Create new human - artificial agent interactions through the concept of similarity in order to enhance social competence in patients suffering from social deficits.

Project FP7-ICT-2011-9-600610

AlterEgo

"Enhancing Social interaction with an AlterEgo Artificial Agent"

Collaborative Project

Cognitive Systems and Robotics

Deliverable D.4.2
"Report on models of patients' motion ported on the avatar and iCub robot"

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Dissemination Level		
PU	Public	X
PP	Restricted to other programme participants (including the Commission Services)	
RE	Restricted to a group specified by the consortium (including the Commission Services)	
CO	Confidential, only for members of the consortium (including the Commission Services)	

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1. Deliverable description

The deliverable D.4.2 "Report on models of patients' motion ported on the avatar and iCub robot" summarizes work progresses done over the course of the second year on analysing and modelling human motion data in view of designing controllers for the robot and avatar that mimic the patient's motion. This year's work was devoted to two main ideas:

1) Modelling the motion of the follower, given a particular motion of the leader. We use the mirror paradigm to study coupling of hand motion in a leader-follower game. We propose a mathematical model consistent with the internal model hypothesis and the delays in the sensorimotor system. A qualitative comparison of data collected in human dyads shows that it is possible to successfully model typical patterns of follower's motion, such as overshoot in the face of a sudden change in amplitude or direction of the leader's motion. This work which is summarized in Section 2 has already been published[1].

2) Exploiting an important modularity in the iCub to enforce the similarity and affiliation in interaction with patients; i.e. gaze. This deliverable reports on an experimental study conducted at EPFL. Although the conducted experiment was limited to healthy subjects, its results are promising and will set the stage for a follow-up experiment at CHU with Schizophrenic patients. Since the results of this experimental study will be submitted for publication, in the Section 3, we present this deliverable in the format of standard journal publication.

[1] M.khoramshahi, A.Shukla, and A. Billard, "Cognitive mechanism in synchronized motion:An internal predictive model for manual tracking control", IEEE International Conference on Systems Man and Cybernetics, 2014.

2. Modelling human motion tracking behaviour

For modelling human motion tracking behaviour, we focused on temporal and spatial error extracted from leader and follower's motion when they change the direction of the motion; see Figure 1a. We believe that these features encapsulate the follower's behaviour. The distribution of these features represents the synchrony (temporal correspondence) between the leader and the follower; see Figure 1b. Based on fundamental properties of human sensori-motori system (internal models to cope with delays), we proposed a cognitive model for human motion tracking; see Figure 1c. In this model two underlying parameters need to be tuned for particular tracking performance; i.e. memory and delay. Using the human experimental data, the cognitive model can act similar to human in the level of distribution for temporal and spatial error. An example of the model performance using tuned parameters (300ms for delay and 5s for memory) is illustrated in Figure 1d. As this figure shows, the model exhibits a very similar behaviour as human follower.

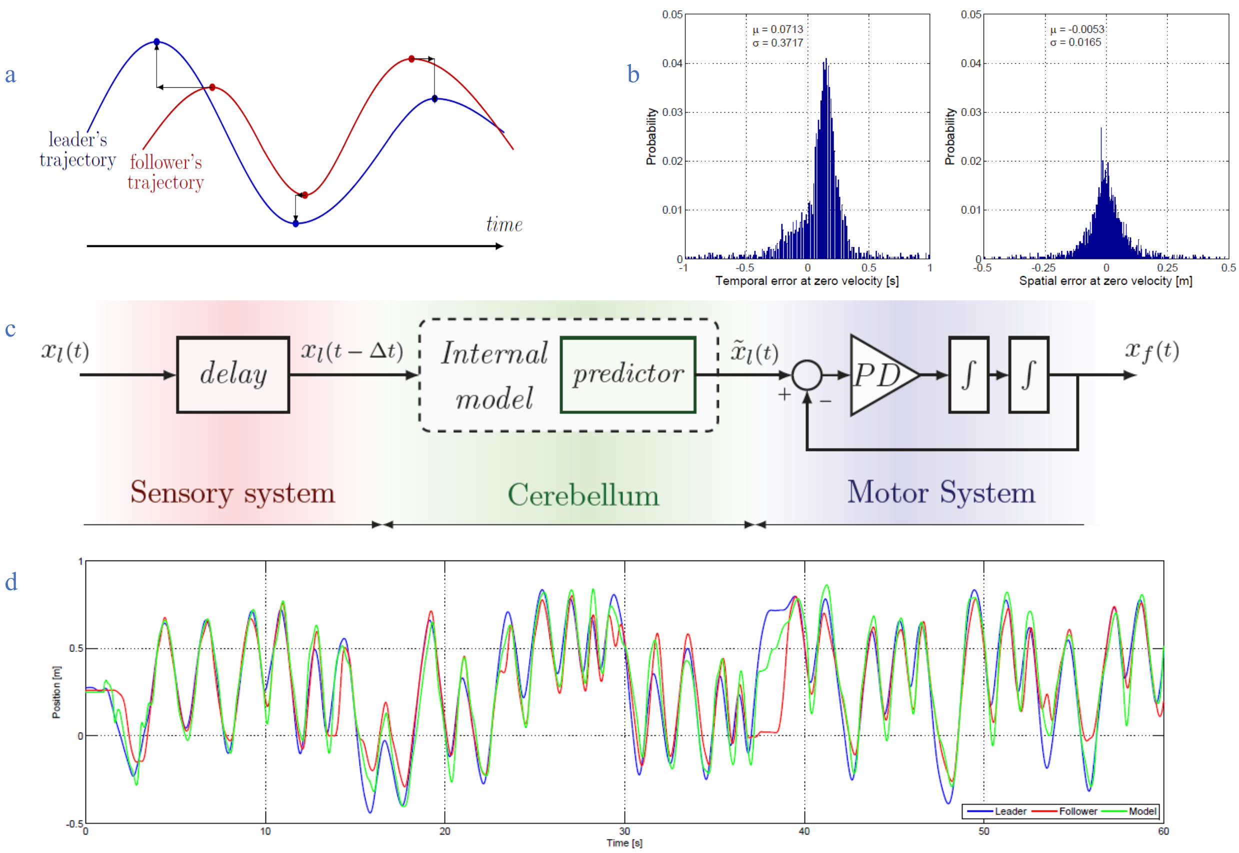

Figure 1. a) Extraction of temporal and spatial error from zero-velocity points. b) Probability distribution of temporal and spatial error in zero-velocity points for human follower in mirror game setup. c) The proposed cognitive mechanism incorporating delay and internal model. This model incorporates the delay in the sensory system and the memory span for updating internal models. In this work, we update a 2nd order dynamical system least-square method as an internal model. d) Model performance for Leader-follower setup after optimizing the parameters based on the human experimental data.

