ROBotic Open-architecture Technology for Cognition, Understanding and Behavior

Project no. 004370

RobotCub

Development of a cognitive humanoid cub

5.5 Results from Interaction Studies on Synchronization, Mirroring and Interaction Kinesics

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PU	Public	**PU**
PP	Restricted to other programme participants (including the Commission Service)	
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1 Executive Summary

D5.5 extends the analysis of the experiments report in D5.4 (submitted for the RobotCub project year 2 review). This deliverable consists of the article (Appendix 1) entitled "*Behaviour Delay and Robot Expressiveness in Child-Robot Interactions: A User Study on Interaction Kinesics*" by Ben Robins, Kerstin Dautenhahn, René te Boekhorst and Chrystopher L. Nehaniv. A shortened version of this report has been submitted to a conference in September 2007.

The work reported in this deliverable shows the impact of interaction kinesics in human-robot imitation and interaction studies, strongly suggesting the important role of timing, synchronization and non-verbal gestures, cues and signals that are known to regulate human-human interactions. Our results support the hypothesis that the same factors also play a significant role in human-robot interaction and robots developing in interaction with humans.

2 Introduction

This study presents results of a study where 18 children interacted with a humanoid child-sized robot called KASPAR via turn-taking interaction and imitation. Each child took part in six experimental trials involving two games in which the dynamics of interactions played a key part: a body expression imitation game, where the robot imitated expressions demonstrated by the children, and a drumming game where the robot mirrored the children's drumming. In both games KASPAR responded either with or without a delay (2 conditions). Additionally, in the drumming game, KASPAR responded with or without exhibiting facial/gestural expressions. These 6 experimental conditions per child allowed between- and within participant comparisons. Individual case studies as well as statistical analysis of the complete sample are presented. Results highlight individual differences in the children's responses. The statistical analysis of the complete data set showed that a delay of the robot's drumming response lead to larger pauses (with and without robot nonverbal gestural expressions) and longer drumming durations (with nonverbal gestural expressions only). In the imitation game, the robot's delay led to longer imitation eliciting behaviour with longer pauses for the children. Different possible explanations of these results are discussed. Overall results indicated the impact of timing and gesture on human-robot interaction kinesics via observed changes in human behaviour in the different conditions.

Note, the overall experiment was conducted with 22 children, however, 4 children were not able to attend all sessions (off school due to illness or other reasons), thus, the detailed analysis as described in the Annex has been performed with 18 children.

3 Future Work

In RobotCub year 4 the work reported in D5.5 will be continued but, instead of solely relying on a wizard-of-oz methodology (controlling the robot remotely), human-robot imitative interaction dynamics will be implemented to run autonomously, within the YARP framework (suitable for the iCub).

4 Appendix

Ben Robins, Kerstin Dautenhahn, René te Boekhorst and Chrystopher L. Nehaniv.(2007) *Behaviour Delay and Robot Expressiveness in Child-Robot Interactions: A User Study on Interaction Kinesics*. Report.

APPENDIX

Behaviour Delay and Robot Expressiveness in Child-Robot Interactions: A User Study on Interaction Kinesics

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Abstract – **This paper presents results of a study where 18 children interacted with a humanoid child-sized robot called KASPAR. Each child took part in six experimental trials involving two games in which the dynamics of interactions played a key part: a body expression imitation game, where the robot imitated expressions demonstrated by the children, and a drumming game where the robot mirrored the children's drumming. In both games KASPAR responded either with or without a delay (2 conditions). Additionally, in the drumming game, KASPAR responded with or without exhibiting facial/gestural expressions. These 6 experimental conditions per child allowed between- and within participant comparisons. Individual case studies as well as statistical analysis of the complete sample are presented. Results highlight individual differences in the children's responses. The statistical analysis of the complete data set showed that a delay of the robot's drumming response lead to larger pauses (with and without robot nonverbal gestural expressions) and longer drumming durations (with nonverbal gestural expressions only). In the imitation game, the robot's delay lead to longer imitation eliciting behaviour with longer pauses for the children. Different possible explanations of these results are discussed.**

I. Introduction

Human-robot interaction (HRI) presents challenges related to, but distinct from, those of human-computer interaction (HCI) and the design of non-autonomous artifacts. In HCI, it has been established that in certain ways people tend to treat computers as they treat other people [1]. With technology that adheres to human social expectations, it is expected that people will find interactions enjoyable, feel empowered and competent [1]. For applications, levels of autonomy and anthropomorphism need to be carefully designed cf. [2-4].

Developmental psychologists have proposed that communication (an integral part of human social interaction) can be divided into a primary, expressive system which has semantic and intentional content but does not take account of the communication partner, and a pragmatic, referential system which can predict, and infer intention in the communication partner; and that two key processes are involved in supporting a transition from primary to pragmatic communication - these are mastering interpersonal timing and shared topic [5]. The importance of rhythm and timing and inter-subjectivity in early communicative interaction of infants with a caregiver, termed *protoconversation*, has been described by Trevarthen [6] in the natural developmental progression of human infants. Turn-taking between adult and infant in these protoconversations are closely coordinated and reach rapid mutual entrainment. Following this view of the importance of timing, rhythms and entrainment in the development of communication, we pursue these as key areas in this research.

