1
Science Museum	3	1
Pup-Up-Science	0	47
STEM-6 Day Three	0	23
STEM-6 Day Four	0	23
GLO Logan 2018	3	14
Total	29	156

We use virtual reality devices to transport the participant to a virtual world; however, the immersion world reflects the vision of a nearby robot. This setting transports the person into a tele-operator or pilot for the legged robot. During this time, participants tele-operate a robot near a Standard Platform League (http://spl.robocup.org) soccer goal from RoboCup. Figure 1 shows our typical set up of the presentations outside the campus. Our experiments are radically different than the only two experiments we are aware of in a similar setting [7] [16]. While those experiments were concern on the optimal and most loyal reflection of the human pilots' walk and hand motion to the body of the robot in real time, and to the feeding back to the human sensors the images of the robot with maximum fidelity, our work concentrates more on the achievement of a meaningful mission. Thus, our human participants face immediately the task of scoring a goal in an environment with adversaries (those other experiments [7] [16] focus on how precise is the reproduction of a straight walk from the human in the robot, how accurate is a turn by the human pilot on the robot, and how loyal is the imitation of operators' arm movements on the robot). Our approach is rather different, no-one better at executing the kick on the robot's body than the robot itself with its onboard software. Similarly, the best routine to get up from falling is in the

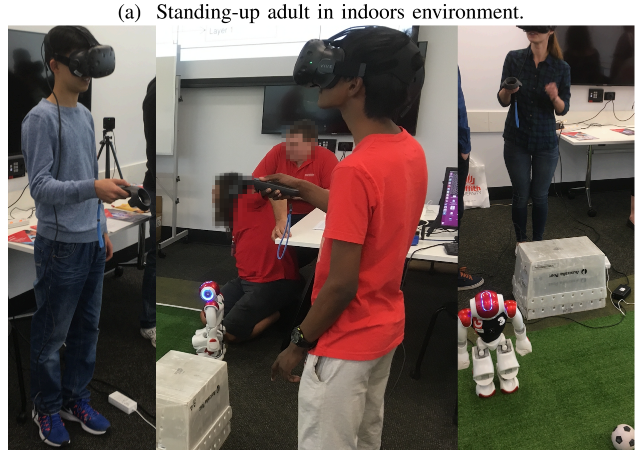
(a) Set up during Science Week.

(b) Set up at Pop-Up Science Day.

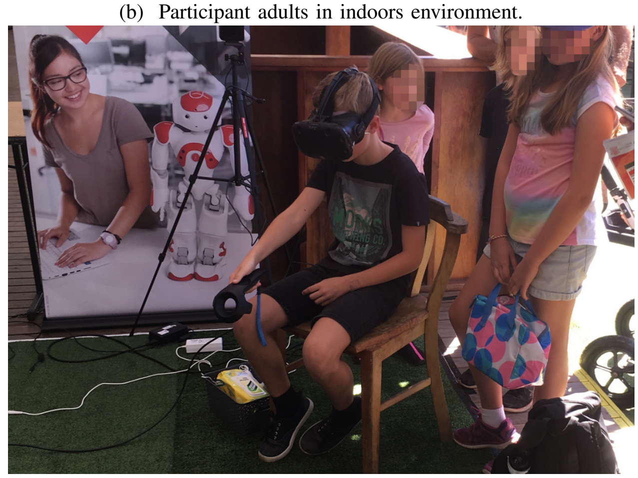
Figure 1. Typical set-up of a robot soccer field and demonstration of autonomous soccer playing robots.



(a) Standing-up adult in indoors environment.



(b) Participant adults in indoors environment.



(c) Sitting-down child facing a goal.

(d) Sitting-down child behind goals of the soccer field.

Figure 2. Adult participants were standing, children participants were sitting. Participants' hearing coincides between virtual world and real world.

software on the robot. We do not want human pilots to teach their human bodies how to replicate such get-up motion or kick motion so their surrogate robot can perform these tasks. However, we do believe the humans would find themselves transported to the world of the robot.

During the activity, we requested participants to guide their robot towards the ball, issue kick commands and if possible score a goal (if they were to score the goal, they can chose how to celebrate it, or shall we say, have their robot shall celebrate it). We advised that their objective is to be efficient pilots of the robot, and score as many goals as possible in two minutes. Most of the time, before engaging with the activity, participants had been observing Nao robots playing robotic soccer autonomously. On several occasions, participants had to perform under the competitive circumstance of an autonomous robot also approaching the ball.

Figure 3 shows a sample of the questions used in the pre-activity questionnaire for adults. Figure 4 displays a sample of questions in the post-activity survey.