3. Effects of gaze on human following motion

3.1. Abstract

Background

Abnormal gaze behaviour along with gaze discrimination impairment severely affect the social interactions (social withdrawal) and deteriorate the quality of life. The mirror game tries to encapsulate the nature of the interactions via hand motions in different scenarios (leader-follower or joint-improvisation motions). We are interested to investigate the effects of gaze on the human-computer interactions (playing mirror game). Results of this study are important to design an efficient computer-assisted cognitive therapy for patients suffering from schizophrenia. In this study, we focus on i) whether healthy subjects are able to exploit the gaze cue in order improve their tracking behaviour; ii) whether introducing gaze cue for avatars and robots makes them more human-like (from user point-of-view) and increases the affiliation.

Methodology/Principal Findings

43 healthy subjects (never diagnosed with SCZ, autism, cognitive impairment, or any severe motor disability) participated in a dyadic interaction we the iCub avatar. Each participant played the mirror game, following the stochastic motions of the avatar, in two different conditions; without and with gaze cue. Upon completion of the mirror game, they were asked to answer a short questionnaire reporting their impressions on the level of difficulty the game and on the amount of similarity of iCub's behaviour to human behaviour. The analysis of motion patterns revealed that healthy subjects are able to exploit the gaze cue in order to improve their performance. Specifically, the Reaction Time (RT) of the human follower to the avatar leader improved significantly when the gaze cue introduced to the mirror game. Analysis of the subjective evaluations via the questionnaires revealed that, in presence of gaze cue, participant found it not only more human-like, but also easier to interact with the avatar.

Conclusions/Significance

The auspicious results of these study shed light on possible strategies to design computer-assisted cognitive therapy for gaze impairment. Moreover, analyses shows, by embedding active gaze behaviour in avatars/robots, affiliation in human-computer interaction can be systematically improved.

3.2. Introduction

Impairment in the ability to discriminate and interpret gaze direction when watching other people' faces has been reported as one fundamental impairment in schizophrenia. They are impaired markedly on distinguishing both the direction of the gaze (left and right) and whether the face or the eyes are directed at the viewer [1]. However, [2] discussed that directed gaze capture patients' attention and delay their responses to nearby stimuli. This abnormal gaze behaviour toward others in schizophrenic patients make them look significantly less at the others head and because of that they have lower performance in belief and goal attribution [3]. High task-specific distractibility of schizophrenics has been also been studied where Schizophrenics made more saccades than control subjects in the instructed task only[4].

Because of the predominant role played by gaze in social interaction, impairment in gaze discrimination in schizophrenic patient has received a lot of attention in recent studies. According to these studies, impaired "Theory of mind" in schizophrenia might be related to a deficit in visual attention toward gaze orientation [3]. Moreover, this impairment in processing eyes and gaze my represent a core deficiency in several other brain pathologies and may be central to abnormal social cognition [5]. It also has been proposed that impairment in gaze determination is responsible for the paranoid symptoms reported in schizophrenia [6].

Recently, several cognitive therapy methods, for schizophrenia, have been proposed [7-12]. Interestingly, using computers and intelligent systems for the purpose of cognitive therapy is also getting momentum [13]. Of particular interest to us, attentional-shaping has also been used as an operant conditioning procedure to enhance neurocognition and functioning in Schizophrenia [14]. This method achieves remediation by directing attention to the key areas of interest (face, gaze, or emotion) [15].

These evidences led us to propose to investigate the role that gaze may play in enhancing the interaction in the mirror game [16]. Shifting the visual attention toward the gaze direction in the mirror game will result in a cognitive therapy method where the patient is encouraged to process eyes and gaze information. Gaze cue may hence be crucial in the mirror game to help the follower prepare for and, more rapidly adapt to, sharp changes in hand direction from the leader.

To test this, we implemented a version of the mirror game where the iCub robot [17]is the leader and the subject the follower. We programmed two conditions for iCub's behaviour as the leader; see Figure 1. In the first condition, the iCub's gaze is fixated on its hand; i.e. the gaze moves synchronously with the hand and is "attached" to the hand. In this condition, the robot no gaze cue. In the second condition, iCub is trying to provide the follower with a hint for the next movement using the gaze; i.e. with gaze cue. We examine if subjects can exploit this cue in order to improve their tracking behaviour.

Based on mentioned evidence of poor tracking of gaze direction in Schizophrenic patients, we hypothesize that, while healthy subjects would benefit from gaze cues generated by the robot to improve their tracking performance, schizophrenic patients may remain unresponsive to these gaze cues and would not improve their tracking performance. To first assess our hypothesis that healthy subjects would benefit from gaze cues, we conducted an experiment that involved uniquely healthy subjects. Although this experiment was limited to healthy subjects, its results are promising and will set the stage for a follow-up experiment at CHU with Schizophrenic patients.

Figure 2. iCub robot (in simulator) acting as the leader in the mirror game generating random sinusoidal trajectories. (Left) the gaze is fixated on the hand. (Right) the gaze precedes the hand. The blue arrows show the next hand movement and the green arrows show the current gaze fixation point.

3.3. Methods

Participants

We recruited 43 participants (31 male, and 12 female) from the EPFL campus (Bachelor, Master, and PhD students). Their average age was 23.1 (4.7) [18-39] (Values are presented in the form mean (standard deviation) [min-max]); see Figure 3 for boxplot of this distribution. All participants were self-reported as healthy; i.e. not diagnosed with schizophrenia, autism, any cognitive impairment, or motor disability.

