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Cognition, Understanding and Behavior

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RobotCub
Development of a Cognitive Humanoid Cub

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D5.4 First results of experiments on mirroring and communicative aspects of imitation
WP5 - Imitation and Interaction

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PU	Public	**PU**
PP	Restricted to other programme participants (including the Commission Service)	
RE	Restricted to a group specified by the consortium (including the Commission Service)	
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1 Executive Summary

This deliverable reports results from experimental trials involving 22 children interacting with a humanoid expressive robot called KASPAR. The research focuses on the regulation of interaction dynamics of social interaction during human-robot play, and in particular investigates the effect of timing delays and contingent expressive behaviour on communicative interaction through imitation.

KASPAR is a humanoid robot with an 8-DOF head and two 3-DOF arms, capable of producing a range of facial and body expressions and motions. In these trials KASPAR is controlled by the experimenter out of sight of the subject (Wizard-of-Oz model) and imitates behaviour exhibited by the child.

Each of the 22 children took part in six experimental trials involving two games in which the dynamics of interactions played a key part. In the first game the robot imitated expressions or motions demonstrated by the children, chosen from a range of expressions that the children were told that the robot was capable of. The expressions used were appearing “happy”, “sad” or “thoughtfull-excited”[1], waving a hand, and moving the hands up and down. In the second set of trials, the robot imitated short phrases (patterns) played by the child on a tamborine.
Each of these trials were conducted under two timing condiditons: without delay between model and imitation, and with a fixed 2 second delay. Additionally, in order to study the effect of the robot’s expressions on the interaction, the drumming task was conduted under a further independent condition where the robot displayed expressive motions (nodding the head and blinking) while it was drumming.

Recorded video of these interactions were analysed in detail. For the drumming call-response game, two variables were measured: the delay between the robot finishing the previous phrase to the child starting a new phrase, and secondly the duration of the child’s phrase itself. Similarly, in the imitation game the delay between the robot reaching a posture and the child assuming a new posture or expression was measured.

In total 22 children each participated in 6 trials of 2 minutes duration each. At the point of this deliverable, the video data from 6 children has been analysed. These early results indicate that, for some children, a short delay in the robot’s response regulates and enhances the interaction by increasing the duration of the children’s drumming phrases, and the duration of the pauses which preceded these phrases. Additionally, results indicate that 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 expressions (nodding of the head and eye blinks).

Further details on background, motivation and results from the 6 interactions already analysed can be found in the research paper included in the appendix to this report.

[1] See Appendix for pictures of these expressions taken from the robot.

Synchronization and interaction dynamics in dyadic child-robot interaction kinesics[1]

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***Abstract* – This paper presents initial results of a study where 22 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 expressive movement 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 body expressions. These 6 experimental conditions per child allow between- and within participant comparisons. Thus far video material of six out of 22 children has been analyzed, and very first results are presented in this paper. Future work will present the analysis of the complete data.**

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 (Reeves and Nass, 1996). With technology that adheres to human social expectations, it is expected that people will find interactions enjoyable, feel empowered and competent (Reeves and Nass, 1996). For applications, levels of autonomy and anthropomorphism need to be carefully designed cf. (Dautenhahn and Nehaniv, 2000), (Shneiderman, 1989), (Mitchell and Hamm, 1997).

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 (Nadel, et al., 1999). The importance of rhythm and timing and

[1] The work described in this paper was conducted within the EU Integrated Project RobotCub (Robotic Open-architecture Technology for Cognition, Understanding, and Behaviours) and was funded by the European Commission through the E5 Unit (Cognition) of FP6-IST under contract FP6-00437.

inter-subjectivity in early communicative interaction of infants with a caregiver, termed *protoconversation,* has been described by Trevarthen (Trevarthen, 1999) 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 (Condon & Ogston, 1967; Kendon, 1970; Hall, 1983) 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 (Watanabe, 2004, Robins, et al. 2005), therapeutic walking devices (Miyake, 2003), as well as in evolved artificial social turn-taking agents (Iiizuka & Ikegami, 2004)..

Goldin_Meadow argues that the gestures people produced in their conversations are tightly intertwined in their timings and meaning, and that they are non-verbal components of people's communication which cannot be separated from the content of conversation (Goldin-Meadow and Wagner, 2005).

Kinesics can be described as the study of the role and timing of nonverbal behaviour, including body movements, in communicative and interactional dynamics . Exploration of its application to studying human robot interaction is presented in (Robins, et al., 2005).

This paper focuses on the regulation of interaction dynamics of social interaction during human-robot play, and explore communicative aspects and interaction dynamics of imitative behaviour between a robot and children interacting with it.

The RobotCub project is developing an open humanoid robotic platform for research in embodied cognition and, simultaneously, advancing the understanding of cognitive systems by exploiting this platform in the study of the development of cognitive capabilities in humanoid robots. The robotic platform that is being developed in the RobotCub project, the iCub, has a physical size and form similar to that of a two and a half year-old child with the aim of achieving its cognitive capabilities through development and learning in its environment: by interactive exploration, manipulation, imitation, and gestural communication. Since the iCub is still under development, we have developed and used as our robotic platform, the minimal interactive robot KASPAR (**K**inesics **A**nd **S**ynchronisation in **P**ersonal **A**ssistant **R**obotics). KASPAR is a child-sized humanoid robot developed by the Adaptive Systems Research Group at the University of Hertfordshire (Blow, et al., 2006a, b).

In this paper we report initial results from experiments on synchronization and mirroring in human-robot interaction.

2. The Robotic Platform - KASPAR

KASPAR is a child-sized robot which acts as a platform for HRI studies, using mainly bodily gestural expressions (movements of the hands, arms, head, eyes, eyelids, and facial effector `muscles') to interact with a human. The robot has a static body (torso, legs and hands do not move and were taken from a child-sized commercially available mannequin doll) with an 8 DOF head and two 3 DOF arms. Important features of KASPAR head are minimal design, the inclusion of eyelids, and aesthetic consistency of the face (Blow, et al., 2006a, b).

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 figure 1 below). An emphasis on the features used for communication allows the robot to present facial feedback clearly by changing orientations of the head, moving the eyes and eyelids, facial `muscles' 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 been inspired in part by Scott McCloud's work on comic design and Japanese noh masks, cf. discussions in (Blow, et al., 2006a, b).
These are both 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.

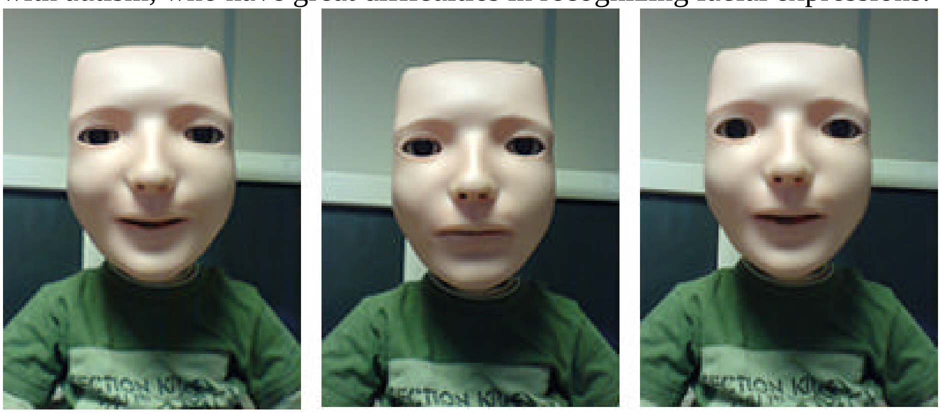

Figure 1 – KASPAR's minimal expressive face

Initial observations of interactions of people with KASPAR indicate that subtle change in expression coupled with subtle gestures is already effective in conveying "the message" associated to a particular expression. KASPAR's existing expressions differ from each other by a minimal change in the mouth opening (see Fig1). Together with small changes in the tilt of the head and the direction of the eyes already creates recognizable expressions (see figure 2).

Figure 2 – Still shots from the three dynamic bodily expressions of KASPAR used in the current work (future work will investigate further gestural expressions)

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 figure 3).

Figure 3 – Children's pronounced expressions during imitation game with KASPAR

3. The present study

Exploring the space of Robot-Child Interaction Kinesics

In this study, we follow Ogden et al.'s definition 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* (Ogden, et al., 2002).

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. (Condon and Ogston, 1967), (Kendon, 1970). Nodding, movements of the hands, coordinated rhythmic 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 (Hall, 1983). This suggests that interacting with robot, which has no sense of time and does not follow human timing, will also lead to difficulties as it may be uncomfortable and unnatural to interact with (Robins, et al., 2005). The present study is adopting a wider view of kinesics to include the role and timing of non-verbal 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 gestures on interactions with children:

1) in what way and to what extent do the robot's facial expressiveness affect the timing of children interacting with the robot?