For children, we will be assessing how rapidly they accept language about the body of the robot as if it was their own

1) Have you ever experienced a virtual reality scenario?
2) How often do you play video games?
3) How often do you engage in competitive games against artificial systems where the opponent has no human input (computer chess, XBOX™ alone away from Internet)?
4) How often do you engage in competitive games against other humans (chess, XBOX™ where opponent is piloted by another person)?
5) Rank your interest in engaging in a game with a robot that is the surrogate of another person?
6) Rank your interest in interested in engaging in a game with a robot that is completely autonomous (no human pilot can influence the robot during the game)?
7) Are you familiar with physical presence scenarios such as "reality" TV shows such as *Survivor* and *Big Brother*?
8) In the film *The Truman Show*, Truman (played by Jim Carrey) lives in a television studio manufactured to look like the real world (and he is unaware of this). Do you think this could happen to some person?
9) The film *The Matrix* presents the possibility that although we are in control of our own consciousness, our bodies and the material world that surrounds us are an artificial construction. Do you think it is possible for humans to be immersed in such simulation?
10) Avatar scenarios, such as the popular "life-simulating game" called *The Sims*, are so called because players create characters, profiles and control their lives. Would it be possible to have robots around us that we "control" in such a way?

Figure 3. Sample questions from the pre-activity questionnaire.

body. So, rather than say "*Make the robot kick with its left foot*", we will evaluate the time it takes for them to accept *"Kick with your left leg"*. For all minors, approval will be requested from parents or guardians as this research was conducted under Griffith University Ethics Reference Number: 2018/846.

The setting could be considered a mix of a computer game with a virtual reality headset and 3D hand-held controllers. We have developed software that renders the camera video stream of the robot to the participant's headset. The 3D hand-held controllers enable pointing at cubes (labelled with icons) in the 3D-virtual environment and triggering an action. To trigger an action, pilots must select a cube. Upon selection, the cube spins in the 3D-virtual environment. The cube changes colour and tilts when triggered (and the chosen action is forwarded). The design of the 3D-virtual world is not a soccer field; it is a pilot's room. Figure 5 illustrates the environment's design.

That is, the human user is still doubled in a controller room, and the cubes offer control to actions that impact the robot's body. The 3-D room has a large screen where the vision of the Nao is presented. The Nao has cameras one above the other (and not side to side as most mammals). So the presentation is an image that reflects such upper and lower camera.

For children and adults, instructions were given regarding the virtual world. We described, prior to placing the headset, the 3D room of Figure 5. Participants were also introduced to the hand-held controllers. These are visible in the virtual world in extremely look-alike objects placed in proportionally the same position relative to the headset in the real world. That is, the hand-held controllers are common element between both worlds. We indicated that the upper button would produce a ray, which does not appear in the real world, but that selects cubes in the virtual world. The trigger under the controller sparks the corresponding action.

At least two assistants support the experiment. One provides instructions to participants, answers their questions, and also plays a role of a bridge between being in the soccer field, and being with the participant in the virtual world by sustaining

1) Did you felt at some point in the experience that your mind was purely confined within the simulated environment and there was no other existence; that is, did it felt for at least an instant that your world was the mixed reality experience?
2) When trying to score a goal, were you aware other opponents were completely autonomous or piloted somehow like your own; that is, did it matter other robots degree of autonomy and simulation?
3) Would you consider other technologies that directly interact with your optical nerve or your senses and connect to your neural hardware for such an experience?
4) As technology improves, would this type of experiences be better if everything was simulated, and no robot in the real world existed, but still felt completely real?
5) After this experience, re-rank your interest in engaging in a game with a robot that is the surrogate of another person?
6) After this experience, re-rank your interest in interested in engaging in a game with a robot that is completely autonomous (no human pilot can influence the robot during the game)?
7) After this experience, and revisiting the hypothesis of the film *The Truman Show*, where Truman (played by Jim Carrey) living in a television studio manufactured to look like the real world (and he is unaware of this). Do you think this could happen to some person?
8) After this experience, and revisiting the hypothesis of the film *The Matrix* (the possibility that although we are in control of our own consciousness, our bodies and the material world that surrounds us are an artificial construction). Do you think it is possible for humans to be immersed in such simulation?
9) After this experience, would you enjoy interacting with avatars (artificial robots that have some control or configuration by humans), for example as receptionists in hotels (and not as boring as vending machines)?
10) Avatar scenarios, such as the popular "life-simulating game" called *The Sims*, are so called because players create characters, profiles and control their lives. After the experience, re-rank your belief that it would it be possible to have robots around us that we "control" in such a way?

Figure 4. Sample questions from the post-activity questionnaire.