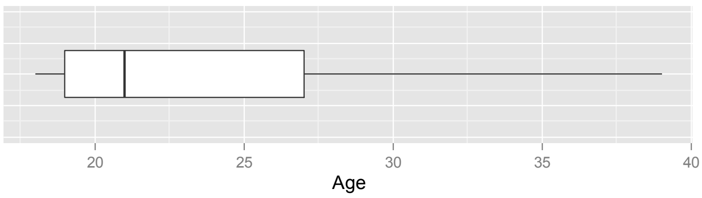

Figure 3. Boxplot for age distribution of the participants

Each participant took part in one session that lasted a maximum of 10 minutes. All participants successfully completed the session, and as a consequence, no data had to be removed from the experiments. They also gave their written informed consent to take part in this experiment.

Apparatus

For this study, we used the iCub simulator [18]; see Figure 2. We controlled the right arm of this robot for play mirror game. In our inverse kinematics method, we used the result of our previous work [19] in order to generate human-like posture (motion of the shoulder and the elbow). To have the robot as the leader, we controlled the position of the hand over a sinusoidal trajectory with stochastic parameters (random amplitude, offset, and frequency).

In order to have a random motions for the hand, we first, scale the hand reachable range to [-1,+1] interval. Note that the reachable range for hand is symmetric with respect to body sagittal plane. Then we consider four modes of oscillation as depicted in Figure 4. Each mode has a different combination of offset and amplitude as follows:

$$\begin{bmatrix} offset \\ ampliude \end{bmatrix} \in \left\{ \begin{bmatrix} 0 \\ 0.3 \end{bmatrix}, \begin{bmatrix} -.5 \\ 0.3 \end{bmatrix}, \begin{bmatrix} .5 \\ 0.3 \end{bmatrix}, \begin{bmatrix} 0 \\ 0.7 \end{bmatrix} \right\}$$

The number of oscillation in each mode is random number between 2 and 5 (inclusive and uniformly) except the large oscillation where the number of oscillations is fewer (one or twice). Starting the oscillation, velocity of motion is also selected randomly (1 or 1.3 m/s) increasing the difficulty of the game. Moreover, upon completion, the next mode is randomly (uniformly) chosen.

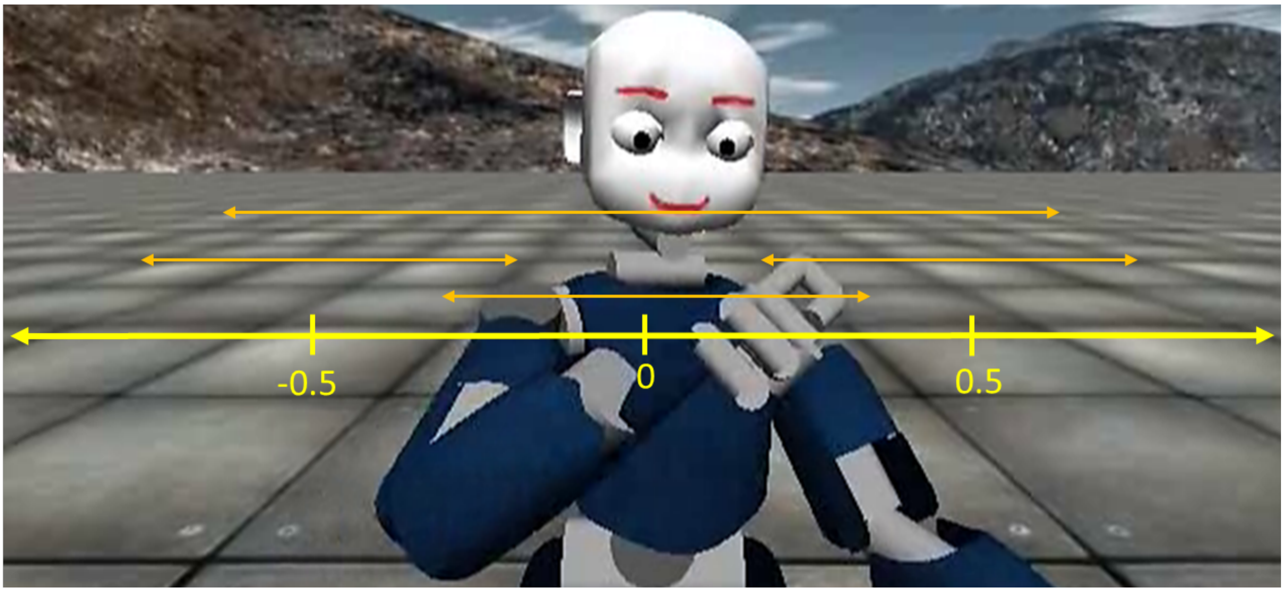

Figure 4. 4 modes of oscillations composite the random motion of the hand for the avatar. There are three small oscillations (one to the left, on in the center, and one to the right with amplitude of 0.3) and one large oscillation (with amplitude of 0.7). Number of oscillations in each mode and transition to the next mode are random. The symmetric reachable range of hand is scaled to [-1,+1] in for the motion generation, and it will mapped into the robot's coordinates later on.