2) does the introduction of a short delay in the robot's response (designed as similar to the natural pauses occurring during turn-taking in human conversation) enhance/regulate the timing and synchronization of robot-child interaction?

3.2 The interaction design

To start studying these questions we were investigating 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. In this game the child was sitting opposite the robot and was 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 expressive postures shown in figure 2, complemented by a 'goodbye' hand wave, and up/down arm movements.

3.3 The trials set-up

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, and the other placed behind the robot to try and capture the facial expressions of the children during these interactions.

The robot has been programmed to operate as a puppet, whereby the investigator is the puppeteer and controlled all the robot's movements and expressions, by a simple press of buttons on his laptop (this approach is related to the Wizard-of-Oz technique used in human-computer interaction (HCI) and more recently in human-robot interaction (HRI) research, e.g. (Maulsby, et al., 1983) (Hüttenrauch, et al., 2004). 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 separate sets of experiments: one trial playing the imitation game, and one playing the call & response drumming game. In total, each child took part in six separate experiments of approximately two minutes each, over two different days.

3.4 Trials' procedures

i. The Call & Response Drumming game:

The child, sitting opposite the robot, (see figure 4) initiated the drumming of a short rhythmical phrase, and waited for the robot to respond with an identical phrase, before drumming a new phrase. Each experiment ran twice, (on separate occasions), once where there was no delay in the robot's response and once where the robot was programmed with a global delay of two seconds before executing any behaviour. In addition, we monitored the effect of the robot's gestures and expressions on the child's interaction so the above two experiments (with and without delay) were repeated again with additional two conditions - one where the robot carried out head and eyelid movements when it was drumming (nodding with the head, and eye blinking) and one when it had no such "expressive" movements (a 2x2 experimental design with a total of 4 drumming experiments for each child)

Figure 4 – a child playing Drumming Call and Response game

ii. The Imitation game

Here the child, standing opposite the robot, produced a movement or a gesture (selected from the robot's range of gestures) and waited for the robot to imitate him, before moving to a new posture (see figure 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.

4. 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 variable - one is the duration of the pause of the child from the moment the robot finished to drum the previous phrase, to the moment the child starts drumming his new phrase. We also measured the duration of each of the child's drumming phrases.

b) In the *Gesture Imitation* game, we measured 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.

As mentioned above, 22 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 132 experiments averaging 2 minutes duration each which yielded in 15840 seconds of video recorded 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 second 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 frame by frame, and repeatedly.

Please note, due to the highly time consuming annotation process, so far only 36 experiments of 6 children have been notated. This paper therefore, reports the possible trends that we found in case study evaluations. As the quantitative analysis of the data for the remaining children is in progress, additional results (which seem likely to be statistically significant, given observed trends in the part of analysis so far completed – see below) will be reported in due course. A brief statistical analysis based on the data of 6 children is reported below. Note, in future the inter-rater reliability of the coding and annotation of the videos would have to be verified.

4.1 The effect of delayed robot's response on the children's interaction dynamics during the drumming game

<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 conversation) regulated and enhanced the interaction by increasing the duration of the children's drumming phrases, as well as the duration of the pauses which preceded these phrases. As might be expected, since the experimental trials were of about the same length, the number of call and response rhythmic drumming bouts is smaller in the conditions involving delays. Figures 5 and 6 show the time line of durations of each rhythmic phrase produce by two of the children with and without delays in the robot's responses. Figures 7 and 8 show the corresponding result data when, in addition, the robot exhibits head and eyelid movement.

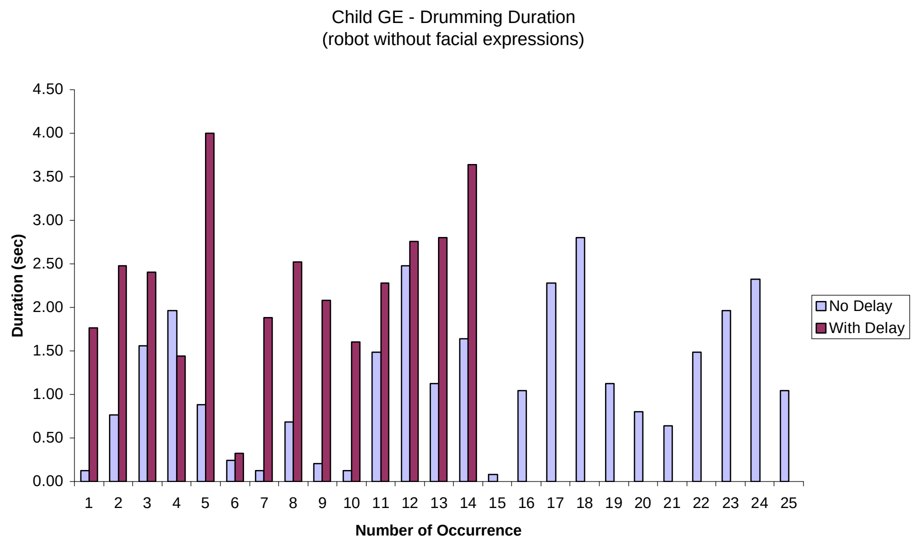

Figure 5 – time series of the duration of drumming phrases produced by GE

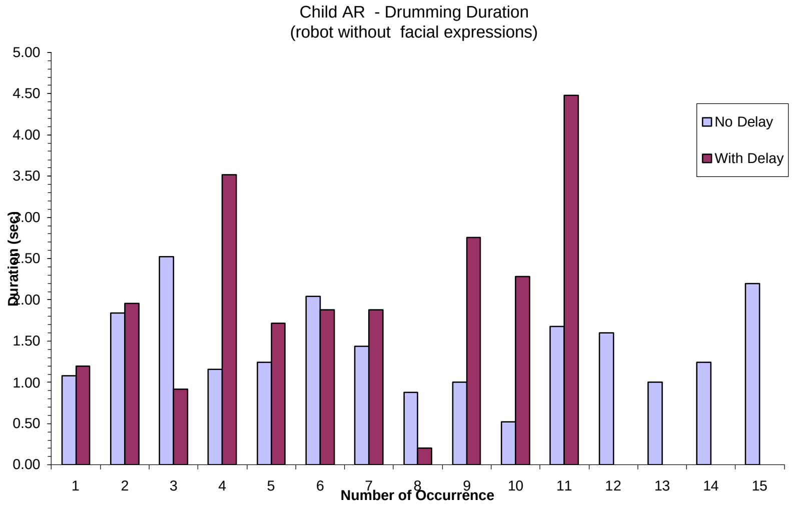

Figure 6 – time series of the duration of drumming phrases produced by AR.

Results indicate that 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 head/eyelid movement (nodding of the head and eye blinks) as can see below:

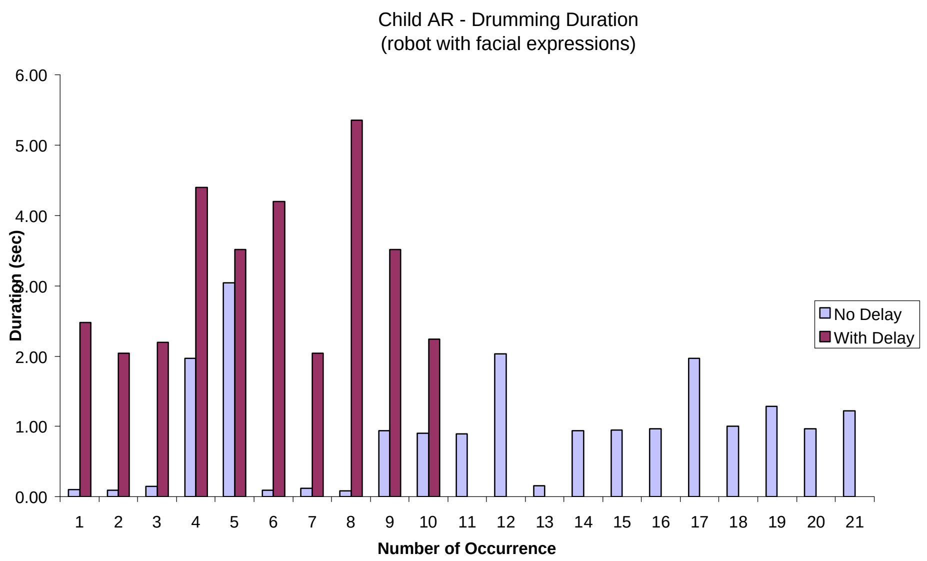

Figure 7 – time series the duration of drumming phrases produced by AR when the robot had head/eyelid movement.