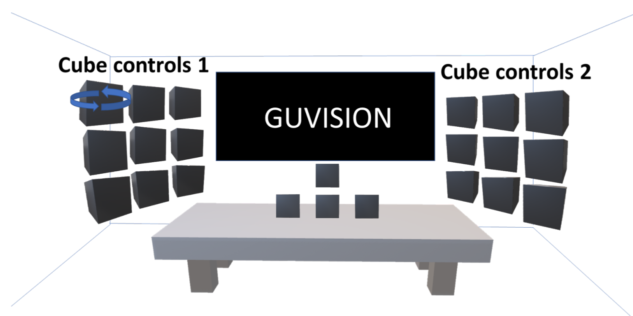


Figure 5. Design of the 3-D worlds the pilot sees.

a dialogue. This first assistant can only see the soccer field as a spectator. The second assistant monitors the execution of the application in a flat monitor with a display similar to Figure 6. The second assistant can monitor the time left, whether all devices (hand-held controller, handset, tracking towers) are operational, whether WiFi link to the robot is operational, and a fraction of the participants view. For example, in Figure 6, we see part of the icon on one of the cubes for waiving (celebrating a goal) and the images of the robot's cameras.

The sessions with a participant consisted of a protocol with the following stages.

1) Demonstration of robotic soccer. The participant encounters a clearly identified soccer field, and humanoid robots dressed in either red or black jerseys engaging in a match that resembles the Standard Platform League setting for RoboCup (refer to Figure 1).

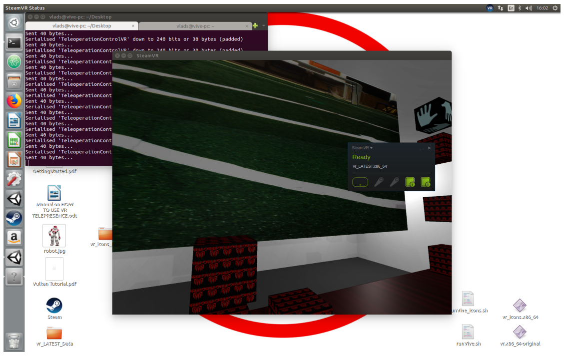


Figure 6. Screen shot of the monitor running the application.

2) Participants are invited to take part in the match. If the participant is an adult, we present ethics information sheet, and pre-activity questionnaire. If the participant is a child, we secure parental consent. Adults are allowed to pilot standing while children are requested to sit (refer to Figure 2).
3) Establishing the control. This stage consists of describing the headset and hand-held controls cloned into the virtual room (in particular, the button used and the trigger). A brief description of what to expect (there are cubes in a room, some to the left, some to the right, some in the middle). A description of the task: to score as many goals as possible in two minutes. The first assistant indicates what robot the human will pilot before setting up the headset (typically, "you are the robot in black jersey 3").
4) Establish the language. From the beginning, the first assistant will purposely engage in a dialogue where it refers to actions on the field by the piloted robot as if it was the body of the person. For instance, "you should be able to see the ball ahead", "walk forward a bit still, the ball is still far from you", "the robot in red will challenge you for the ball". However, on occasion, guidance of the virtual environment would be necessary, with advice such as "the cubes on your right control your motions", "if you want to kick, you must use the cube with the icon of a foot", "if you want to stand-up, you need to activate the higher cube" "if you want to sit down, you need to activate the lower left cube". There will also be perhaps backward situations, such as "after you kicked, you have fallen", and intentionally all celebrations of the goal finish with the robot kneeling down, so the first assistant would say "stand-up, to keep on playing." We record whether the child responds to these commands using their own body, or continues to engage the first assistant as if their body is the robot's body.
5) After two minutes, the activity stops. The headset is removed, and the participant has completed the experience.
6) If the participant is an adult, collect completed post-activity questionnaire.

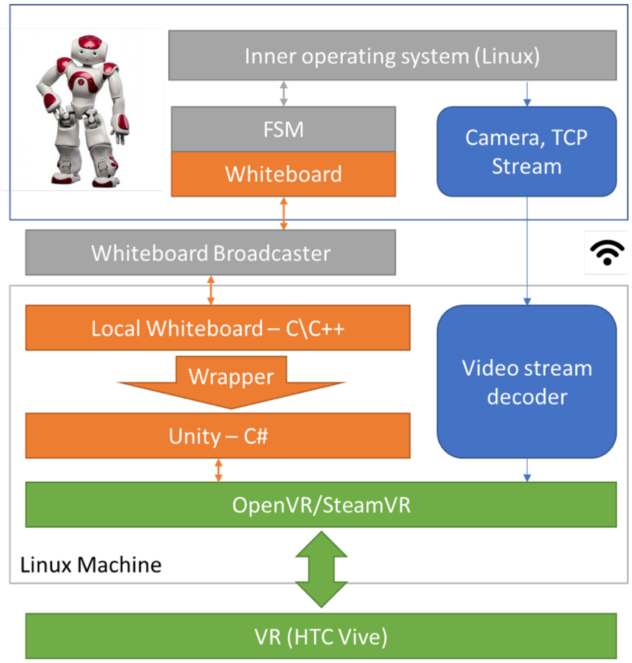


Figure 7. Schema of the components of the application.