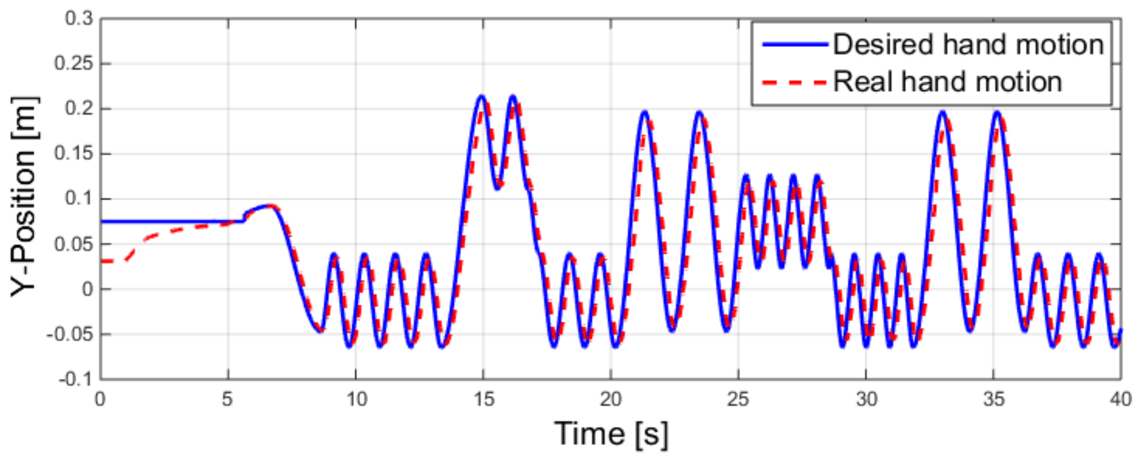

Figure 5. A sample of generated motion for the hand of avatar. Tracking performance of PD controller in this simulator is satisfactory enough. It is visible that generated motion is comprised of different modes (combination of offset and amplitude). The Y-axis corresponds to the one in the simulator.

We adjust the difficulty of the game (speed and complexity of the motion) to bring out the effects of gaze; only rely on the hand motion cannot result to a satisfactory tracking. Thus, participants are persuaded to pay attention to gaze and exploit these extra information. Moreover, the generated motions are similar to human motion in terms of range and frequency.

To control the gaze, we used the default gaze IK solver provided by the simulator [20]. To have a smooth and human-like gaze behavior, we used the following parameters in this solver.

Parameter	setting
Duration of the trajectory for the neck actuator	*1.0 s*
Duration of the trajectory for the eyes actuator	*0.4 s*
Oculo-collic reflex (OCR) gain	*0.0*
Vestibulo-ocular reflex (VOR) gain	*0.0*
Neck roll	*Blocked*
Neck yaw	*[-10 +10] deg*
Neck pitch	*[-15 +15] deg*
Tolerance to gaze at the target with the neck	*5 deg*

As mentioned before, our experiment has two condition; without and with gaze cue. For the first condition, we send the same desired trajectory to both arm and gaze controller. This will results in the trajectories plotted in Figure 6 (first row). For the second condition, we add 500 ms lead to the gaze desired trajectory, but only the offset of oscillation, resulting in the plots illustrated in Figure 6 (second row).

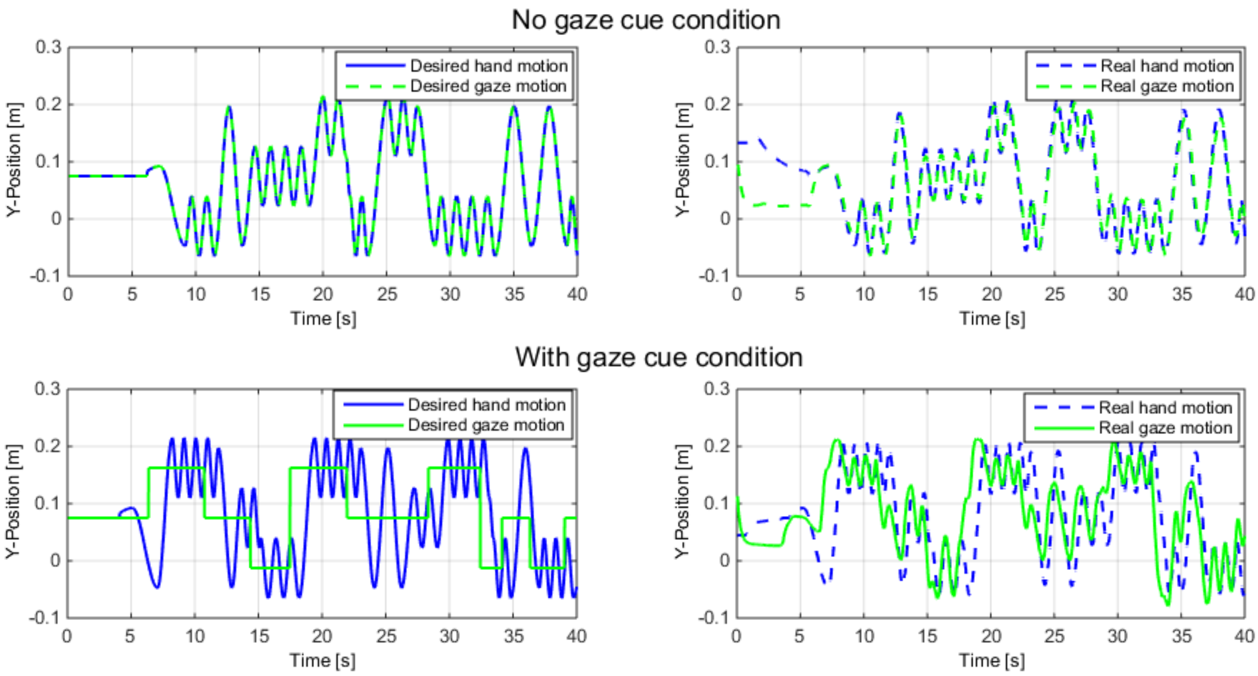

Figure 6. An example of desired trajectories for the hand and the gaze in two conditions. To have a better feeling of these two conditions check the video attached.

Figure 7. The experimental setup: Avatar is displayed on a big screen (46 inches; Sony KDL-46V4000). The iCub robot (in the simulator) is leading and the participant is following the motion. The participant holds a marker for recording purposes.

So far, we discussed the leader in the mirror game; i.e. the avatar (iCub in simulation). As dyadic interaction, we asked the participants to follow the motion of the avatar. While following, we asked the participant to hold a marker in their hand which enabled us to track their motion using Vicon system [21] (120Hz for sampling rate, and accuracy of 0.1mm).