The importance of timing, turn-taking, and synchronization dynamics in human-human interaction has long been recognized [7-9] even before the link to development was clearly made, and their potential in sciences of the artificial is increasingly being explored in areas such as interactive robots [10, 11], therapeutic walking devices [12], as well as in evolved artificial social turn-taking agents [13] .

Goldin-Meadow argues that the gestures people produced in their conversations are tightly interwined in its timings and meaning, and that nonverbal gestural components of people's communication which cannot be separated from the content of conversation [14].

Kinesics can be described as the study of the role and timing of nonverbal behaviour, including body movements, in communicative and interactional dynamics. An exploration of its application to studying human robot interaction is presented e.g. in [11].

This paper focuses on the regulation of interaction dynamics during human-robot play, with an emphasis on timing and delays in interaction and the impact of robot facial/gestural expressiveness.

II. The Robotic Platform - KASPAR

KASPAR is a child-sized robot which acts as a platform for HRI studies, using mainly bodily expressions (movements of the hand and arms) and head and facial gestures to interact with a human. The robot has a static body (torso, legs and fingers do not move and were adapted from a child-sized commercially available mannequin doll) with an 8 DOF head and two 3 DOF arms. Important features of KASPAR are minimal design, the inclusion of eyelids, and aesthetic consistency of the face [15, 16].

The overall design rationale of KASPAR's head and face aims to approximate the appearance and movements of a human without trying to create an ultra-realistic appearance, i.e. not trying to imitate every detail of a human face (see Fig. 1 below). An emphasis on the features used for communication allows the robot to present nonverbal feedback clearly by changing orientations of the head, moving the eyes and eyelids, mouth, and moving the arms. Furthermore, a reduction in detail de-personalizes the face and allows the interaction partner to project his/her own ideas on it and make it, at least partially, what they want it to be. This design rationale has partly been inspired by

Scott McCloud's work on comic design, cf. discussions in [15, 16].

These are potentially desirable features for a robot to be used in different HRI scenarios, e.g. when used in assistive technology with different user groups, such as people with autism, who have great difficulties in recognizing facial expressions.

Fig. 1. KASPAR's minimally expressive face.

Initial observations of interactions of people with KASPAR indicate that subtle change in expression coupled with subtle gestures is already evocative of various interpretations for particular expressions. Several of KASPAR's existing expressions differ from each other by a minimal change in the mouth (see Fig. 1). Together with small changes in the tilt of the head and the direction of the eyes already creates recognizable expressions (see Fig. 2).

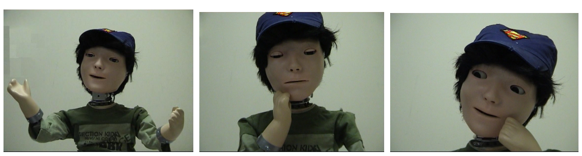

Fig. 2. Ending postures of three dynamic expressions of KASPAR used in the current work (including facial expressions and gestures).

Initial observations of children engaging in an imitation game with KASPAR (whereby KASPAR imitated the children), showed that the children's expressions were much more pronounced than the robot's. This suggests that the children already recognize KASPAR's minimally expressive movement as a salient expression and are 'filling the gap', i.e. producing fully pronounced expressions in return (see Fig. 3).

Fig. 3 .Children's pronounced expressions during playing of an imitation game with KASPAR

III. THE PRESENT STUDY

Exploring the Space of Robot-Child Interaction Kinesics

In this study, we follow Ogden et al.'s characterization of interaction as *a reciprocal activity in which the actions of each agent influence the actions of the other agents engaged in the same activities, resulting in a mutually constructed pattern of complimentary behaviour* [17].

As mentioned above, kinesics is described as the study of the role and timing of nonverbal behaviour, including body movements, in communicative and interactional dynamics. Traditionally kinesics has focused on human-human interaction in anthropological and psychological studies. We know that in human-human interaction there are subtle adjustments and synchronizations of timing of movement which take place throughout the interaction and of which we are often unaware, cf. [7,8]. Nodding, movements of the hands, coordinated rhythmic movements and timing of our speech, and mirroring, all are subtly used to regulate human-human interaction. Timing and rhythms in speech are significantly different from culture to culture and can lead to significant difficulties in human interaction [9]. This suggests that interacting with a robot which has no sense of time and does not follow or engage in human timing will also lead to difficulties as it may be uncomfortable and unnatural [11]. The present study is adopting a wider view of kinesics to include the role and timing of nonverbal behaviour in *human-robot* interactions.

A. The research questions

In the context of the above issues, we formulated the following research questions in order to better understand the space of possible human-robot interaction kinesics, focusing on the effect of aspects of timing and gestures on interactions with children:

1) In what way and to what extent does the robot's nonverbal expressiveness affect the timing of children interacting with the robot?

2) Does the introduction of a short delay in the robot's response (similar to the natural pauses occurring during turn-taking in human conversation) influence the timing and synchronization of robot-child interaction?