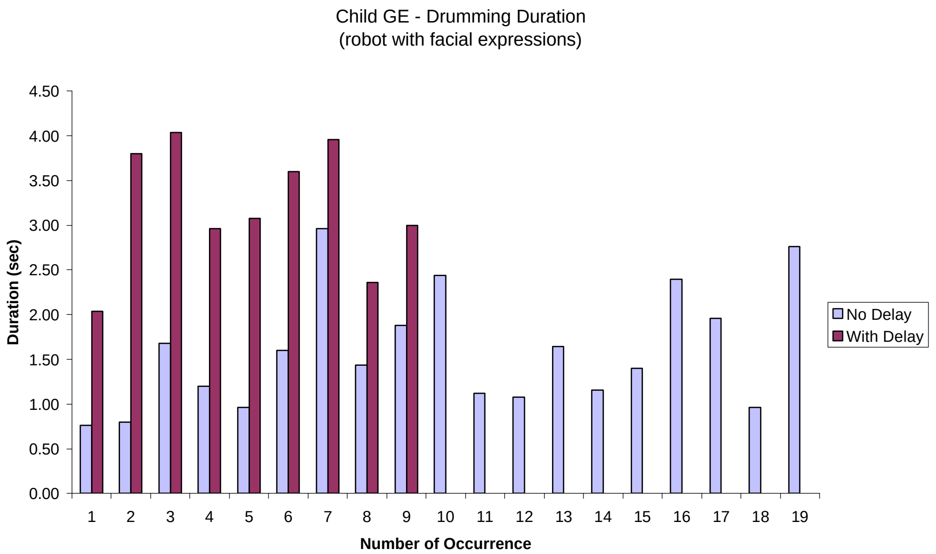

Figure 8 – time series of the duration of drumming phrases produced by GE when the robot had head/eyelid movement.

We can see that for both children, AR and GE, the combination of head-eyelid movement and delayed response in the robot, produced longer duration of drumming phrases by the children.

ii. Effect on duration of the pauses which preceded the drumming:

Figures 9 and 10 below reveal 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.

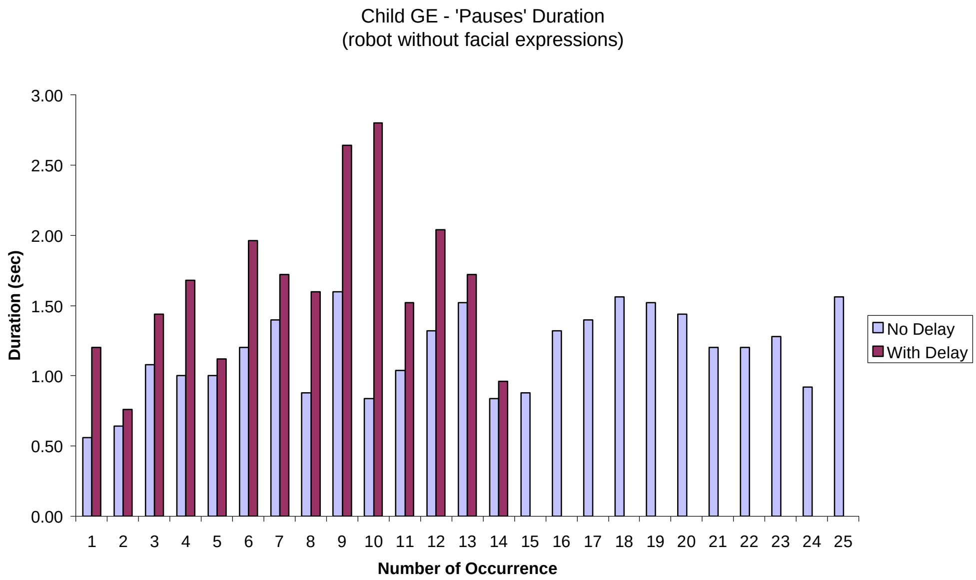

Figure 9 – time series of the duration of pauses produced by GE prior to his drumming.

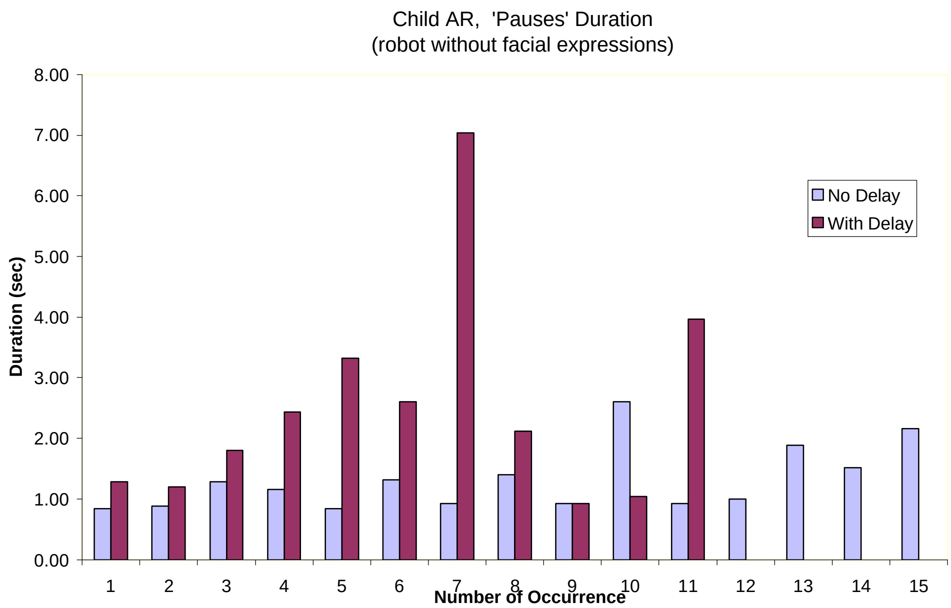

Figure 10 – time series of the duration of pauses produced by AR prior to his drumming.

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

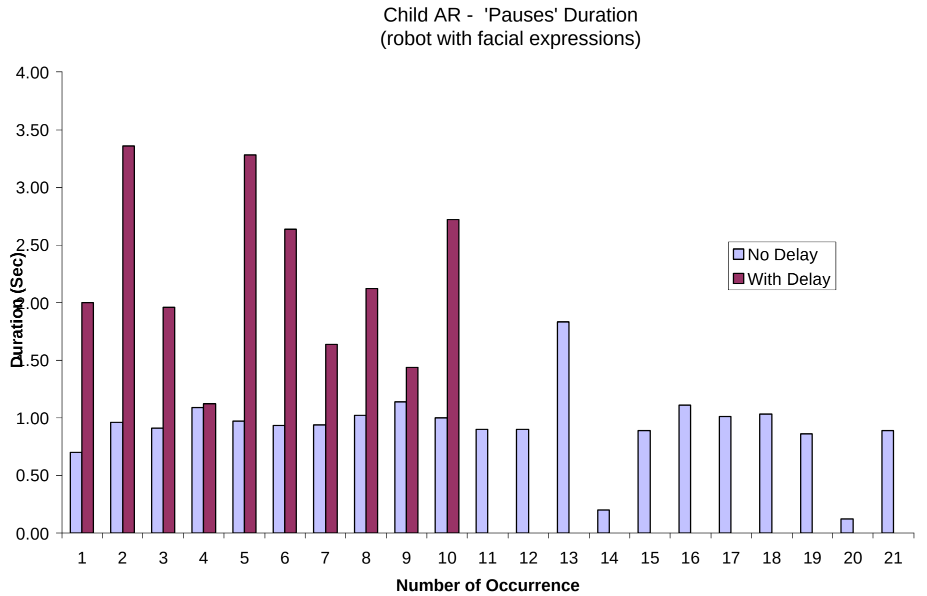

Figure 11 – time series of the duration of pauses taken by AR prior to drumming, when the robot did have head/eyelid movement.