III. ARCHITECTURE

Our application architecture displays a pilot's room which may seem a small cinema, where a projection screen is centred and slightly above a theatrical stage. As we explained above, the projection screen renders the video feed of the robot's cameras. Cubes in the centre of the virtual environment are like GUI-buttons for the control of movement on the robot, so that it walks forwards, backwards, spins to the right or to the left. There are some behaviour templates, such as kick with either foot, pass the ball with either foot, kneel and rest, stand up, waive with left or right hand briefly, or wave extensively.

We run our application on a Linux – Ubuntu 16.04LTS WS, and virtual reality equipment of an HTC Vive set, we use Unity 3D 2017.2 BETA Ubuntu, the OpenVR on SteamVR tools set, and other software elements (refer to Figure 7). Unity enabled high-level programming, and facilitated integration with SteamVR, although C/C++ had to be wrapped into C#. However, this wrapping enabled all C++ infrastructure and model-driven behaviour with logic-labelled finite-state machines (LLFSMs) to integrate smoothly [17]. Control commands (captured by Unity) are delivered over the distributed whiteboard, and the distributed object-oriented whiteboard also achieves feedback from sensors in the robot. The local whiteboards are shared-memory middleware that interface well with the concurrent but reliable sequential scheduling of an arrangement of LLFSMs. The distributed middleware operates over idempotent control/status messages over UDP, which has been shown to be more responsive that standards such as ROS [18].

All messages are, therefore, C++ classes, and operate over local whiteboards on the robot and on the host. However, the video feed is a dedicated socket channel of compressed `jpeg` images from the robot to the host. Therefore, the development effort included several technologies, from the

Copyright (c) IARIA, 2019.

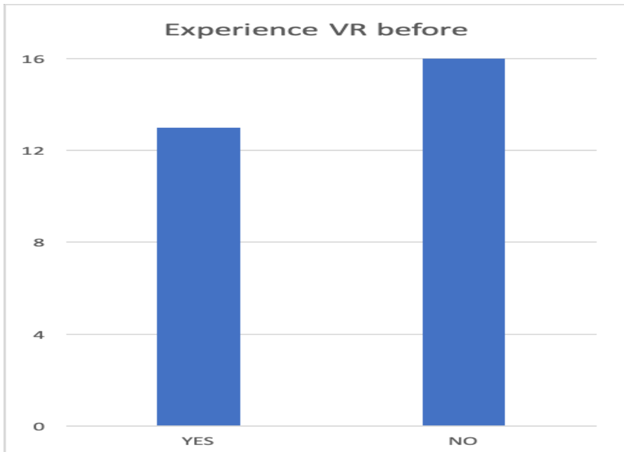


Figure 8. Histogram of responses to first question in pre-activity questionnaire.

programming of C# scripting in Unity, to designing recorded motion gestures in Nao's Choreographe motion composing system, extending the C++ classes/messages known to the whiteboard, and developing finite-state machines that enable behaviours in the robot. Also, some network programming and Open-CV wrapping were required to forward the video stream from the robot to the host.

IV. THE RESULTS

We review the results for adults first and then for children.

A. Adult subjects

The questionnaires were scanned and analysed to compare answers. The first part of the pre-activity questionnaire enables us to judge whether the person is a suitable subject. Griffith University Ethics committee required us to minimise the risk that participants experience adverse reactions to virtual reality exposure (e.g., dizziness, nausea etc.). Therefore, we excluded any individual we suspect was susceptible to a neurological condition (e.g., epilepsy) or that had experienced adverse reactions to virtual reality previously. Side effects of virtual reality exposure are usually associated with long periods of immersion [19]. All our subjects were limited to a period of 2 minutes.

Figure 8 shows that our sample of adult participants (29 individuals) is almost divided evenly (13/16) among those who had previous experience with VR and those who had not.

The pre-activity questionnaire shows that our sample of adult participants holds significant diversity. Figure 9a shows that our subjects are significantly familiar with video games, engaging quite regularly with them. While they have some engagement in competitive games against opponents known to be artificial (Figure 9b), there is a slight predilection for versing other humans (Figure 9c).

The after-experience questionnaire does not show a definite illusion on the subjects that they were transported to a different world. Figure 10a shows that 16 users out of 29 (more than half) felt immersed in another world *on occasions* and although this is more than 50% of the subjects, the other 13 were not definite. We believe this is the participants' perception, and that is one measure which is affected by the lag in the image, and the fact that sounds in the real world have not a perceivable source in the immersed world. However, our experiments with the children, later on, show that children were significantly immersed and one could say even consumed by the task and the activity. Adults also show a slight predilection for experiencing more similar immersions and more accurate and directly reproduced virtual worlds into their senses, with more than a third declaring they would enjoy too much being immersed (Figure 10b). Whether a complete simulation or transportation to another real world is preferable is also undecided (Figure 10c). However, there is a slight preference to have some robot and some reality over a complete simulation.

Now, we report on our analysis of the change in attitude or belief from the adult participant from the pre-activity questionnaire to the post-activity questionnaire. The type of hypothesis we formulate is that the 2-minute immersions results in a positive change towards the technology or to the belief that how humans perceive reality and existence can be opened to new interpretation and possibilities.