B. The interaction design

To study questions we investigate aspects of timing, synchronization and responsiveness of children playing social interaction games with the robot. We devised two games for the children to play:

a) *Drumming Call & Response Game* with the child sitting opposite the robot and drumming on a tambourine some definite rhythmic phrases chosen by the child, after each phrase the child stopped and waited for the robot to drum a similar phrase in response, on an identical tambourine that was placed on the robot's lap.

b) *Gesture Imitation Game* where the children, knowing the robot's repertoire of the expressive gestures and movements, would initiate one of these gesture or movement for the robot to imitate. The robot's repertoire included the three dynamic behavioural expressions illustrated in Fig. 2, complemented by a 'goodbye' hand wave, and also mechanical up/down arm movements.

C. Set-up of the trials

The trials took place in Bentfield Primary School in Essex, UK. This is a mainstream school with approximately 220 typically developing pupils. Twenty-two children from year 3 and year 5 were randomly chosen by the school's headmaster to participate in this study. The trials were conducted in a room familiar to the children, often used for various other activities. The room was approximately 3m x 3m, with a carpeted floor and had one main door and a window overlooking the main hall. The robot was connected to a laptop and placed on a table against the back wall. Two stationary video cameras were placed in the room: one at the side near the wall pointing to the front of the robot, capturing the children when interacting with the robot, the other was placed behind the robot to try and capture the behavioural and facial expressions of the children during these interactions.

The robot had been programmed to operate as a puppet, whereby the investigator as the puppeteer controls all the robot's movements and expressions, releasing them by a simple press of buttons on his laptop (this approach is a variant of the Wizard-of-Oz technique used in human-computer interaction (HCI) and more recently in human-robot interaction (HRI) research, e.g. [18, 19]). Although the investigator was sitting near-by, his control of the robot was hidden from the children.

All the children first participated together as a group in a familiarization session prior to the commencement of the trials. In this session they were introduced to the robot and were shown the robot's range of movements postures/gestures and given free time to express their thoughts and to ask the experimenter any questions about the robot. Once the study begun, the children attended the experimental trials individually.

Each child participated in two sets of experiments: one playing the imitation game, and one playing the call & response drumming game. In total, each child took part in six separate experimentally conditioned trials of approximately two minutes each, over two different days.

D. Procedures of Trials

The Call & Response Drumming Game:

The child, sitting opposite the robot (see Fig. 4), initiated the drumming of a short phrase, and waited for the robot to respond with an identical phrase, before drumming a new phrase. Each set of experimental trials ran twice (on separate occasions) with randomized order of presentation, once where there was no delay in the robot's response and once where the robot was programmed with a delay of two seconds before executing any behaviour. Note, two seconds is a short delay that may naturally occur in interaction. Due to our WoZ methodology, 'no delay' meant that the experimenter triggered the robot's behaviour as fast as possible, i.e. as soon as he perceived that the child had stopped drumming. In addition, we monitored the effect of the robot's gestures and expressions on the child's interaction so the above two conditioins (with and without delay) were repeated in two variants - one where the robot had exhibited nonverbal head/face expressions while drumming (nodding with the head, and eye blinking) and one when it had no such expressions (a 2x2 experimental design with a total of 4 drumming experiments for each child).

Fig. 4. A child playing a drumming call and response game with KASPAR.

The Imitation Game:

Here the child, standing opposite the robot, produced a movement or a gesture (selected from the robot's range of gestures previously seen by the child) and waited for the robot to imitate, before moving to a new posture (see Fig. 3 above). Two conditions were tested in this game, one where the robot imitated the child straight away, i.e. as soon as the child moved to a new position the robot immediately started to move to a similar position. The second condition introduced a short delay (2 seconds) in the robot's response, as in the drumming game.

The children participated in the six experimental conditions (4 for the drumming game and 2 for the imitation game) in two sets on two separate days when they were exposed to either set 1 or set 2 respectively. Half of the children did first set 1 first and then set 2, the other half did set 2 on the first visit and set 1 on the second visit. The two experimental sets are:

Set 1:
a. A drumming game: robot with no delay, no nonverbal gestural expressions
b. An imitation game: robot with no delay
c. A drumming game: robot with no delay, with nonverbal expression

Set 2:
a. A drumming game: robot with delay, no nonverbal expressions
b. An imitation game: robot with delay
c. A drumming game: robot with delay, with nonverbal expressions

IV. Data Collection and Analysis

As stated above, in order to better understand the space of possible human-robot interaction kinesics, we focused on the effect of the aspects of timing and gestures on interactions of the children with the robot as follows:

a) In the *call & response drumming* game, we measured the effect of the robot's delayed response, on two variables: (1) the duration of the pause of the child from the moment the robot finishes drumming the previous phrase to the moment the child starts drumming a new phrase, and (2) the duration of each of the child's drumming phrases.

b) In the *imitation* game, we measured (1) the duration of the pause from the moment the robot became still as it reached its new posture/gesture, to the moment the child started to move to a new posture, and (2) the duration of each of the child's imitation eliciting bouts.

