

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

Ben Robins, Kerstin Dautenhahn, René te Boekhorst, Chrystopher L. Nehaniv
Adaptive Systems Research Group, School of Computer Science, University of Hertfordshire
College Lane, Hatfield
Hertfordshire, UK
+44 1707 284 333

{b.robins, k.dautenhahn, c.l.nehaniv, r.teboekhorst}@herts.ac.uk

ABSTRACT

This paper presents results of a novel study on interaction kinesics where 18 children interacted with a humanoid child-sized robot called KASPAR. Based on findings in psychology and social sciences we propose the temporal behaviour matching hypothesis which predicts that children will adapt to and match the robot's temporal behaviour. 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. Additionally, in the drumming game, KASPAR responded with or without exhibiting facial/gestural expressions. Individual case studies as well as statistical analysis of the complete sample are presented. Results show 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, but systematic individual differences are observed in regards to the effects on the children's pauses. Results are generally consistent with the temporal behaviour matching hypothesis, i.e. children adapted the timing of their behaviour, e.g. by mirroring to the robot's temporal behaviour.

Categories and Subject Descriptors

H. Information systems; H.0 General

General Terms

Experimentation

Keywords

human-robot interaction, humanoid, interaction kinesics.

1. 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 conversation are tightly intertwined in its timings and meaning, and that nonverbal gestural components of people's communication cannot be separated from the content of conversation [14]. According to Bernieri and Rosenthal "[i]nterpersonal coordination is present in nearly all aspects of our social lives, helping us to negotiate our daily face-to-face encounters...We also coordinate our nonverbal behavior with

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others to communicate that we are listening to them and want to hear more” ([15] p. 401). In this context, interpersonal coordination is loosely defined as "...the degree to which the behaviors in an interaction are nonrandom, patterned, or synchronized in both timing and form." ([15] p. 403).

Within the wider context of interpersonal coordination, in our work we focus on kinesics which can be described as the study of the role and timing of nonverbal behaviour, including body movements, in communicative and interactional dynamics. Surprisingly, interaction kinesics in human-robot interaction is a relatively unexplored area of research. With few exceptions, only few studies focus on experimental investigation of this important topic. For example, Yoshikawa et al. highlight the role of responsive gaze in human-humanoid interaction [16]. Yamamoto and Watanabe found differences in people’s preferences concerning the timing of utterances in human-robot greeting interactions [17]. Robins et al. explored interaction kinesics in child-robot interaction in a play context involving a robotic dog [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. This work is part of a European project studying robot cognitive development.

2. 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 [18, 19]. 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). 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 narrative art design and by Japanese Noh masks, cf. discussions in [18, 19].

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, dynamic movement already creates recognizable expressions (see Fig. 2). 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 salient expression and are ‘filling the gap’, i.e. producing fully pronounced expressions in return (see Fig. 3).



Fig. 1. KASPAR’s minimally expressive face.



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



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

3. THE PRESENT STUDY

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* [20].

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.

3.1 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 facial/gestural expressions on interactions with children. Specifically, we study the following research questions:

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

Based on our earlier review of interpersonal timing and interaction kinesics we hypothesize that *children will adapt to and match the robot's temporal behaviour*. According to this suggested *temporal behaviour matching hypothesis* we make the following predictions:

Children will respond to the robot's delay with a change in the timing in interaction games (Hypothesis 1). (In the games described here, this would correspond to change in timing of the next posture/drumming bouts –see Sec. 4 below.) This change may affect the onset, pauses in, and/or duration of the children's behaviour.

Since non-verbal cues are natural signals in human-human interaction we expect to see significant differences between the expression/no-expression conditions (Hypothesis 2).

3.2 The interaction design

To study the above research 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 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 gestures or movements 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.

3.3 Participants and location

The trials took place in Bentfield Primary School in Essex, UK. 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 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.

3.4 Experimental procedures

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 (WoZ) technique used in human-computer interaction (HCI) and more recently in human-robot interaction (HRI) research, e.g. [21, 22]). 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 experimental trials of approximately two minutes each, over two different days.

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. 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. (The response time of the experimenter can be considered negligible compared to the robot's two-second delay.) In addition, we monitored the effect of the robot's gestures and expressions on the child's interaction so the above two conditions (with and without delay) were repeated in two variants - one where the robot 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.