Therefore, we start with the re-evaluation offered by Question 5 in both surveys. Our hypothesis is that

> (H) after the experience, participants are more interested in engaging in games with robots on a tele-existence world.

The corresponding null hypothesis is that

> (H_{null}) after the experience participants have no more preference (or potentially less interest) in engaging in games with robots on a tele-existence world.

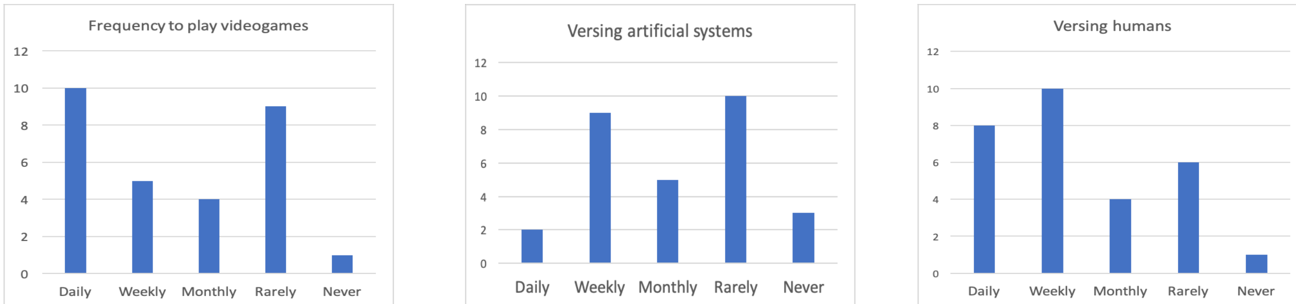
Since we had a total of 14 responses out of 29 where participants upgraded their interest, 14 maintained the same interest and only one reduced their interest, we observe a prevalence for our hypothesis. The result would not be statistically significant. Nevertheless, when we consider the change in response to Question 6, we have that all participants, that is the 29 of them, preferred to engage in contests challenged by a robot that is totally autonomous. This outcome is naturally a statistically significant result that the experience changed the views of the adult subjects. We also find that the results seem to contrast how our sample of participants engage in competitive games. We note the contrast of Figure 9b with Figure 9c that shows a preference to have humans as opponents, but for this tele-existence, having purely artificially controlled robots is the absolute preference!

If we evaluate the following hypothesis by the change in response to the question regarding the film *The Truman Show*, we also observe a remarkable result. Our hypothesis is that,

> (H) after the experience, participants believe more strongly that human beings can be fooled long-term about the reality they experience.

In this case, responses are such that 25 respondents increased their ranking on the possibility of scenarios like in the film *The Truman Show*. If we make the null hypothesis as follows

> (H_{null}) after the experience participants have no more belief (or potentially even less belief) on the

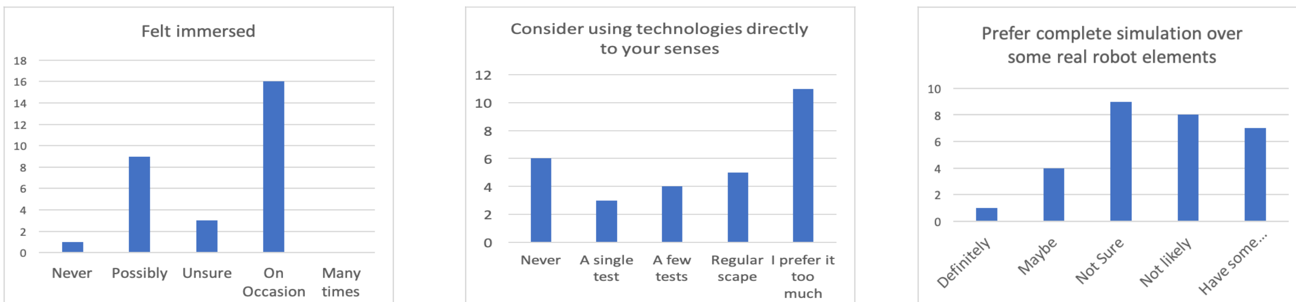


(a) Histogram for usage of video-games.

(b) Histogram for choosing and artificial opponent.

(c) Histogram for selecting a human opponent.

Figure 9. Illustrating the dispersion of personal preferences and habits by adults reflected in the pre-activity questionnaire.



(a) How transported to another world.

(b) Wishing to have more direct and seamless immersion.

(c) Shall we keep a robot and keep it *real* or should it be a complete simulation.

Figure 10. Post-activity histograms on responses showing slight preference for tele-existence experiences.

> plausibility of a human being living on a staged reality.

Then, the hypothesis testing using the binomial distribution with 28 degrees of freedom show statistical significance at the 99% level.