As mentioned above, 18 children participated in the study, each playing 4 call & response drumming games and 2 imitation games with the robot. This resulted in the recording of 108 experiments averaging 2 minutes duration each which resulted in a corpus of 12960 seconds (or 3.6 hours) of recorded video data. As the time scale of pauses, drumming phrases, and imitation phrases is very small (e.g. a pause duration between drumming phrases could be as short as 0.15 seconds in some cases) in order to notate the variables accurately, each experiment had to be analysed on a 10^{th} of a second basis, often moving through the video recording repeatly and frame by frame. During initial analysis, it was noticed that in some cases children are responding differently to the robot's delay, and to its facial expression. It was therefore decided to conduct two kind of analysis. Firstly, a statistical analysis was performed including all 18 participants in order to investigate whether there is overall significant effect of facial/gestural expressions and/or delay in the robot response, on the pauses, drumming, and imitation durations for the children. Secondly, in order to show examples of different traits in the interaction dynamics, examples of the behaviour of specific children are shown (the children were selected as 'typical' representatives of the overall sample), and the effect of the delayed response and the facial/gestural expression of the robot on these children was analysed in detail. The following sections analyse the drumming game (A) and the imitation game (B) in more detail, using these two kinds of analysis.

A. ***Analysis of the Drumming game****- the effect of delayed robot's response on the children's interaction dynamics during the drumming game*

The following sections present results from two children (i and ii) and 5 children (iii) in order to highlight particular observed effects in detail. Section iv covers the whole sample of 18 children. Statistical analysis of the data is used in sections iii and iv.

<u>*i. Effect on duration of the drumming phrases:*</u>

For some children, the introduction of a short delay in the robot's response (similar to the natural pauses occurring during turn-taking in human-human conversation) regulated and enhanced the interaction by increasing the duration of the children's drumming phrases, and the duration of the pauses which preceded these phrases. This is exemplified in the behaviour of children GE and AR which this section focuses on.

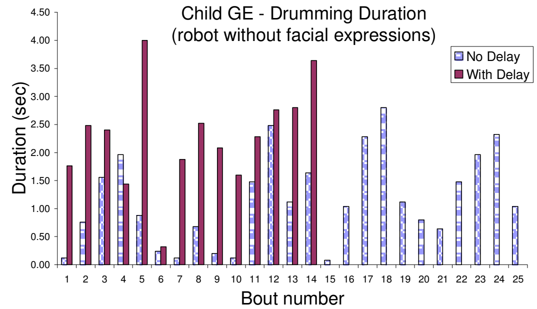

Fig. 5. The duration of drumming phrases produced by GE.

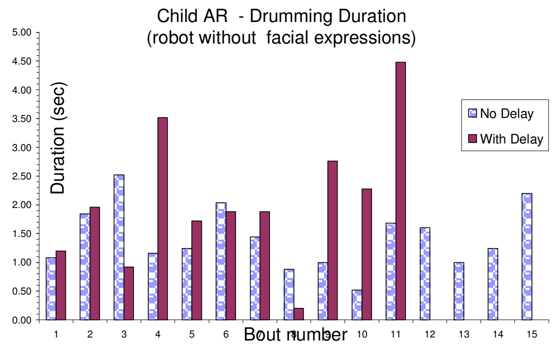

Fig. 6. The duration of drumming phrases produced by AR.

The effect of the delayed robot's response on the duration of the children's drumming phrases is more pronounced when combined with the robot's facial/gestural expressions (nodding of the head and eye blinks) as can be seen in Figures 5-8. The figures show that for both children, combination of facial/gestural expressions and delayed response in the robot, produced longer duration of drumming phrases by the children.

<u>*ii. Effect on duration of the pauses which preceded the drumming:*</u>

Figures 9 and 10 below show the effect of the introduction of a short delay to the robot's response on the duration of the pauses that the children took prior to their drumming initiatives. We can see that for the same children (GE and AR) the introduction of delayed responses in the robot's actions had a similar effect, e.g. increased the duration of their pauses.

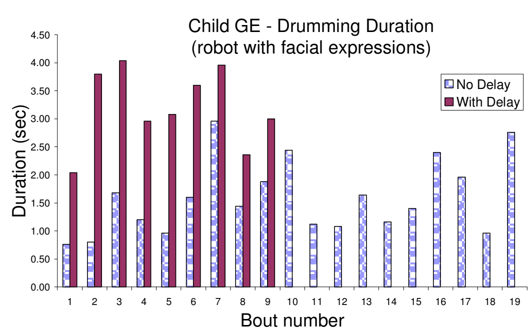

Fig. 7. The duration of drumming phrases produced by GE when the robot showed facial/gestural expressions.

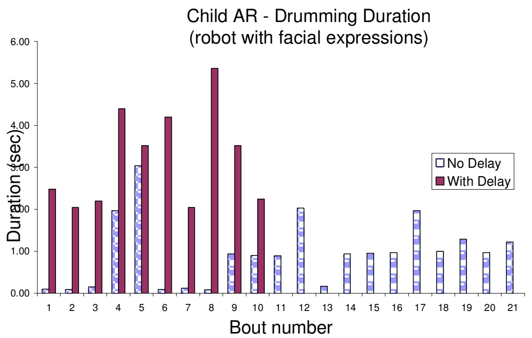

Fig. 8. The duration of drumming phrases produced by AR when the robot showed facial/gestural expressions.