Procedure

We tested each participant exposed to both conditions. In order to remove the effects of ordering, we divided the participant in two groups. In first group, participant are exposed to the "no gaze" condition first, and the "with gaze condition" afterwards. The reverse order happens in the second group. See Figure 8. In each condition, subjects play four consecutive trials, each 30 seconds long. Having played in both conditions, participants are asked to answer to a short questionnaire.

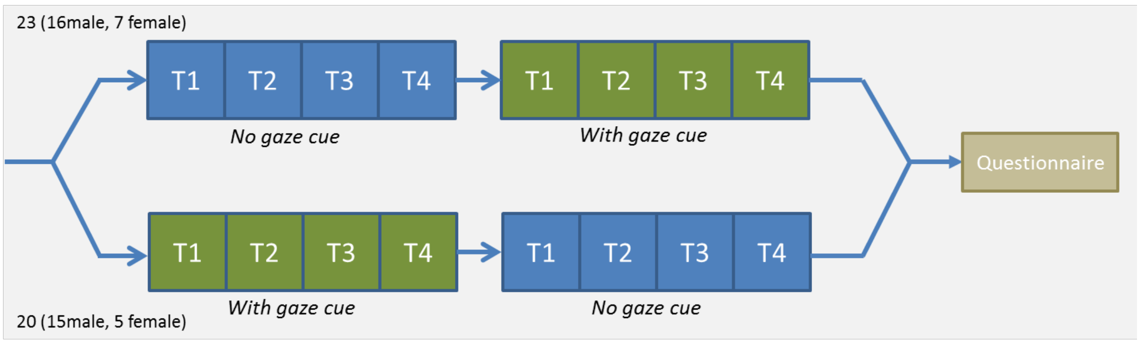

Figure 8. The protocol used for the experiment. Subjects are divided into two groups which participate in the experiment with different ordering of conditions. Participants are asked to answer a short questionnaire.

Questionnaire

In the questionnaire, we asked five short questions about the game. These questions are:

1- Difficulty for following the motion in the absence of gaze cue.
(five options: very hard, hard, normal, easy, very easy)
2- Difficulty for following the motion in the presence of gaze cue.
(five options: very hard, hard, normal, easy, very easy)
3- Similarity to human behaviour in the absence of gaze cue.
(score from 0 to 5, five being highly similar to human behaviour)
4- Similarity to human behaviour in the presence of gaze cue.
(score from 0 to 5, five being highly similar to human behaviour)
5- Difficulty of paying attention to both hand and gaze
(five options: very hard, hard, normal, easy, very easy)

Data Analysis

In our previous studies [22], we showed that human tracking performance can be captured by the temporal error. Here we use the same measure; see Figure 4. For each subject in a condition, we will have a distribution of this error. We simply choose the average to compare the two conditions.

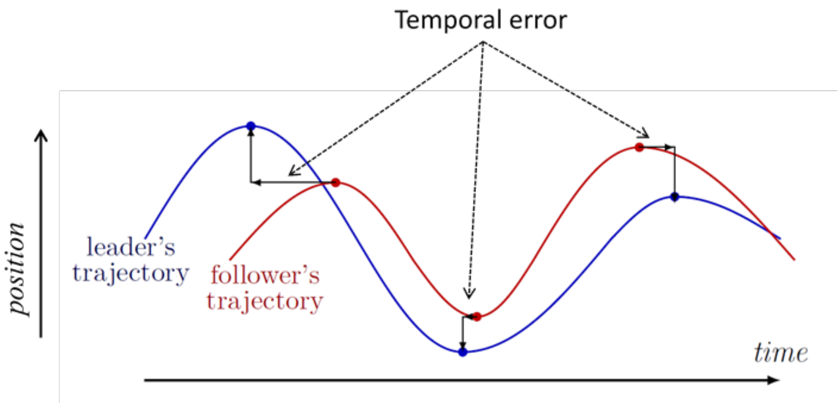

Figure 9 : Temporal error

3.4. Results

We present the results of our analysis starting by analysing the result from the questionnaire. Then, we carry on by investigating the results obtained from the motion capture systems. Afterward, we crosscheck the subjects' performances with their impressions reported in the questionnaire. Effects of age, gender and group is reported in this section.

Cooperative and natural interaction using gaze

Figure 10 summarizes the results of the questionnaire (first four questions). Figure 10.A shows that in the absence of gaze, most of the subjects found it slightly harder to follow the avatar. On the other hand, Figure 10.B shows that in the presence of gaze, following avatar is perceived as slightly easier. Figure 10.C shows how each individual changed his/her opinion from the first condition to the second one, irrespective of condition ordering. As it can be seen from this histogram, the majority of subjects (60%) upgraded their opinion (by either 1 or 2 steps) on the naturalness and difficulty of the interaction in the condition with gaze. The second row of Figure 10 shows subjects' responses to the question of how similar they found the robot's behaviour to be compared to human behaviour. Figure 10.D shows a bell-shaped distribution for similarity index in the absence of gaze while Figure 10.E shows a skewed distribution in the presence of gaze implying higher similarity to human behaviour when the avatar uses its gaze actively. Figure 10.F illustrates how each individual changed his/her opinion on the similarity index when gaze was added to the avatar. A majority of subjects (71%) upgraded their opinion on the similarity index (by either 1, 2, or 3 steps); presence of the gaze increases the similarity of the avatar to human behaviour. In conclusion, based on participants' impression, existence of the gaze cue made the interaction easier (cooperative), and more human-like (natural).