4. DATA COLLECTION, ANALYSIS, AND RESULTS

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 10th of a second basis, often moving through the video recording repeatedly and frame by frame. During initial analysis, it was noticed that in some cases individual children are responding differently to the robot’s delay, and to its facial/gestural expression. In addition to the statistical analysis of the whole sample of 18 children we thus also present individual data from several specific children (the children were selected as ‘typical’ representatives of the overall sample). The following sections analyse the drumming game (4.1) and the imitation game (4.2) in more detail.

4.1 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 for duration of drumming phrases (i) and pauses (ii) to illustrate the data, while (iii) covers the statistical analysis of the whole sample of 18 children.

i. Effect on duration of the drumming phrases: For some children, the introduction of a short delay in the robot’s response 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. 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 Figure 5. The figure shows that for both children, combination of facial/gestural expressions and

delayed response in the robot, produced longer duration of drumming phrases by the children.

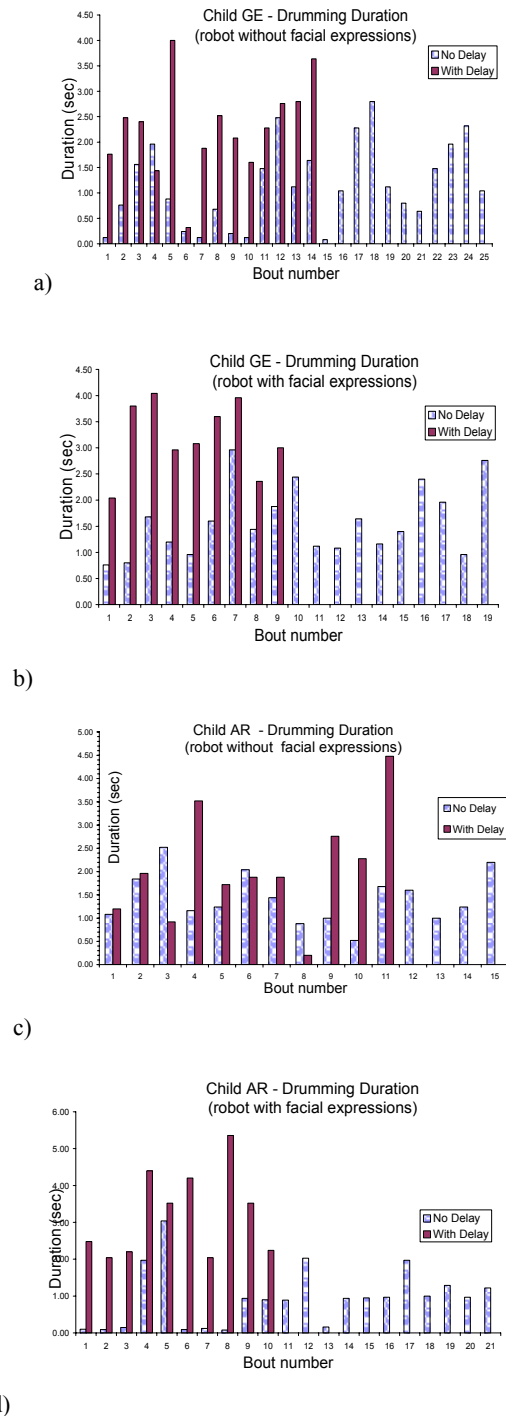
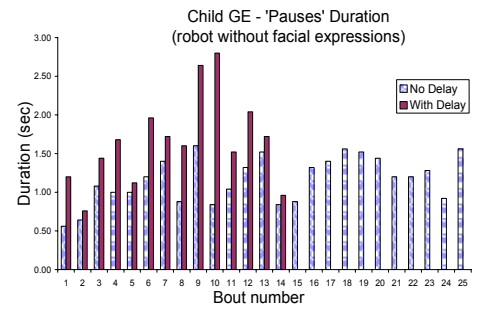
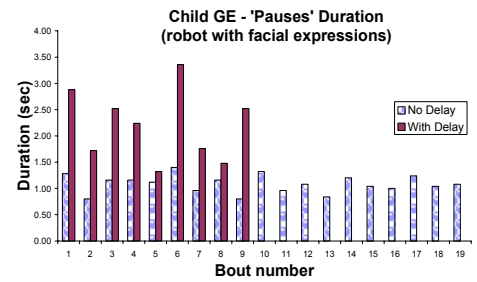


Fig. 5. The duration of drumming phrases produced by GE (a,b) and AR (c,d) in the call and response drumming game when the robot exhibited no facial/gestural expressions (a,c) and when the robot exhibit facial/gestural expressions (b,d).