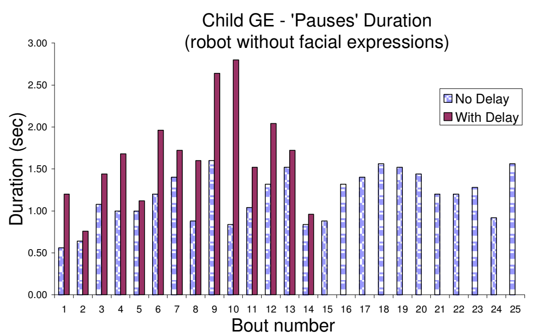

Fig. 9. The duration of pauses produced by GE prior to his drumming.

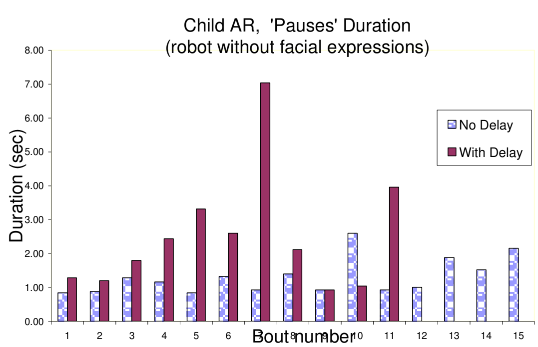

Fig. 10. The duration of pauses produced by AR prior to his drumming.

The delayed robot's response had a similar effect (if slightly more pronounced) on the duration of the children's pauses also when combined with robot's facial/gestural expressions (nodding of the head and eye blinks) as can be seen in Figures 11and 12 below:

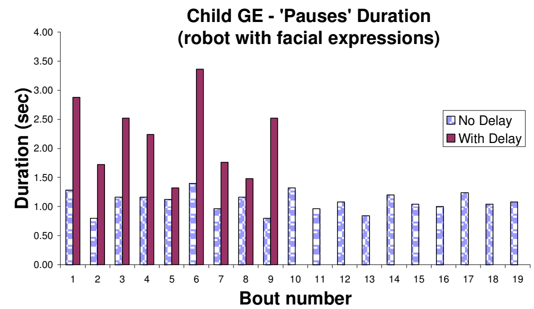

Fig. 11. The duration of pauses taken by GE prior to drumming, when the robot showed facial/gestural expressions.

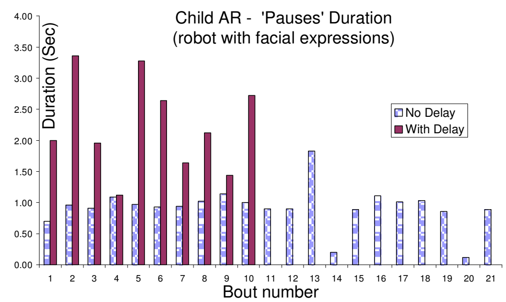

Fig. 12. The duration of pauses taken by AR prior to drumming, when the robot showed facial/gestural expressions.

iii. Statistical analysis of the effects of delayed response and facial/gestural expression during the drumming game

For five children, two boys (AR, GE) and three girls (DA, AI and CH), the effect of the delayed response and the facial/gestural expression was analysed in detail. We hypothesized that possible effects of the robot's timing of behaviour (whether or not it responded by a delay) and outward dynamic appearance (whether or not it showed facial/gestural expressions) on the timing of the children's behaviour would be visible as:

a) temporal dependency of the pause and drumming bouts of the children;
b) correlations between the duration of drumming bouts and the preceding pauses of the children
c) differences in duration of both pause and drumming bouts between the combined conditions of delay/no delay and facial-gestural expression/no expression

Temporal dependency was investigated by calculating the autocorrelations (up to N - 4 lags, where N is the number of bouts) for the pause and drumming durations of each child. Correlations between the durations of drumming and preceding pause were computed as Kendall rank correlation coefficients. To test for the effects of the variables Delay (ND = no delay, DE = delay) and facial/gestural expression (NE = no expression, EX = expression) we applied two factor Analysis of Variance

(ANOVA) when the requirements were met by the data. These include homogeneity of variance (tested by Cochran's test and Levene's test), normal distribution of the error (verified by inspection of normal probability plots) and the absence of correlation between standard deviation and mean of the samples. In case these assumptions did not hold, differences in duration between conditions were tested by means of non-parametric procedures (Mann-Whitney U tests).

The results showed conspicuous differences between the children. Whereas the data from GE indicated clear temporal dependency (significant correlations between the durations of subsequent bouts), significant autocorrelations were rare in the other children. Correlations between the duration of pauses and the following drumming bouts hardly occurred.

For the duration of pause, no significant effects of facial/gestural expression were found. However, delay had a positive effect on the duration of pause irrespective of facial/gestural expression in AR and DA. It also increased pause duration in GE, but only when the robot did not show a facial/gestural expression.

Drumming was clearly more strongly influenced by the behaviour of the robot. In all children but DA, delay by the robot increased drumming duration. In three of them this was the case irrespective of the facial/gestural expression of the robot, but in AR this effect was only significant in combination with facial/gestural expression.

Facial/gestural expression had an impact on the drumming bout lengths of GE, AR and DA. In GE only when the robot responded with a delay and in DA irrespective of delay. The case of AR is interesting in that facial/gestural expression increased drumming duration when the robot delayed but had a negative impact when the robot responded directly.