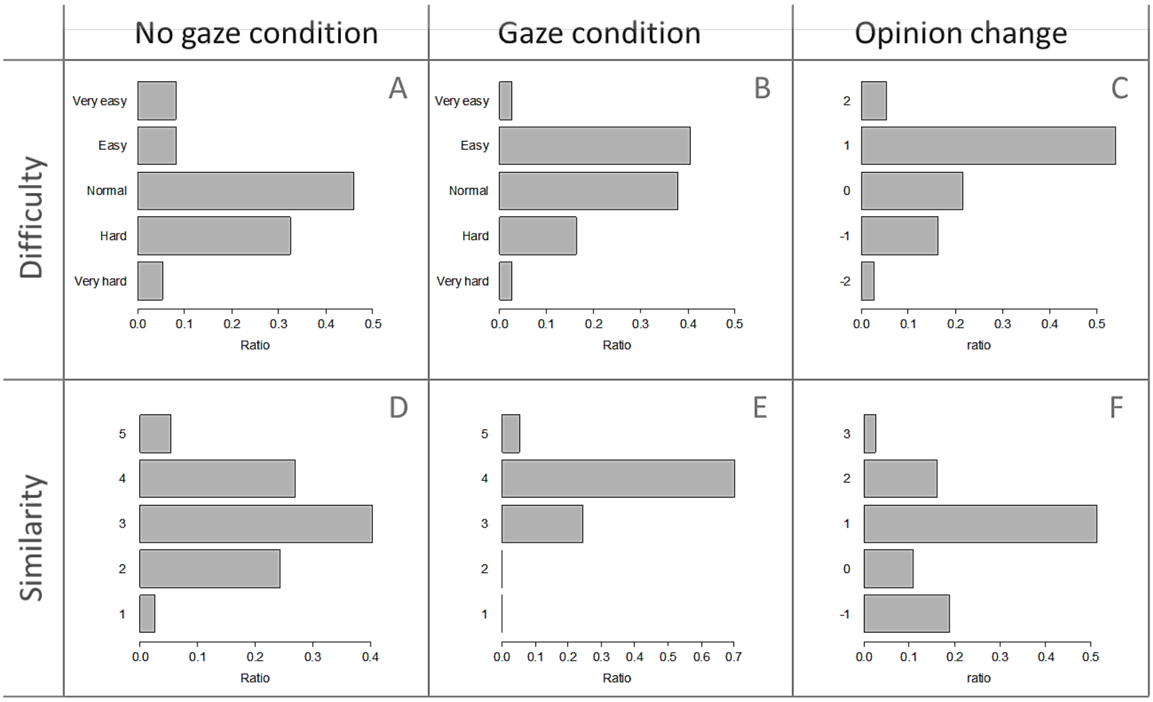

Figure 10. Distributions obtained from the answers to the questionnaire. (A) Difficulty in the "no gaze" condition. (B) Difficulty in the "gaze" condition. (C) Changes in the subjects' opinion from the "no gaze" to the "gaze" condition. (D) Similarity to human behaviour in the "no gaze" condition. (E) Similarity to human behaviour in the "gaze" condition. (F) Changes in the subjects' opinion form the "no gaze" to the "gaze" condition.

Does cooperative interaction lead to natural interaction?

An interesting investigation at this point is to see if subjects' impressions on the difficulty (cooperativeness) and similarity to human behaviour (being natural) are correlated. For this purpose, a contingency table is computed based on the opinion changes of the subjects on both difficulty and similarity. Table I shows that for a majority of subjects (sum of diagonal elements: 53%), their opinions changes consistently for the difficulty index and similarity index. However, no significant dependency between difficulty and similarity was detected using Fisher's exact test in this table.

Table 1. Contingency table for opinion changes on difficulty and similarity indices. Upward/downward arrow shows the upgrade/downgrade in the opinion from "no gaze" to "gaze" condition. Horizontal lines indicate no change in an opinion.

		Similarity			Total
		↓	—	↑	
Difficulty	↓	5%	0%	14%	19%
	—	3%	5%	14%	22%
	↑	11%	5%	43%	59%
Total		19%	10%	71%	100%

Gaze cue reduces the reaction time

Now, we turn to non-subjective quantifiable results on the effect of gaze on the subjects' tracking performance. To this end, we analyse the data on the relative velocity of subject and robot's hand motion. As mentioned in Section X, the tracking performance of each participant is measured by the average of absolute temporal error (so called reaction time or in short RT). Therefore, for each participant, we compute the RT in "no gaze" condition, and RT in "gaze condition". To contrast the two conditions, we take the difference between the RT in each case, which we name "Improvement in RT" .Figure 11 shows the overall results of this analysis.

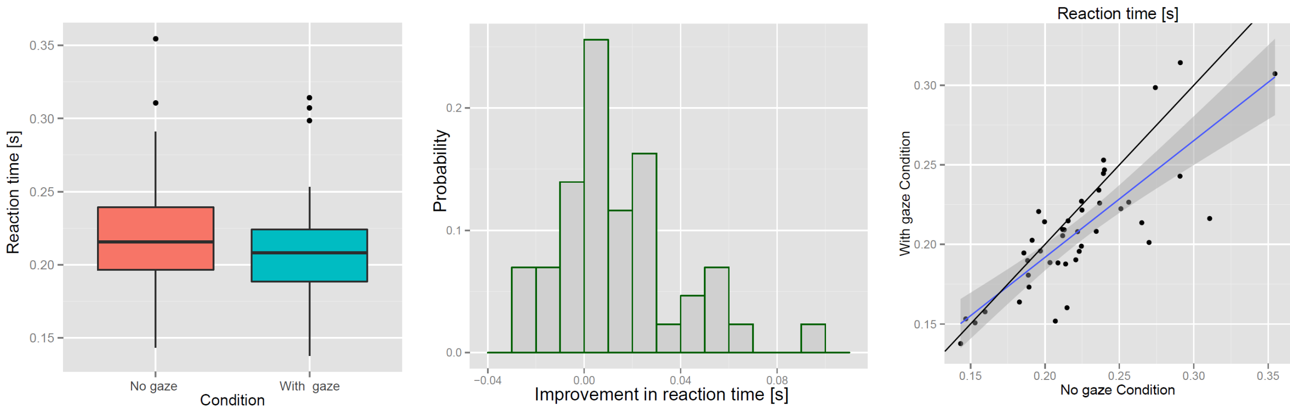

Figure 11. Overall analysis of the recorded motions. (Left) Boxplots of subjects' reaction times in each condition. (Center) histogram of improvements in RT. (Right) RT in gaze condition vs. RT in the "no gaze" condition. Each dot represents a participant. Black line is the unity line and the blue line in the result of the linear regression.