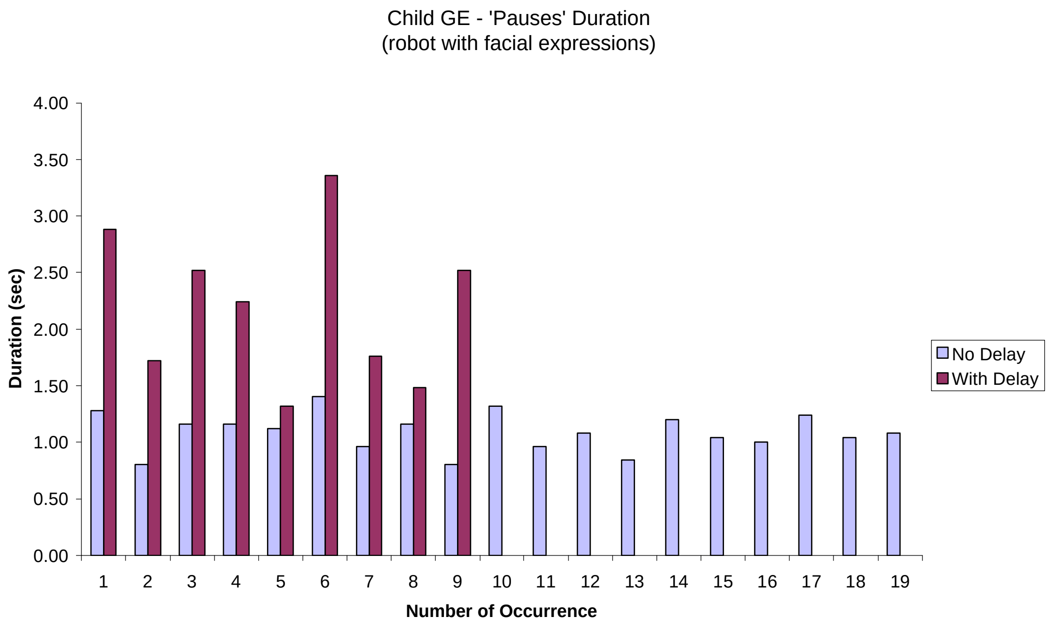

Figure 12 – time series of the duration of pauses taken by GE prior to drumming, when the robot did have head/eyelid movement.

4.2 Statistical analysis of the effects of delayed response and facial 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 expression was analyzed 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 head/eyelid movement) 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 expression/no facial expression

Temporal dependency was investigated by calculating the autocorrelations (up to N - 4 lags, where N is the bout number) 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 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 qualitative and quantitative 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 pauses, no significant effects of facial expression were found. However, delay had a positive effect on the duration of pause irrespective of facial expression in AR and DA. It also increased pause duration in GE, but only when the robot did not show a facial 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 expression of the robot, but in AR this effect was only significant in combination with facial expression.

Head and eyelid movement 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 head 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 particularly 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

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

DRUMMING						
RESPONSE	EXPRESSION	Mean	Standard Error	Confidence -95%	Limits +95%	N
ND	NE	1.266	0.160	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

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 in seconds.

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 ($F = 17.665$, $p = 0.014$) (Figure 13).

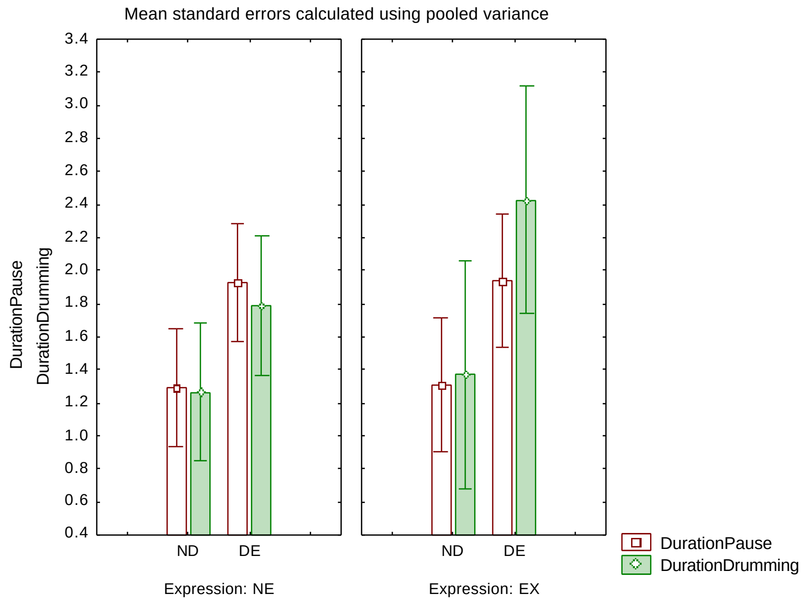

Figure 13 – Mean values and standard errors of Pause and Drumming duration under four experimental conditions of Delay and Head Expression.

4.3 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. Figure 14 shows that the introduction of the delay had somewhat a regulatory/calming effect on DY's actions.

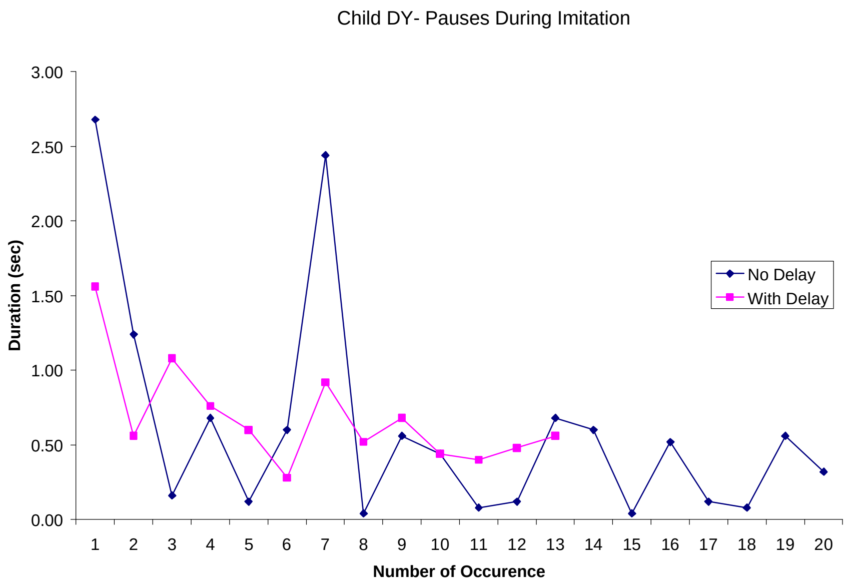

Figure 14 – time series of the duration of pauses taken by DY during the imitation game.

In figure 15 below we can see how the introduction of delay in the robot's response caused a longer pauses to be taken by the child .

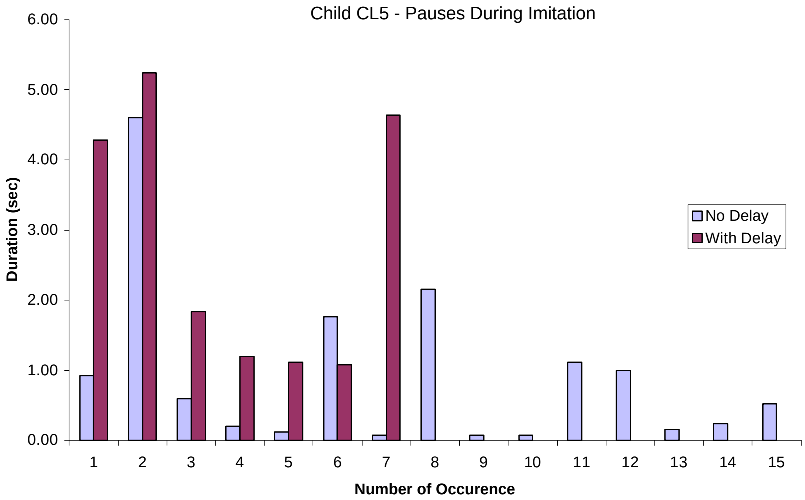

Figure 15 – time series of the duration of pauses taken by CL5Y during the imitation game.

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 expression. An example can be seen in figure 16 below.

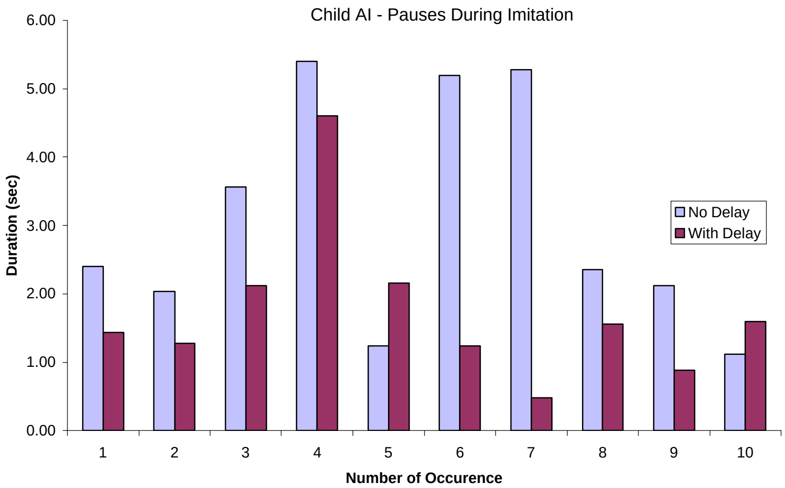

Figure 16 – time series of the duration of pauses taken by AI during the imitation game are shortened when the robot delay its responses.