To sum up, from this small sample it appears that delay of the robot's behaviour has an effect, in particular on the duration of drumming.

This impression is supported by a statistical comparison of the mean durations of pause- and drumming bouts of each child. These means and the matching standard errors are provided in Table I below.

Table I. Statistics for the experimental conditions (ND = No Delay, DE = Delay, NE = No Expression, E = with Expression). Mean is the average of the means of each of the five subjects.

PAUSE

RESPONSE	EXPRESSION	Mean	Standard Error	Confidence -95%	Limits 95%	N
NE	NE	1.288	0.127	0.935	1.640	5
NE	NE	1.310	0.175	0.825	1.795	5
EX	EX	1.932	0.178	1.439	2.425	5
EX	EX	1.938	0.177	1.447	2.429	5

DRUMMING

RESPONSE	EXPRESSION	Mean	Standard Error	Confidence Limits -95%	+95%	N
ND	NE	1.266	0.16	0.821	1.711	5
ND	NE	1.372	0.226	0.745	1.999	5
DE	EX	1.788	0.201	1.231	2.345	5
DE	EX	2.426	0.357	1.435	3.417	5

A repeated measurements ANOVA on the mean values of each child revealed a significant effect of Delay on pause duration (F = 7.874, p =0.04857). Drumming durations are significantly prolonged by both Delay (F = 8.03, p = 0.047) and Expression (F = 17.665, p = 0.014) (Fig. 13).

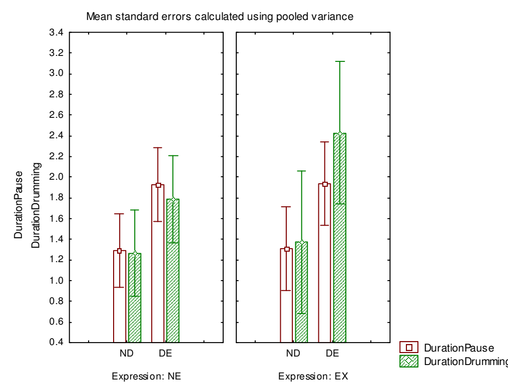

Fig. 13. Mean values and standard errors of Pause and Drumming duration under four experimental conditions of Delay and Expression.

iv. The overall effect of the delayed response and the facial/gestural expression on all 18 children:

For 18 children the effect of the delayed response and the facial/gestural expression was analysed. We hypothesized that possible effects of the robot's behaviour (whether or not it responded with a delay) and outward appearance (whether or not it showed facial/gestural expressions) on the timing of the children's behaviour would be visible as differences in duration of both pause and drumming bouts between the combined conditions of delay/no delay and facial/gestural expression/no facial expression..

To test for the effects of the variables Delay (ND = no delay, DE = delay) and facial/gestural expression (NE = no expression, EX = expression) we applied two factor Analysis of Variance (ANOVA) (repeated measurement design). The data analysed are the durations of pause and drumming bouts, averaged over the runs for each child. Therefore, four values (EX-ND, EX-DE, NE-ND and NE-DE) are compared within each subject. Before carrying out the ANOVA, we checked the correctness of the underlying assumptions. These include homogeneity of variance (tested by Cochran's test and Levene's test), normal distribution of the error (verified by inspection of normal probability plots) and the absence of a correlation between standard deviation and mean of the samples. The assumptions were met by the pause durations after logarithmic transformation. However, log transformation could not reduce the correlation between mean and standard deviation of the drumming durations and these data were therefore analysed by means of non-parametric procedures (Wilcoxon Matched Pairs Signed Rank Test).

For the duration of pause, no significant effects of facial/gestural expression were found. However, delay had a positive effect on the duration of pause (F = 14.66, df = 1, 17, p = 0.001), but this depended on the presence of facial/gestural expression (F = 4.59, df = 1, 17, p = 0.047); the effect of delay was especially strong when the robot did not show a facial/gestural expression (Figure 14, Table II)

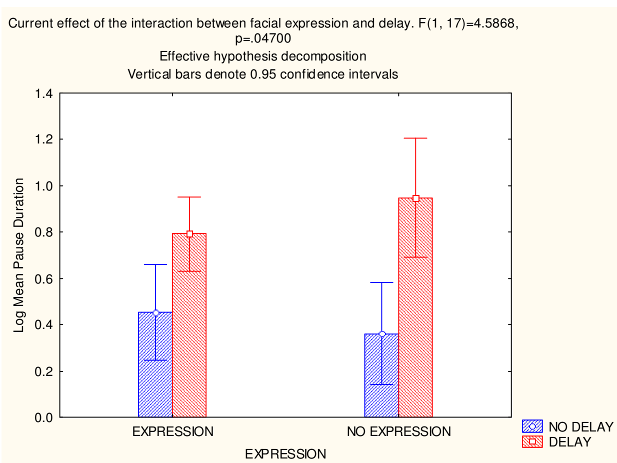

Fig.14. Effect of the interaction between facial/gestural expression and delay.