Since the thesis of the movie *The Matrix* is a direct illustration of tele-existence, we expect to observe some change on the belief for the plausibility of such a scenario. That is we expect

> (H) after the experience, participants believe more strongly that human beings can have their nervous system and brain directly linked to a virtual reality and it would appear a completely real experience.

We found here that 18 out of 29 participants' responses are consistent with the hypothesis. This outcome is not statistically significant. Nevertheless, none of the responses decreased the belief after the experience. It is not methodologically prudent to change the hypothesis after observing the data, but it remains an interesting observation that if we had formulated the hypothesis

> (H) participants would increase or maintain their belief in the plausibility of scenarios like in the movie *the Matrix*.

Then, the null hypothesis would be that they would decrease their belief in such plausibility, and the data would have rejected the null hypothesis. It is reassuring that our tele-existence experiment did not have an effect to reduce the chances of people imagining scenarios of tele-existence. That is, our hardware/software immersion is convincing enough to transport adult subjects to a tele-existence that sustains the plausibility of tele-existence scenarios.

Finally, if we look at the change in belief for participants contrasting on the *existence scenario* exemplified by the life-simulating game *The Sims*, we formulated the hypothesis as follows.

> (H) Participants would increase their belief in the plausibility of scenarios like in the life-simulating game *The Sims*.

Here 18 out of 29 participants increased their belief, and 11 left it unchanged. This outcome is not statistically significant to reject the null hypothesis. However, if we had formulated the hypothesis as *an increase or maintain*, then the 29 participants would have been consistent with the hypothesis and the result would have been statistically significant. However, this would have the questionable methodological issue of revising the hypothesis after inspecting the data. Nevertheless, it is remarkable that none of the participants decreased their perception that surrogate existence as exemplified by *The Sims* is plausible.

B. Children subjects

Since we will measure how immersed are the children in the tele-existence experience by their reaction to statements like "to play you need to get up", we have in our method a mechanism to establish the baseline. Our approach is derived from the requirement by our ethics approval to have the children sitting during the experiment. For all participants, the robot is always kneeling at the start of the experience.

Copyright (c) IARIA, 2019. ISBN: 978-1-61208-686-6

With participants in the four days of STEM, we had at least 5 different groups in each day. That is, the STEM activities partition the children in the day into 5 groups. Therefore, at most 5 and typically 4 children are introduced to the activity. The first child to sit (from a group) is chosen randomly, and the activity commences immediately with the remark by the first assistant: “to play you need to get up”. In total, we had 20 children (5 representatives of a group on 4 days) to which the indication to stand-up was given at the start of the immersion. We iterate that these children had not witnessed the activity, and we suggest the indication is ambiguous as it could refer to the robot’s body or the children’s body. Our results show that 8 out of 20 children stood up themselves, rather than operate the cube that raises the robot. We take this as a strong indication that early in the activity, the statement “to play you need to get up” is ambiguous.

However, when a child pilot manages to score a goal and celebrate it, the robot will purposely finish kneeling. So, the first assistant gives the indication “to continue playing you need to get up”. We only had 44 out of 156 children succeeding in scoring a goal. So, the situation where we evaluate the reaction of children to the indication applies to those 44 participants only. However, 42 children used the control of the virtual world to raise the robot and continue playing for a second goal. Only 2 (two) out of 44 stood up from their sitting position. There was no overlap between the 20 children who received the instruction very early in the activity and the 44 who received it after they succeed in scoring a goal. However, there were 14 children who had witnessed another child participate earlier, scored a goal and not require to stand up themselves, just the robot. So, we exclude those and we are left with 30 children, where 28 used the robot body rather than their own to continue playing. We designed this experiment with the following hypothesis in mind.

> (H) The probability that a child participant interprets the ambiguous statement about the body needing to stand up as referring to the robot rather than his own body is larger after being immersed than before being immersed.

Note that our data for interpreting the statement very early in the experience suggest that the probability of interpreting the statement as the robot’s body is $\hat{p}_0 = 12/20 = 3/5$ (This is the Maximum Likelihood Estimator (MLE) of the corresponding Binomial distribution). Since we had $n = 20$ trials, the Fisher information is

$$I(p) = \frac{n}{p(1-p)}.$$

Thus, the 95% confidence interval is given by

$$\begin{aligned} \mathrm{CI}_0 &= \hat{p}_0 \pm 1.96\sqrt{\frac{\hat{p}_0(1-\hat{p}_0)}{n_0}} \\ &= \frac{3}{5} \pm 1.96\sqrt{\frac{0.6(0.4)}{20}} \\ &= 0.6 \pm 0.2147. \end{aligned}$$

Now, after scoring a goal, the MLE probability of interpreting the statement as the body of the robot is $\hat{p}_1 = 28/30 = 14/15$. And in this case, the 95% confidence interval is

$$\begin{aligned} \mathrm{CI}_1 &= \hat{p}_1 \pm 1.96\sqrt{\frac{\hat{p}_1(1-\hat{p}_1)}{n_1}} \\ &= \frac{14}{15}1.96\sqrt{\frac{0.9333(0.0666)}{30}} \\ &= 0.9333 \pm 0.0892. \end{aligned}$$

Since the 95% confidence do not overlap, we can say that at the 95% level, we have a statistically significant result for our hypothesis. That is, we reject the null hypothesis at 95% and accept that children interpret the language of *your body* as referring to the robot.