5. Conclusion

This article presented initial results from a study carried out with 22 children playing dynamic games with a human-sized robot. The video analysis of the child-robot interactions is currently underway, at the time of submitting the deliverable only six children had been analysed. A framework for the statistical comparison of the data has been outlined. Initial results highlight the impact of the dynamics of interaction in general, and how delay in interactional responses influences the interactions. The results analysed so far suggest that (1) delay in timing and the use of non-verbal gestures (head and eyelid movements) can significantly influence the timing of duration of activity and pauses in human-robot interaction, and (2) there exist significant qualitative individual differences between children in their response to the introduction of delays into turn-taking interactions. The latter point suggests the need for autonomous development and adaptation of timing of interaction kinesics in human-robot scenarios.

Bibliography

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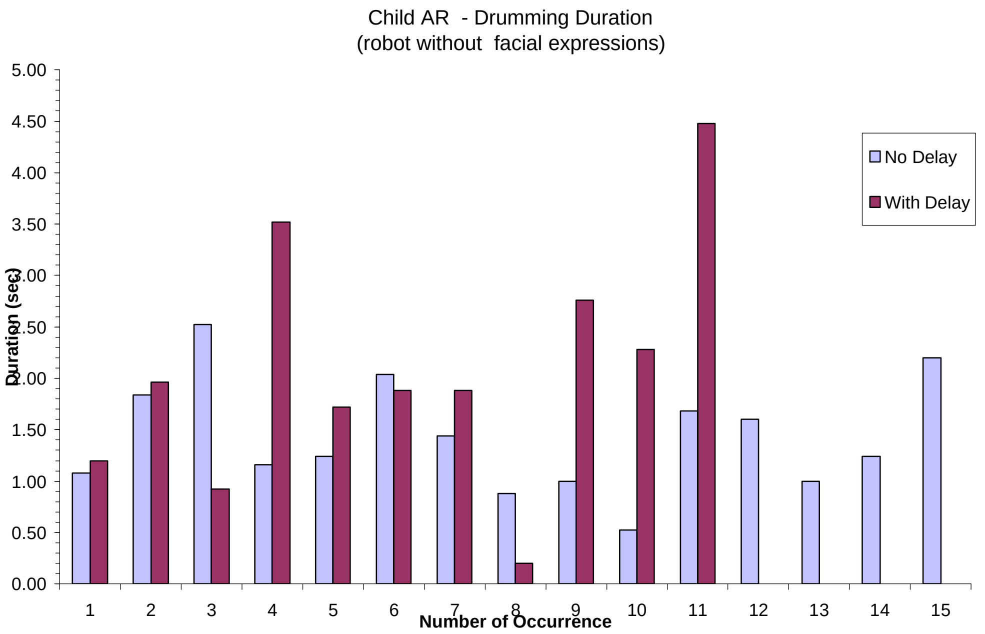
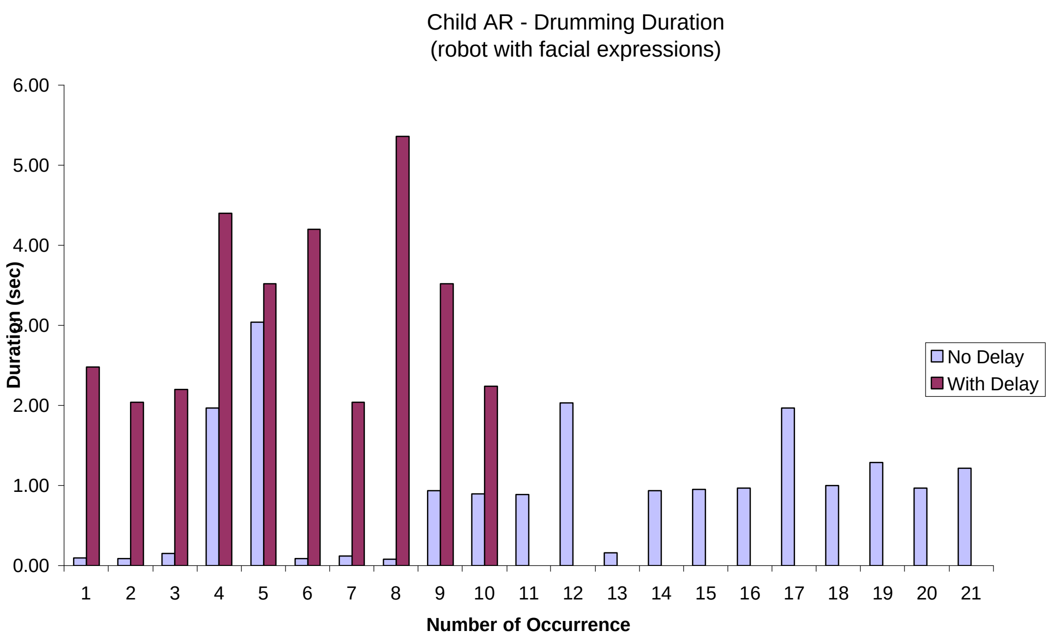
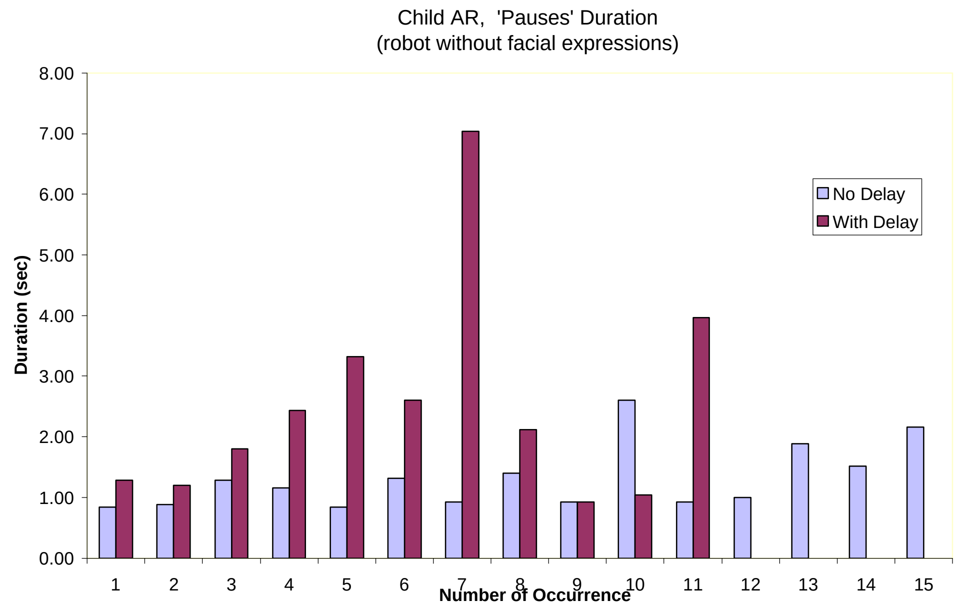
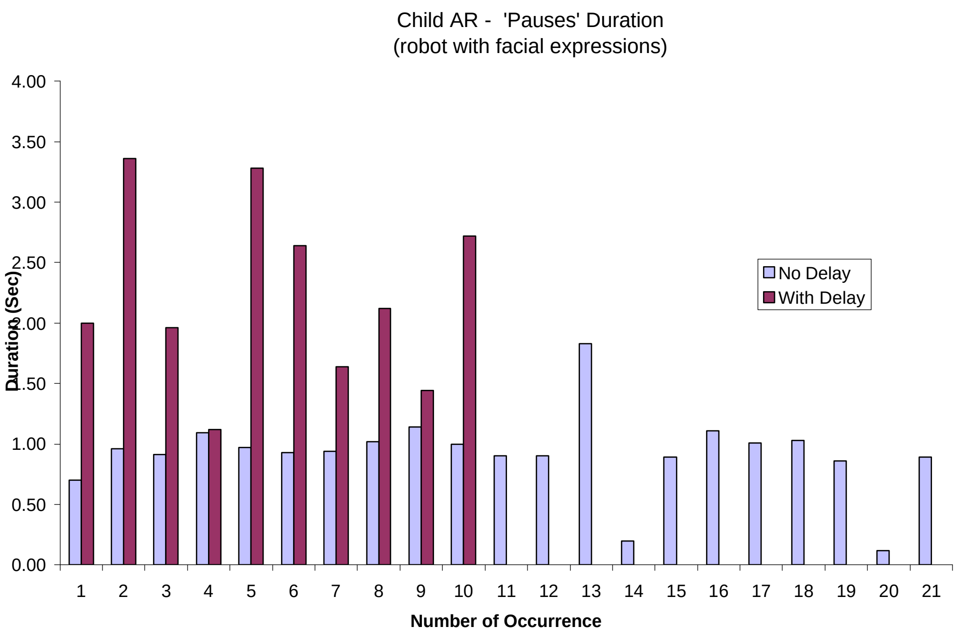
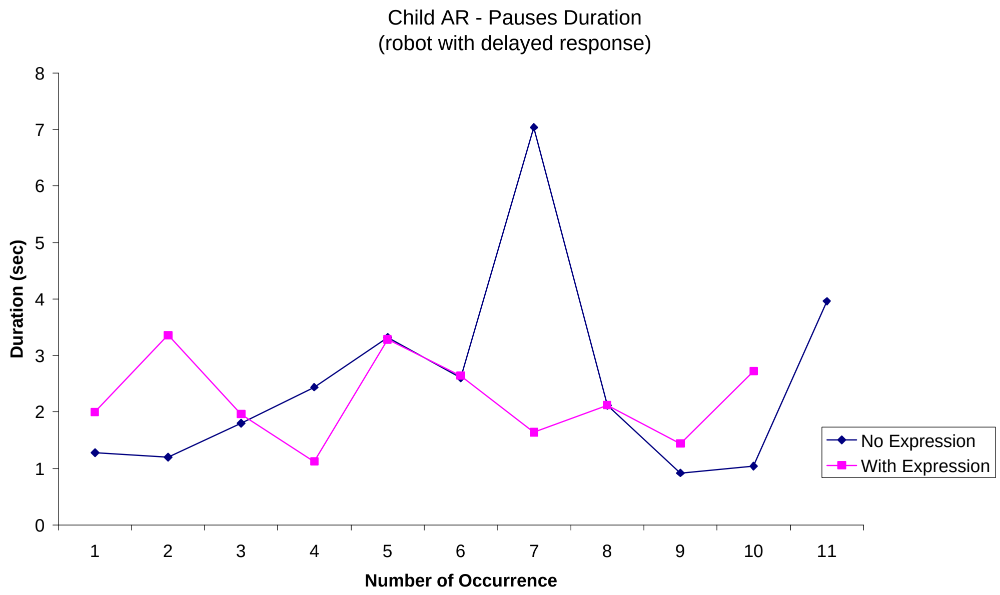
APPENDIX A – Call and Response Drumming game - Charts