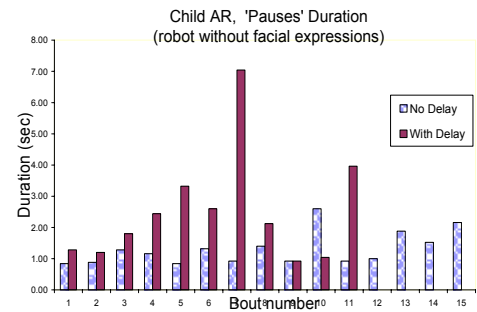
ii. *Effect on duration of the pauses:* Figure 6 shows the effect of the introduction of a short delay to the robot's response on the duration of the pauses that the children took before starting a new drumming phrase. We can see that for the same children (GE and AR) the introduction of delayed responses in the robot's actions had a similar effect, e.g. increased the duration of pauses.



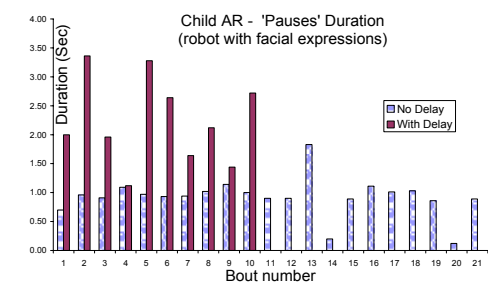
a)



b)



c)



d)

Fig. 6. The duration of pauses produced by GE (a,b) and AR (c,d) prior to his drumming in the call and response drumming game when the robot exhibited no facial/gestural expressions (a,c) and when the robot exhibited facial/gestural expressions (b,d).

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 also be seen in Figure 6.

iii. *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.

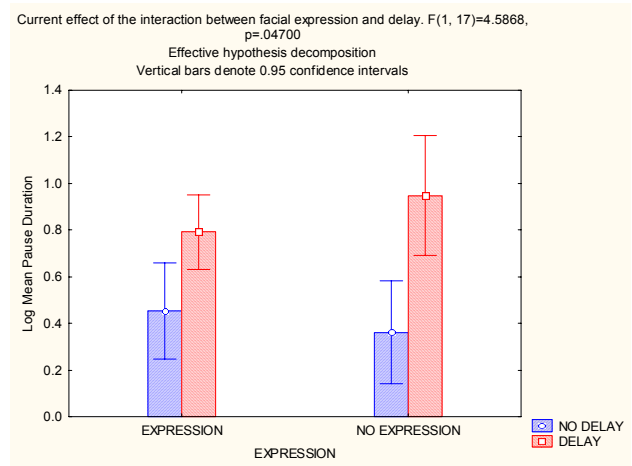


Fig. 7. Effects on children's pause duration of facial/gestural expression and delay.

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 7, Table I top)

Table I. Statistics of the durations of pause (top) and drumming duration (bottom).

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

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, $T = 29$, $Z = 2.46$, $N = 18$, $p = 0.014$), cf. Table I (bottom).

4.2 Analysis of the Imitation game – the effect of delayed robot’s response on the children’s interaction dynamics during the imitation game. Section (i) presents results for 3 children in order to highlight particular observed individual differences in systematic styles of adaptation, while (ii) presents statistical analysis of the whole sample.

i. Individual differences in adaptation to delay. The introduction of delay in the robot’s response during the imitation game had different effects on different children. Fig. 8 shows that the introduction of the delay had somewhat a regulatory effect on DY’s actions by shortening the pauses.

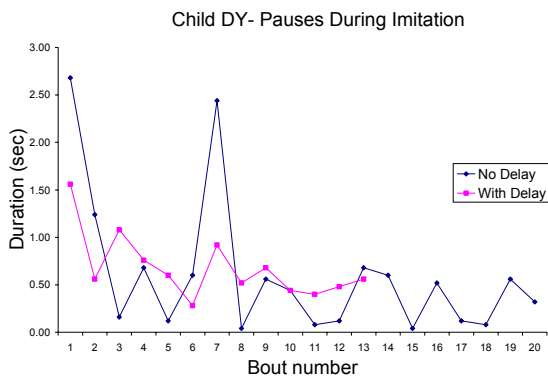


Fig. 8. The duration of pauses taken by DY during the imitation game.

In Fig. 9 we can see how the introduction of delay in the robot’s response resulted in longer pauses being taken by another child CL5.