V. THREATS TO VALIDITY

Analysing the conditions and setting of our experiments we can identify some challenges regarding external validity. The subjects do not represent random samples of adults, neither a random sample of children. The subjects have pre-selected themselves as curious regarding technology, virtual reality or at least robotics. They may be a correlation between the promotion of information technology degrees (being performed during the day), and the belief system of those that approach the display and eventually participated in the activity. The activity is robotic soccer as per the Standard Platform League at RoboCup; it is possible that other challenges or competitive environments of tele-existence deliver different results. There were no awards and perhaps the setting does not constitute realistic pressure on the participants; results could also be different if reaching a specific target of goals would result in receiving a prize. Similarly, if the participant were to perform poorly and a penalty were to be applied, it could cause different behaviour during the activity and different responses regarding the enthusiasm to be involved in competitive settings with physical artificial agents.

While we query about previous experience with virtual environments, it is possible that training and previous practice with the hand-held controllers and familiarity with wearing a VR headset results in skilful tele-operation. Such easy tasks and success with such tasks may impact self-awareness or self-esteem; leading to considering humans more highly, and thus superior than artificial systems.

We also need to consider other aspects of construct validity. Is the pre-questionnaire or post-questionnaire measuring adequately the impact of the exposure to a change in beliefs? Are there other ways by which humans revise their belief system about machines and artificial intelligence? Could the participants (despite answering anonymously) be anticipating what are “normal” responses and trying to please those conducting the research? It is not surprising that people adopt language referring to an avatar as talking about themselves, even for simple video games or massively networked games [20]. However, completely virtual avatars occasionally lead to identity issues [20]. We felt here it was clear to all participants they are the mind for just one body, they could not choose it, and they can not clone it or vary it. All these are elements that are distinctive from the construction of avatars, and would prove interesting avenues to explore in further experimental settings [21].

With respect to statistical validly, challenges could be derived from violations to the statistical assumptions that enable a particular analysis, low statistical power or low effect size. We could have evaluated the results for children using the observed value of the LR statistic [22, Section 12.4, Pages 156-158] and we would establish even stronger (i.e. 99% level) statistical significance. In particular, we reject the hypothesis that assuming the language is about the robot's body is the same before and after scoring a goal. The common MLE for the probability is

$$\frac{12+38}{20+30} = 40/50 = 4/5.$$

Thus,

$$\begin{aligned} D_{obs} &= 2\left(8\log\frac{8}{4} + 2\log\frac{2}{6} + 12\log\frac{12}{16} + 28\log\frac{28}{24}\right) \\ &= 8.42. \end{aligned}$$

and $Prob\{\chi^2_{(1)} \geq 8.42\} < 0.01$. We felt the argument with confidence intervals is more transparent. Thus, we highlighted those results where we could report statistical significance.

VI. Conclusions

The Oxford living dictionary defines tele-presence as

> *"The use of virtual reality technology, especially for remote control of machinery or for apparent participation in distant events. A sensation of being elsewhere, created by virtual reality technology".*

We believe this definition captures the very distinctive notion of *tele-existence* [7] when it suggests the individual is transported somewhere else. However, we have emphasised here the distinction with a large number of tele-presence products essentially equivalent to a tilt-able tablet on wheels. Such products are closer to tele-conference infrastructure as they offer little capability to influence the world one is transported to. By creating a tele-existence environment with a Nao robot, virtual reality headset and VR-controllers, we have transported adults and children to co-exist with other robots in a soccer match opposing other autonomous robots. We have evaluated adults attitudes to the notion of tele-existence comparing it with some scenarios discussed in the literature and exemplified by some widely known movies or video-games. We found humans attitudes to engaging in competitive matches against robots increased significantly, and our setting does not reduce the belief in humans for the plausibility of such scenarios. In the case of children, they very rapidly adopt the robot's body as the body used in the natural dialogue with the presenter of the activity. Our results open the exploration of the emerging notion of tele-existence to reclaim the definition of tele-presence.

There are many improvement opportunities for furthering our current immersion. The camera relay typically has a lag of at least 1.5s. Such a delay should be reduced. Several situations should relay better feedback to the pilot, such as the robot falling or when the waving of hands is finished (waving actions were included to allow scoring celebrations). There is an open field of how much sensor information to forward to the human, and how. The person must believe they are the mind of the robot.

References

[1] M. Minsky, "Telepresence," Omni, vol. 2, no. 9, 1980, pp. 45–52.