Child AR, 'Pauses' Duration
(robot without facial expressions)
Duration (sec)
8.00
7.00
6.00
5.00
4.00
3.00
2.00
1.00
0.00
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15
Number of Occurrence
No Delay
With Delay


Child AR - 'Pauses' Duration
(robot with facial expressions)
Duration (Sec)
4.00
3.50
3.00
2.50
2.00
1.50
1.00
0.50
0.00
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21
Number of Occurrence
No Delay
With Delay


Child AR - Pauses Duration
(robot with delayed response)
Duration (sec)
Number of Occurrence
No Expression
With Expression
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2
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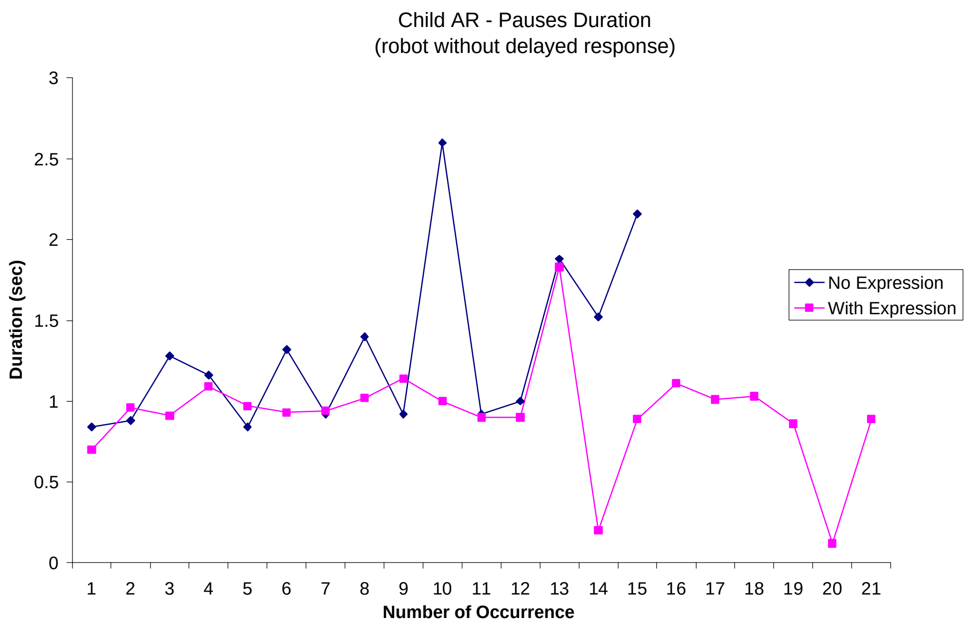
4
5
6
7
8
1
2
3
4
5
6
7
8
9
10
11


Child AR - Pauses Duration
(robot without delayed response)
Duration (sec)
Number of Occurrence
No Expression
With Expression
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1
1.5
2
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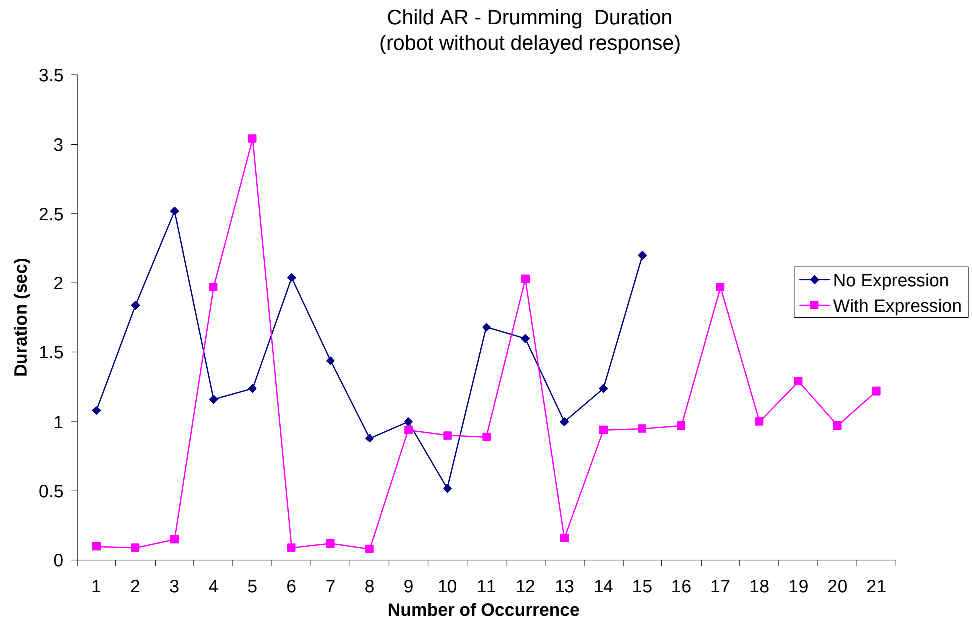
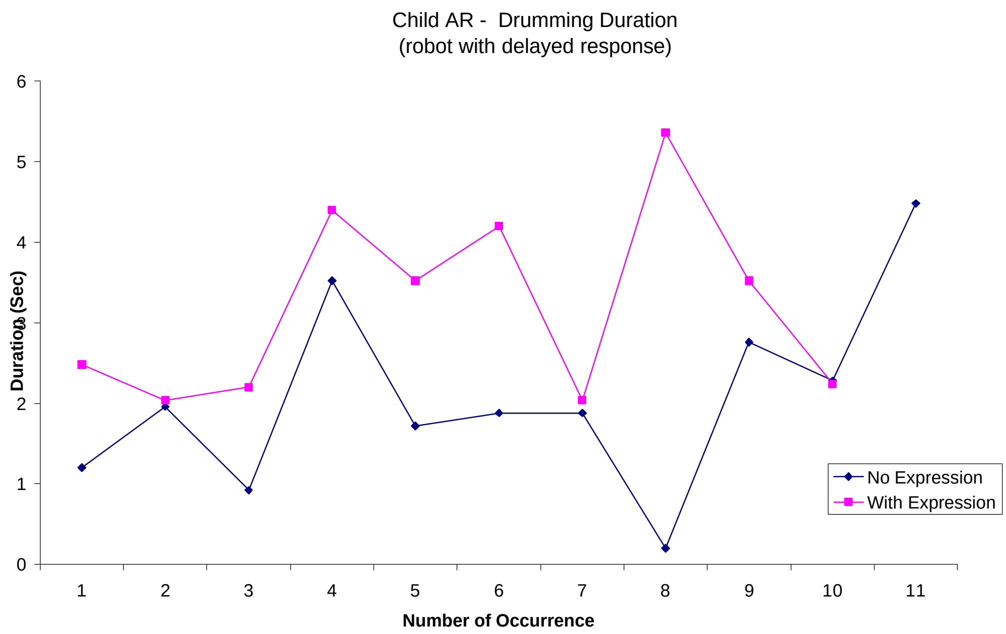
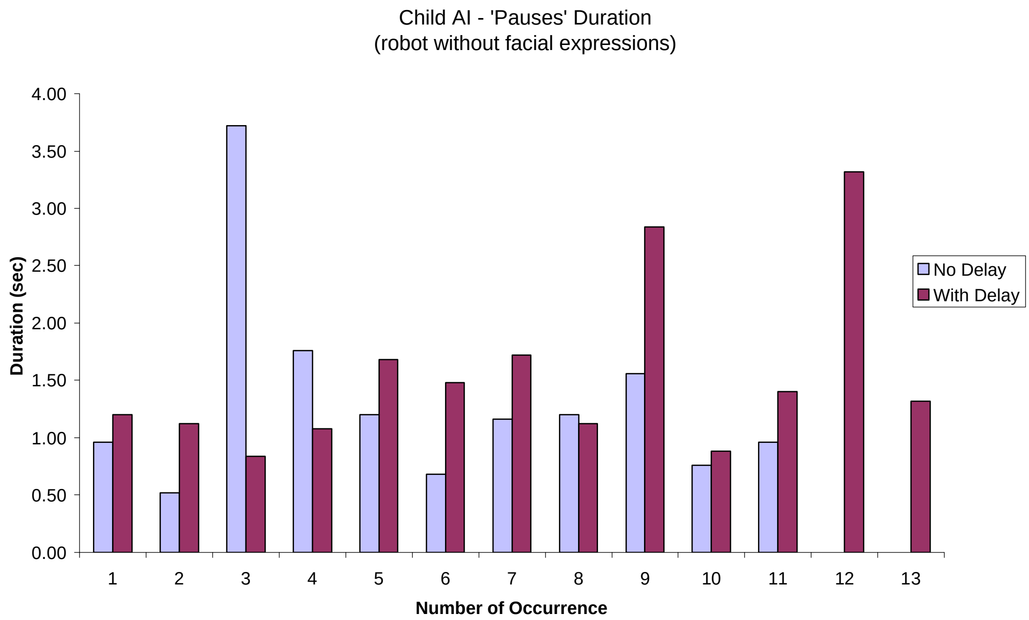