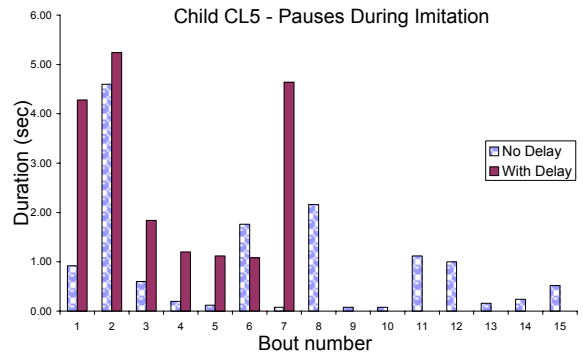


Fig. 9. The duration of pauses taken by CL5 during the imitation game.

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. Another example can be seen in Fig. 10.

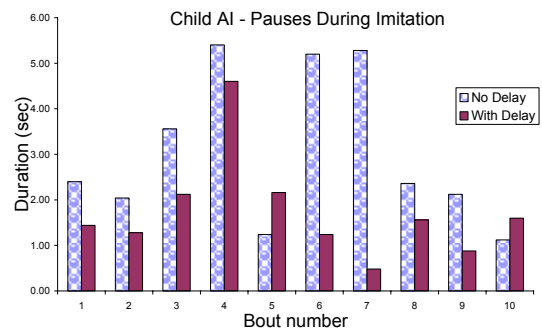


Fig. 10. The duration of AI’s pauses during the imitation game are shortened when the robot delays its responses.

ii. 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 II).

Table II 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

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

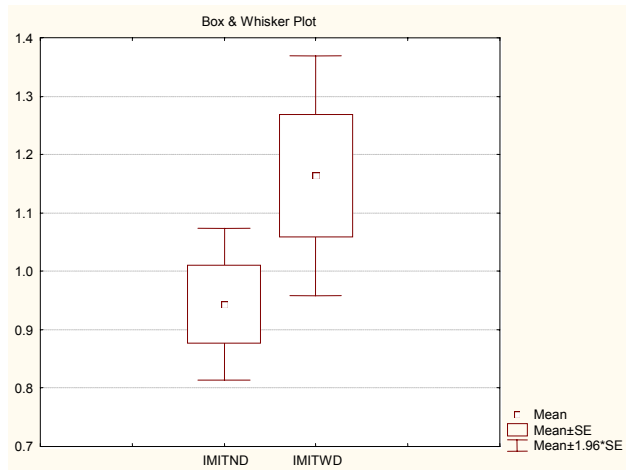


Fig. 11. Comparison of the duration of imitation eliciting behaviour between the conditions delay (IMITWD) and no delay (IMITND).

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 11).

5. 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:

(1) 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.

(2) 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 in both conditions (with and without facial/gestural conditions). 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 exhibit facial/gestural expression.

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

(1) 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.

(2) A statistical analysis of the whole sample found one statistical effect whereby the children’s eliciting imitation behaviour was significantly prolonged by the delay in the robot’s responses.

6. 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 individual data of particular 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 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 the following results:

- R1: In the drumming game, a delay of the robot’s drumming response lead to larger pauses, i.e. children delayed the onset of their next drumming bout. This result supports Hypothesis 1. Further studies need to investigate why this effect was particularly strong in the condition not using facial/gestural expressions.
- R2: In the drumming game, a delay of the robot’s drumming response lead to longer drumming durations (only in the condition where the robot showed facial expressions). This result supports Hypothesis 1.
- R3: In the imitation game, the robot’s delay lead to longer durations of eliciting imitation behaviour. This result supports Hypothesis 1.
- R4: Overall the results do not show clear differences between conditions using robot facial/gestural expressions or not using them. This result does not support Hypothesis 2 via a simple trend at population level; however different individuals appear to exhibit different systematic types of adaptation.

Overall, the results are consistent with the temporal behaviour matching hypothesis proposed above. Result R4 may indicate that the facial/gestural expressions used were not sufficiently salient features. However, the situation is complex: as result R2 shows, when facial/gestural expressions were used in the drumming game, children did not only match the robot’s behaviour (delayed responses) by delaying their own eliciting behaviour (increase in pause) but also responded with an increase in behaviour duration. This demonstrates a specific context where we find temporal behaviour adaptation not only on the level of onset of behaviour but also on the level of form and pattern of behaviour. Further studies will investigate the temporal behaviour matching hypothesis in more detail.

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. 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. [23]), and the individual differences in the different systematic effects of delay on children's pauses for the imitation game (see Sec. 4.2 i above). Including such data in the analysis may illuminate some of the issues.

Results from this work are hoped to improve the design of socially interactive robots that are able to regulate interactions with people via means of cues derived from interaction kinesics (e.g. the timing and duration of behaviour).

7. ACKNOWLEDGMENTS

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