Delay by the robot also increased the average drumming duration in the children, but in this case the effect was significant only when the robot did exhibit facial/gestural expression (Wilcoxon Matched Pairs Signed Rank Test, T = 29, Z = 2.46, N = 18, p = 0.014).

Test Condition	*Mean*	*Standard deviation*	*N*
EX, ND	1.745	1.091	18
EX, DE	2.327	0.842	18
NE, ND	1.572	0.711	18
NE, DE	3.075	2.690	18

Test Condition	*Mean*	*Standard deviation*	*N*
EX, ND	1.766	1.255	18
EX, DE	2.361	0.989	18
NE, ND	1.845	1.361	18
NE, DE	2.214	1.121	18

Table II. Statistics of the durations of pause (above) and drumming (below)

B ***Analysis of the Imitation game -*** *the effect of delayed robot's response on the children's interaction dynamics during the imitation game*

The introduction of delay in the robot's response during the imitation game had different effects on different children. Fig. 15 shows that the introduction of the delay had somewhat a regulatory effect on DY's actions by shortening the pauses.

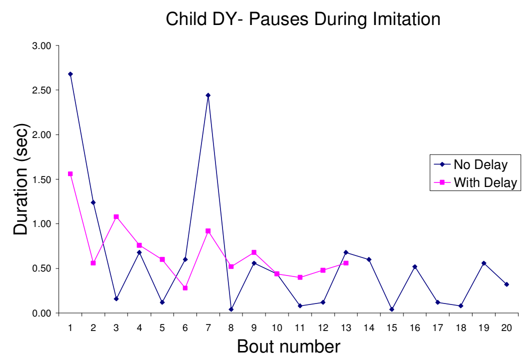

Fig. 15. The duration of pauses taken by DY during the imitation game.

In Fig. 16 below we can see how the introduction of delay in the robot's response resulted in longer pauses being taken by another child CL5.

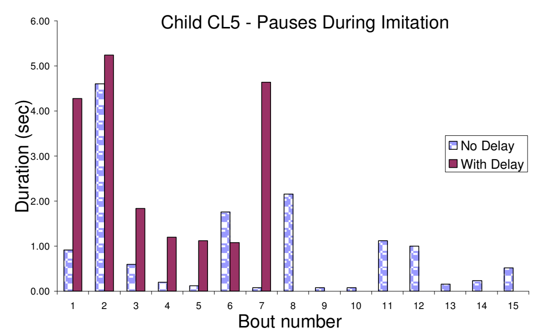

Fig. 16. The duration of pauses taken by CL5 during the imitation game.

For some children, the robot's delayed response had the opposite effect. To the experimenter, it appeared almost as if they 'couldn't wait for their turn', which shortened the pause before they initiated their next drumming bout. An example can be seen in Fig. 17 below.

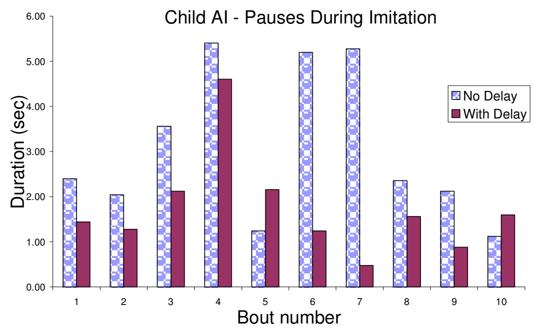

Fig. 17. The duration of pauses taken by AI during the imitation game are shortened when the robot delays its responses.

i. Statistical analysis of the effects of delayed response and facial/gestural expression during the drumming game

For the analysis of the imitation game data, with two experimental conditions (delay and no delay in KASPAR's responses), we focused the analysis on the durations of the child's imitation behaviour, as well as the duration of pause (from the moment the robot became still as it reached its new posture/gesture). Note, in the imitation game, KASPAR showed facial/gestural expressions throughout the experiment. Since there is only one factor with two levels (delay vs no delay) measured within the same subject, the statistical test chosen was Wilcoxon's Matched Pair Signed Rank Test.
The mean durations for children's Pause and Imitation eliciting behaviour are tabulated below (Table III).

Test Condition	*Mean*	*Standard deviation*	*N*
PAUSE, ND	3.090	2.809	17
PAUSE, DE	3.391	1.967	17
IMITATION, ND	0.944	0.274	17
IMITATION, DE	1.164	0.431	17

Table III Statistics of the durations of pause and imitation behaviour. Note, due to a corrupted video clip for one of the
imitation experiments N is 17 in this case.

We found a statistical effect only in the case of imitation eliciting behaviour, which was significantly prolonged by delay (T =35, Z = 1.965, p = 0.05, N = 17) (see Figure 18).

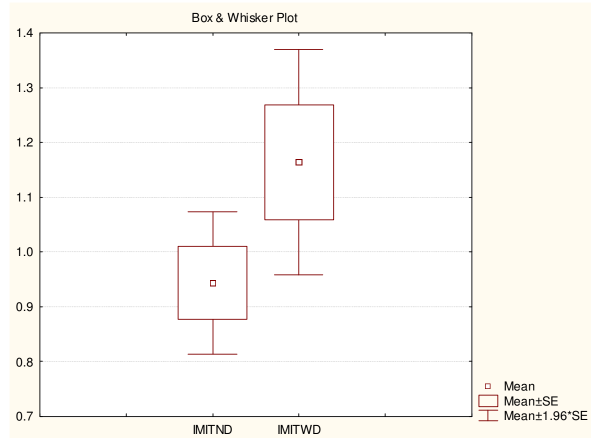

Fig. 18. Comparison of the duration of imitation eliciting behaviour between the conditions delay (IMITWD) and no delay (IMITND).