Figure 11 (Left) shows the boxplots for reaction times in each condition where participants, in average, showed faster reaction in the presence of the gaze cue. To test for statistical significance, a paired Wilcoxon test2 (with the alternative hypothesis that the gaze condition has a lower average) is used. Result of Wilcoxon test shows strongly significant improvement in reaction time for each individual (p-value=0.0006147). Figure 11 (Center) shows the distribution of RT improvements. Result of the Wilcoxon test is simply stating that average of this distribution (14 ms) is significantly greater than zero. Last subplot, Figure 11(Right), how the performance of each individual changes in the presence of the gaze cue. The black line indicates the unity line (the null hypothesis). As this

[2]. The reason for this test (rather than T-test) is that none of these distributions passed the normality test (Shapiro-Wilk test).

it can be seen, the data are skewed to the favourable side of this line (alternative hypothesis). The blue line illustrates the linear regression for these data. The slope of this regression implies that individual with lower performance (higher RT in the "no gaze" condition) can benefit more from the gaze cue.

They know when they do a bad job!

At this stage, we can check if participants' actual performance (RT from recoded motions) is consistent with their impression on difficulty from the questionnaire. Figure 12 shows the boxplots of RT improvement for two groups: (1) the participants who found it harder to follow the avatar with gaze cue, (2) the rest of participants. Wilcoxon test affirms that averages are significantly different (p-value=0.0025). This means participants who stated that it is harder to follow the avatar in the presence of the gaze cue, actually had a worse performance in this condition.

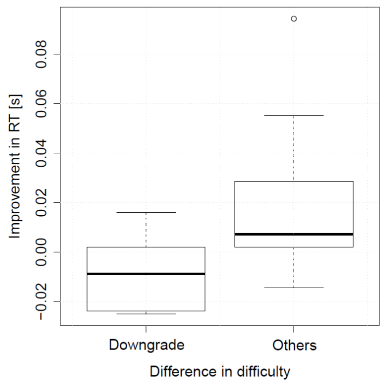

Figure 12. Boxplots of RT improvements for subjects who found it harder to follow with gaze cue (Downgrade) and the rest of the participants (Others)

Blame the avatar for not being human-like

Crosschecking the RT improvement with the results for similarity from the questions reveals interesting facts. These facts are illustrated in Figure 13. Figure 13 (Left) and Figure 13 (Center) show that, in average, participants who benefit more from the gaze cue found the "no gaze" condition less human-like and the "gaze" condition more human-like. However, no significant difference is detected for these distributions. Nevertheless, subjects who found the presence of the gaze cue less human-like (downgrade) had significantly (p-value=0.0038) poorer performance in the "gaze" condition; see Figure 13 (Right). This means they, to some extent, blame the avatar for not being human-like. Consequently, one can infer that sense of similarity to human-being and cooperation (level of difficulty) are highly related; i.e. cooperation builds affiliation and vice versa.

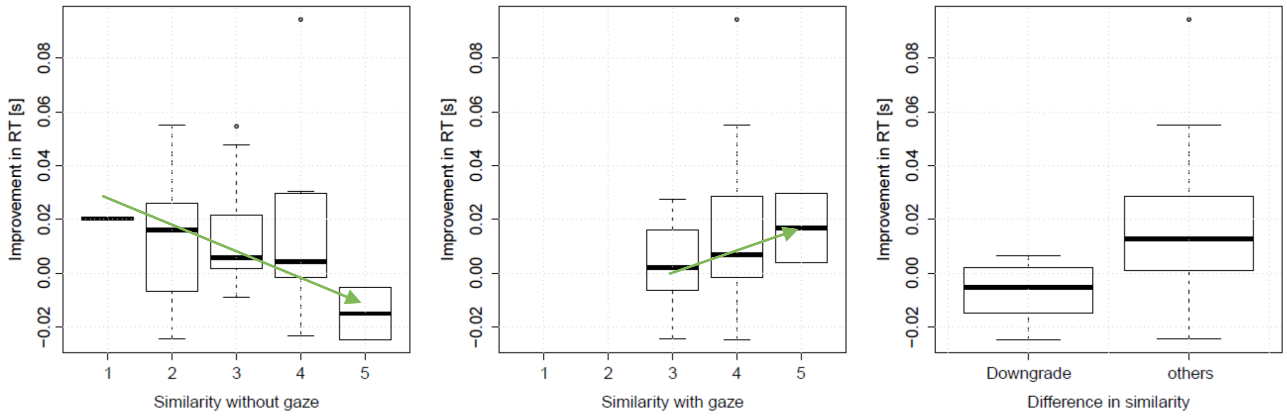

Figure 13. Effects of participant performance on their opinion on the similarity index. (Left) boxplots of RT improvements factored by participants opinion on similarity index when there is no gaze cue. (Center) boxplots of RT improvements factored by participants opinion on similarity index when there is gaze cue. (Right) boxplots of RT improvement for subjects who downgraded their opinion on similarity against the rest.

Is it about age, gender, or order of conditions?

Using statistical inferences3, no significant impact was detected from age, gender or the order of conditions. Figure 14 illustrates this fact. However, it can be observed that older participants could gain from the gaze cue more; see Figure 14 (Center). It can also be observed that gender does not have any effects in this game. Finally, Figure 14 (Left) shows that first group (who did the “no gaze” condition first) benefit more from the gaze cue. This could be due the fact that first group has a progressive learning procedure. They first learn how to follow only the hand, and then they add up the gaze information. In the second group they start learning by following both hand and the gaze.