Child AR - Drumming Duration
(robot without delayed response)
Duration (sec)
Number of Occurrence
No Expression
With Expression



Child AR - Drumming Duration
(robot with delayed response)
Duration (Sec)
Number of Occurrence
No Expression
With Expression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(robot without facial expressions)
Duration (sec)
Number of Occurrence
No Delay
With Delay
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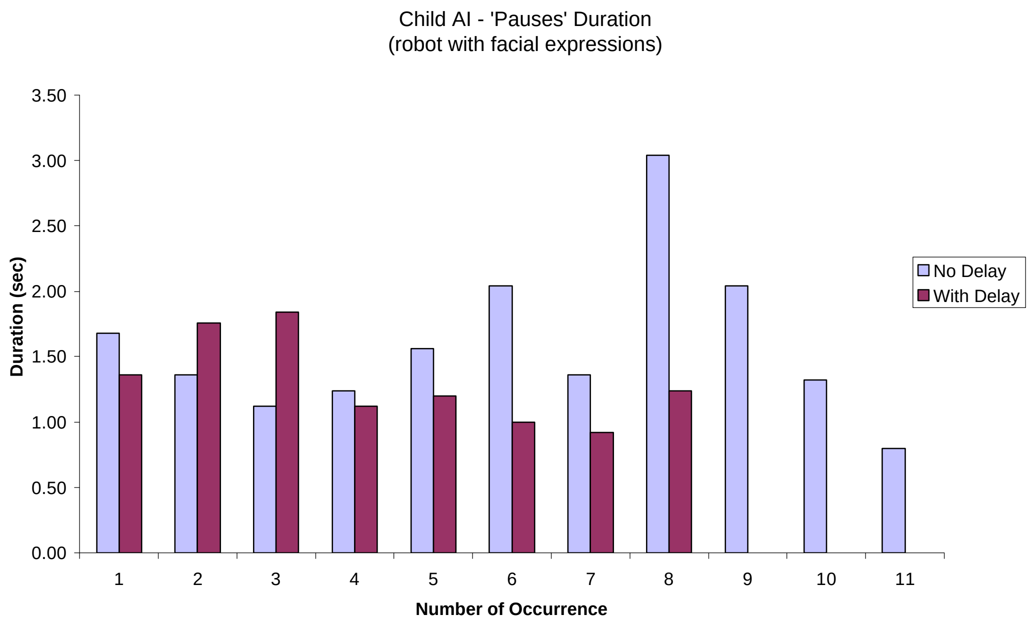
3.00
2.50
2.00
1.50
1.00
0.50
0.00
1 2 3 4 5 6 7 8 9 10 11 12 13


Child AI - 'Pauses' Duration
(robot with facial expressions)
Duration (sec)
Number of Occurrence
No Delay
With Delay
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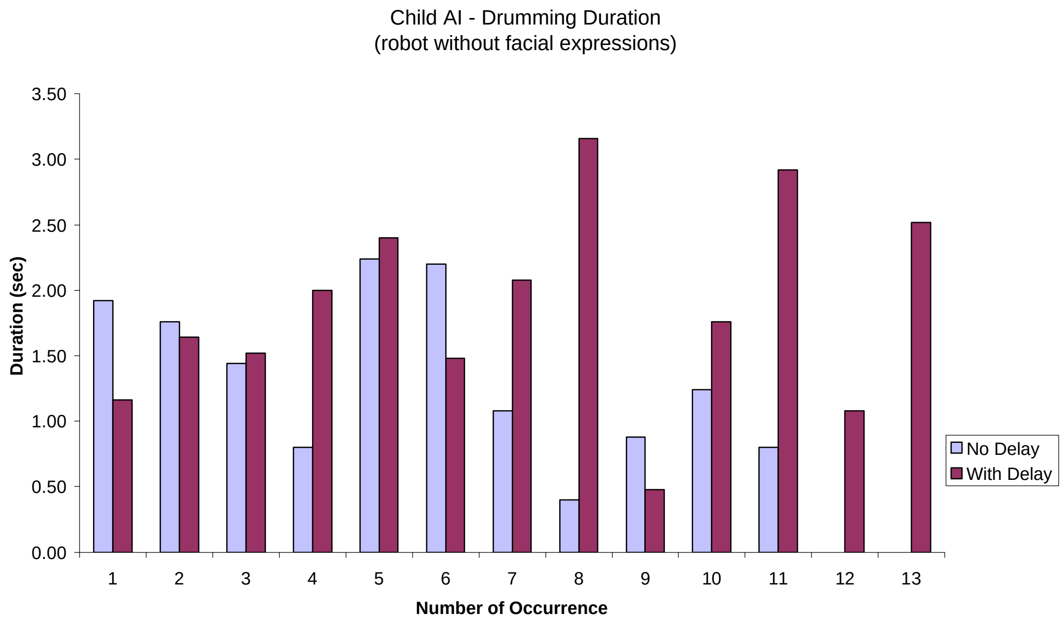
3.00
2.50
2.00
1.50
1.00
0.50
0.00
1 2 3 4 5 6 7 8 9 10 11