[2] G. Ballantyne, "Robotic surgery, telerobotic surgery, telepresence, and telementoring," Surgical Endoscopy And Other Interventional Techniques, vol. 16, no. 10, Oct 2002, pp. 1389–1402.

[3] M. Reid, "Rethinking the fourth amendment in the age of supercomputers, artificial intelligence, and robots," West Virginia Law Review, vol. 119, no. 101, March 16th 2017, pp. 100–126.

[4] E. T. Curtiss and S. Eustis, Telepresence Robots Market Shares, Strategies, and Forecasts, Worldwide, 2017 to 2023. Lexington, Massachusetts: Wintergreen Research, Inc., 2017.

[5] M. T. Jones, M. Lombard, and J. Jasak, "(tele)presence and simulation: Questions of epistemology, religion, morality, and mortality," PsychNology Journal, vol. 9, no. 3, 2011, pp. 193–222.

[6] M. Lombard and T. Ditton, "At the heart of it all: The concept of presence," Journal of Computer-Mediated Communication, vol. 3, no. 2, September 1st 1997, pp. 201–213.

[7] M. Elobaid, Y. Hu, J. Babic, and D. Pucci, "Telexistence and teleoperation for walking humanoid robots," 2018, arXiv:1809.01578.

[8] S. Tachi, "Tele-existence," Journal of Robotics and Mechatronics JRM, vol. 4, no. 1, 1992, pp. 7–12.

[9] P. H. Kahn, Jr., B. Friedman, and J. Hagman, ""I Care About Him As a Pal": Conceptions of robotic pets in online aibo discussion forums," in CHI '02 Extended Abstracts on Human Factors in Computing Systems, ser. CHI EA '02. New York, NY, USA: ACM, 2002, pp. 632–633.

[10] P. H. Kahn, Jr., B. Friedman, D. R. Pérez-Granados, and N. G. Freier, "Robotic pets in the lives of preschool children," Interaction Studies, vol. 7, no. 3, 2006, pp. 405 – 436.

[11] L. Boroditsky and M. Ramscar, "The roles of body and mind in abstract thought," Psychological Science, vol. 13, no. 2, 2002, pp. 185–189.

[12] R. Aylett, Robots: Bringing Intelligent Machines to Life. Woodbury, NY, USA: Barron's Educational Series Inc., 2002.

[13] A. Kristoffersson, S. Coradeschi, and A. Loutfi, "A review of mobile robotic telepresence," Adv. in Hum.-Comp. Int., 2013, pp. 3:3–3:3.

[14] J.-M. Lu, C.-H. Lu, Y.-W. Chen, J.-A. Wang, and H. Y.-L., "TRiCmini - a telepresence robot towards enriched quality of life of the elderly," in First Asia Pacific eCare and TeleCare Congress, vol. 18, June 16th-19th 2011.

[15] S. O. Adalgeirsson and C. Breazeal, "MeBot: A robotic platform for socially embodied presence," in Proceedings of the 5th ACM/IEEE International Conference on Human-robot Interaction, ser. HRI '10. Piscataway, NJ, USA: IEEE Press, 2010, pp. 15–22.

[16] A. Spada, M. Cognetti, and A. De Luca, "Locomotion and telepresence in virtual and real worlds," in Human Friendly Robotics, F. Ficuciello, F. Ruggiero, and A. Finzi, Eds. Cham: Springer International Publishing, 2019, pp. 85–98.

[17] V. Estivill-Castro, R. Hexel, and C. Lusty, "High performance relaying of c++11 objects across processes and logic-labeled finite-state machines," in Simulation, Modeling, and Programming for Autonomous Robots, D. Brugali, J. F. Broenink, T. Kroeger, and B. A. MacDonald, Eds. Cham: Springer International Publishing, 2014, pp. 182–194.

[18] D. Joukoff, V. Estivill-Castro, R. Hexel, and C. Lusty, "Fast mav control by control/status oo-messages on shared-memory middleware," in Robot Intelligence Technology and Applications 4, J.-H. Kim, F. Karray, J. Jo, P. Sincak, and H. Myung, Eds. Cham: Springer International Publishing, 2017, pp. 195–211.

[19] K. Fagan, "Here's what happens to your body when you've been in virtual reality for too long," Business Insider, March 4th 2918, www.businessinsider.com.

[20] Y. B. Kafai, D. A. Fields, and M. S. Cook, "Your second selves: Player-designed avatars," Games and Culture, vol. 5, no. 1, 2010, pp. 23–42.

[21] S.-A. A. Jin, "The virtual malleable self and the virtual identity discrepancy model: Investigative frameworks for virtual possible selves and others in avatar-based identity construction and social interaction," Computers in Human Behavior, vol. 28, no. 6, 2012, pp. 2160 – 2168.

[22] J. G. Kalbfleisch, Probability and Statistical Inference — Volume 2: Statistical Inference, 2nd ed. New York: Springer-Verlag New York, 1985.