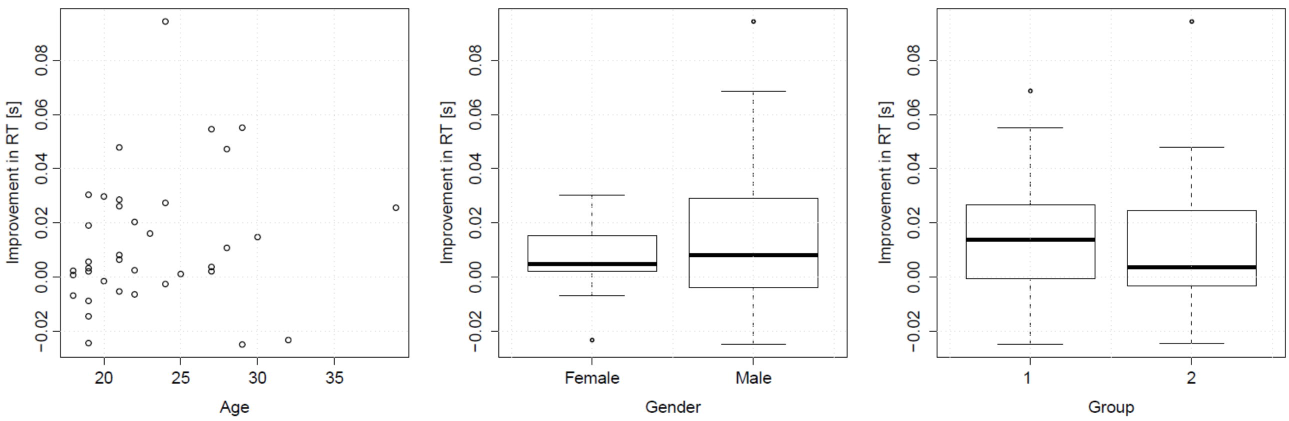

Figure 14. Improvement in RT plotted (Left) against age, (Center) factorized by gender, and (Right) factorized by order of conditions (first group did the “no gaze” condition first)

Is it hard to pay attention on both hand motion and gaze cue?

The last question in the questionnaire is concerned with attention workload in the “gaze” condition. It was meant to assess how subjects managed to divide their attention between tracking the robot's hand and looking at the robot's gaze. Figure 15 (Left) shows the distribution of participants’ answer to this question. It can be seen that, in average, they found it slightly easy to divide their attention between the hand and the gaze of the avatar. In Figure 15 (Center), we focus

[3]Mainly analysis of variances (ANOVA).

on the participant who found it very easy to divide their attention. The boxplot shows that these subjects improved more their performance with the gaze cues. The difference, however, is not significant (p-value=0.1016). In Figure 15 (Center), we focus on the participant who found it hard to divide their attention. This boxplot shows that these subjects are significantly younger than the rest (p-value=0.06838). Along with the fact that young subject are better followers in the no gaze condition (see Figure 16), this implies that young subjects do not rely on the gaze since the attention load for them does not justify minor improvements; see Figure 14 (Left).

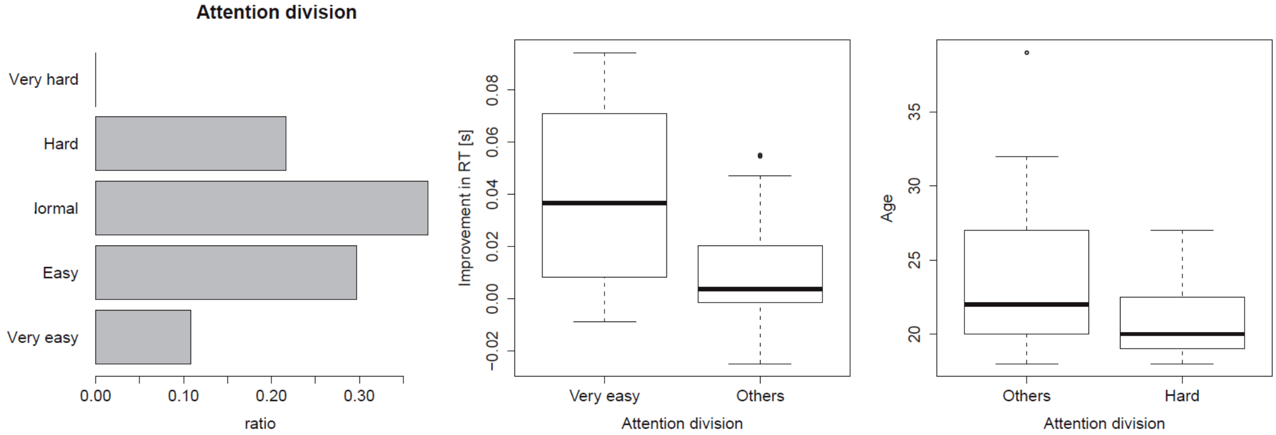

Figure 15. (Left) Attention workload for participants when they are trying to pay attention to both the hand and the gaze. (Center) improvement in RT for subjects who found it very easy to divide their attention against the rest. (Right) Age distribution of the subjects who found it very hard to divide hard to divide their attention against the rest. The dots in two last subfigures are designating the outliers.

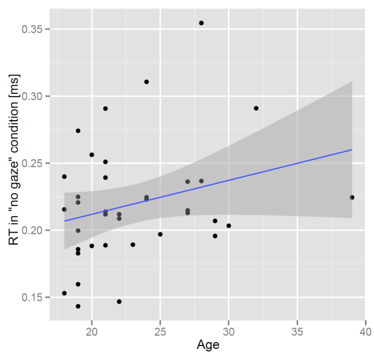

Figure 16. Reaction time (RT) in the "no gaze" condition plotted against age of subjects. Although it is not statistically significant, but young subjects show faster reaction to the motion of the avatar.

3.5. Discussion

In this section, we would like to discuss some key ideas for improving this study.

Robot instead of simulator: We are planning to replicate our experiment using the actual humanoid robot; the iCub. Simulators are suitable for prototyping and obtaining the preliminary results. Studying the different results obtained by simulator and real robot is an interesting topic and in the case of robot superiority it would justify further funding and research for humanoid robotics.

Eye-hand coordination: In this study, we used a simple model for eye-hand coordination. Modeling this coordination from human can implementing it on the robot will boost the similarity between the robot and human. Based on the "theory of similarity", this will increase the affiliation and enhance the interaction.

Using eye-tracking: In this work, we did not have a systematic method to check the subject's attention. Incorporating eye trackers [23] and monitoring subject's attention can lead to better analysis for human-robot interaction and more efficient cognitive therapy methods.

3.6. References

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