V. Summary of Results

This article presented results from an interaction study involving 18 children playing dynamic games with a humanoid robot.

A number of results emerged from the analysis of the drumming game:

- A detailed analysis of the responses of two children showed the impact of a short delay on the child-robot interaction kinesics: the duration of the children's drumming phrases and the duration of the pauses which preceded the phrases were increased compared to the no-delay experimental condition. Moreover, the combination of facial/gestural expressions and delayed robot responses produced longer durations in the children's drumming phrases and longer pauses.
- A detailed analysis of five children regarding several features relevant to interaction kinesics revealed strong individual differences between the children regarding significant correlations between the durations of subsequent bouts, and showed overall that the delay of the robot's behaviour had an effect on the children's behaviour, in particularly on the duration of drumming.
- With respect to the overall sample and the effect of the robot's delayed response and facial/gestural expression on the children's behaviour, no significant effects of facial/gestural expression were found. However, delay had a positive effect on the duration of pause. The effect was particularly strong (longer pauses) when the robot did not exhibit facial/gestural expression. Delay in the robot's response also increased the children's average drumming duration, but in this case the effect was significant only when the robot did exhibited facial/gestural expression.

The analysis of the imitation game data yielded the following results:

- A detailed analysis of three individual children again highlighted individual differences in the children's response whereby the introduction of delay in the robot's response had different systematic effects on different children; while for some children the delay shortened the pauses, for others it increased the pauses.
- A statistical analysis of the whole sample found one statistical effect whereby the children's elecitnig imitation behaviour was significantly prolonged by the delay in the robot's responses.

VI. CONCLUSION

Results highlight the role of the dynamics of interaction in general, and, more specifically, how delay and facial/gestural expressiveness in interactional responses influence child-robot interactions. Statistically significant results are accompanied by interesting observations from data of particular children or sub-groups of children. Methodologically, the latter highlight the need for a variety of different approaches to child-robot (or more generally speaking human-robot) behaviour analysis, including case studies and the analysis of small groups, as well as the statistical analysis of larger data sets. Together, these methods can provide a rich picture of human-robot interaction experience.

The statistical analysis of the data set with 18 children showed that a delay of the robot's drumming response lead to larger pauses (with and without robot facial/gestural expressions) and longer drumming durations (for facial expressions only). In the imitation game, the robot's delay lead to longer imitation behaviour with longer pauses for the children. *How may one explain these effects?*

Generally, how may a robot's change in timing (in this case delay) and facial/gestural expressiveness change the child's behaviour? Several possibilities can be considered:

a) Facial/gestural expressiveness is a 'natural' feature of human-human interaction that benefits communication, mutual understanding, and sustains social relationships (for a population of typically developing children, the situation is different for e.g. children with autism, cf. [20]). We thus hypothesize that a robot's facial/gestural expressiveness may increase the child's involvement in the game by prolonging the children's responses towards the robot and decreasing the children's reactions times. The results of this study do not support this explanation: effects for facial/gestural expressiveness are only found in co-occurence with robot delay, and show an increase in the duration of the pauses. Further studies into robot facial/gestural expressiveness in interaction need to clarify these issues.

b) Human-human communication is very sensitive to changes in timing (cf. how delays in oversea phone calls can disrupt effective communication). Different responses of the children may occur depending on their interpretation of the robot's delayed responses. These include:

1) Children may interpret the delay as the robot's 'lack of interest' in the game. Children then respond by either i) responding with increased involvement and thus attempting to re-engage the robot via faster responses (shorter pauses) and prolonged responses. There is no strong support for this explanation since all detected effects for the whole sample size show an increase in the duration of children's behaviour and pauses. Only for individual children can we find a decrease in pause duration. Further studies including in depth analysis of interaction studies with individual children need to clarify these issues. Alternatively, ii) the children may loose interest themselves and either discontinue the interaction or show decreased involvement with shorter durations of behaviour and longer pauses. There is no support for this hypothesis either since all results point towards an increase in the imitation and drumming behaviour as a response to robot delay.

2) Children may interpret the robot's delay as 'the interaction partner's limited ability' to respond. In this situation the children may either i) not change their responses (compared to the non-delay condition), or ii) will try to mirror the robot's behaviour (delayed responses) by delaying their own responses (increase in pause and / or behaviour duration). The results thus far are most consistent with this explanation.

Future work is required in order to provide a fuller picture on our understanding of the role of timing, delays, and facial/gestural expressiveness in child-robot interaction. This study has provided encouraging results that need to be built upon in future interaction studies. Personality traits of the children may have an impact on their behaviour, as has been shown previously in studies on adult participants' preferences regarding robot behavior and appearance (e.g. [21]). Including such data in the analysis may illuminate some of the issues.

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