Child AI - Drumming Duration
(robot without facial expressions)
Duration (sec)
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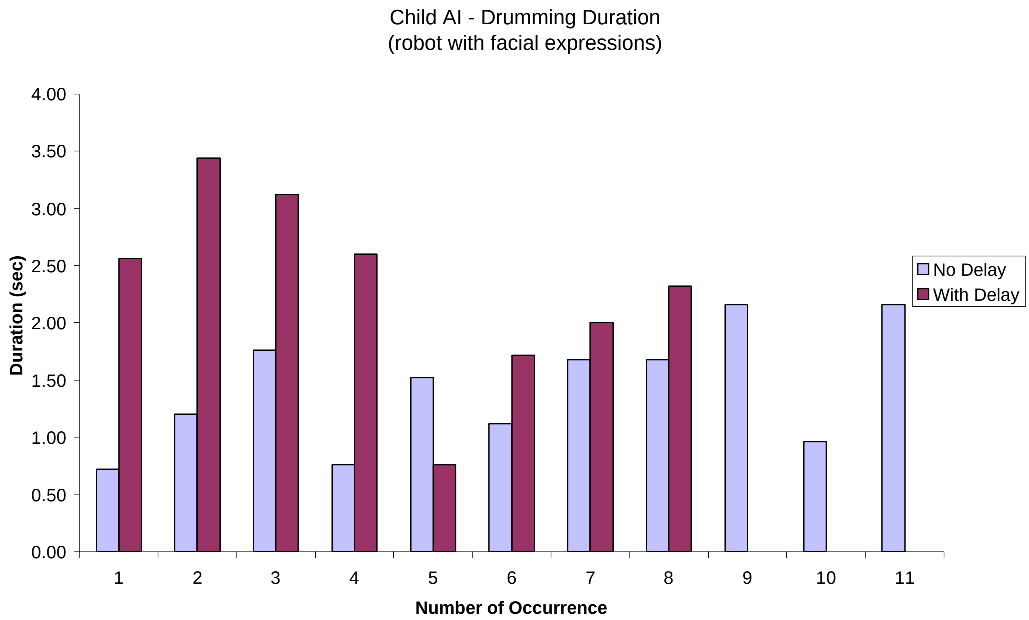
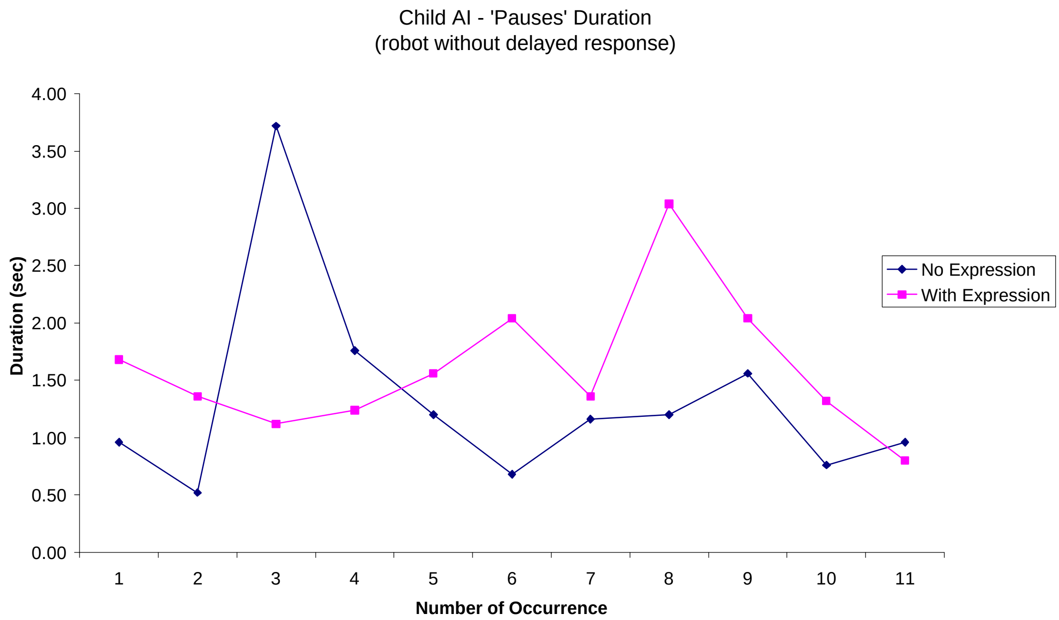
3.00
2.50
2.00
1.50
1.00
0.50
0.00
1
2
3
4
5
6
7
8
9
10
11
12
13
Number of Occurrence
No Delay
With Delay


Child AI - Drumming Duration
(robot with facial expressions)
Duration (sec)
4.00
3.50
3.00
2.50
2.00
1.50
1.00
0.50
0.00
1
2
3
4
5
6
7
8
9
10
11
Number of Occurrence
No Delay
With Delay


Child AI - 'Pauses' Duration
(robot without delayed response)
Duration (sec)
Number of Occurrence
No Expression
With Expression
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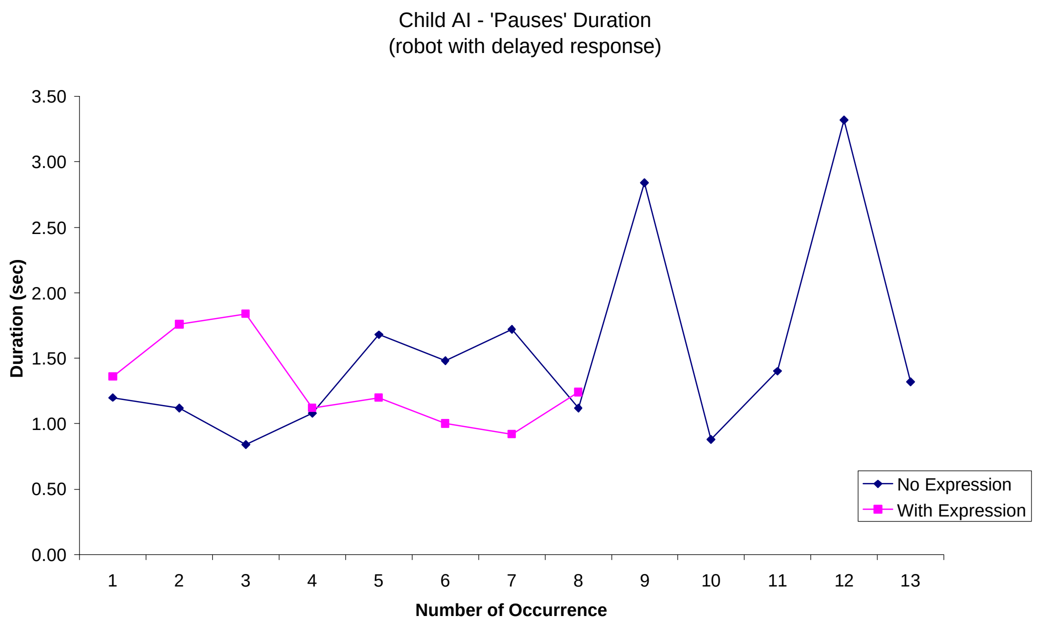
3.00
2.50
2.00
1.50
1.00
0.50
0.00
1 2 3 4 5 6 7 8 9 10 11


Child AI - 'Pauses' Duration
(robot with delayed response)
Duration (sec)
Number of Occurrence
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With Expression
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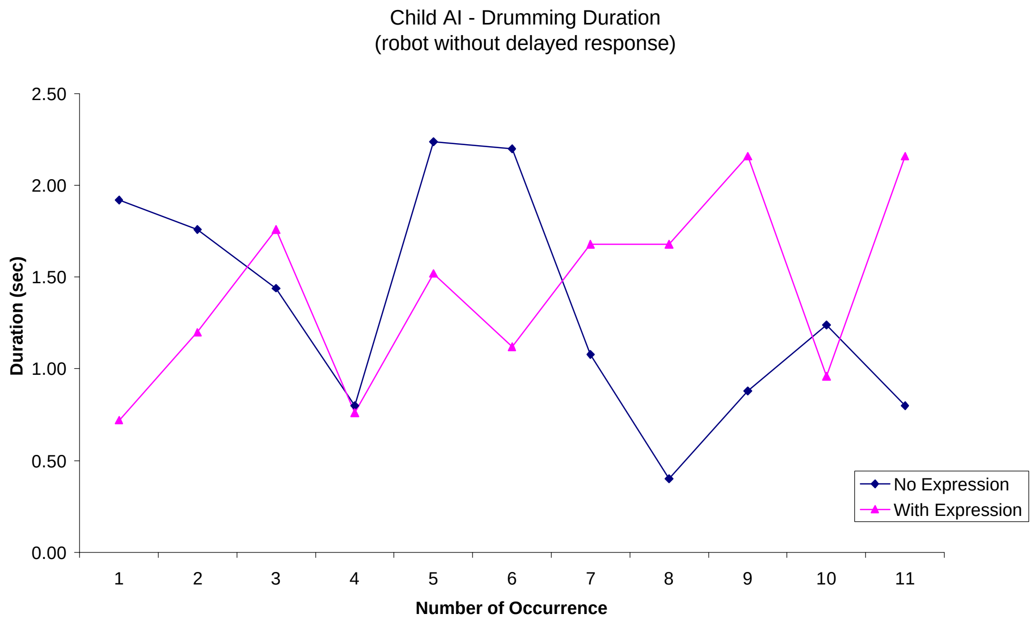
2.50
2.00
1.50
1.00
0.50
0.00
1 2 3 4 5 6 7 8 9 10 11 12 13


Child AI - Drumming Duration
(robot without delayed response)
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2.00
1.50
1.00
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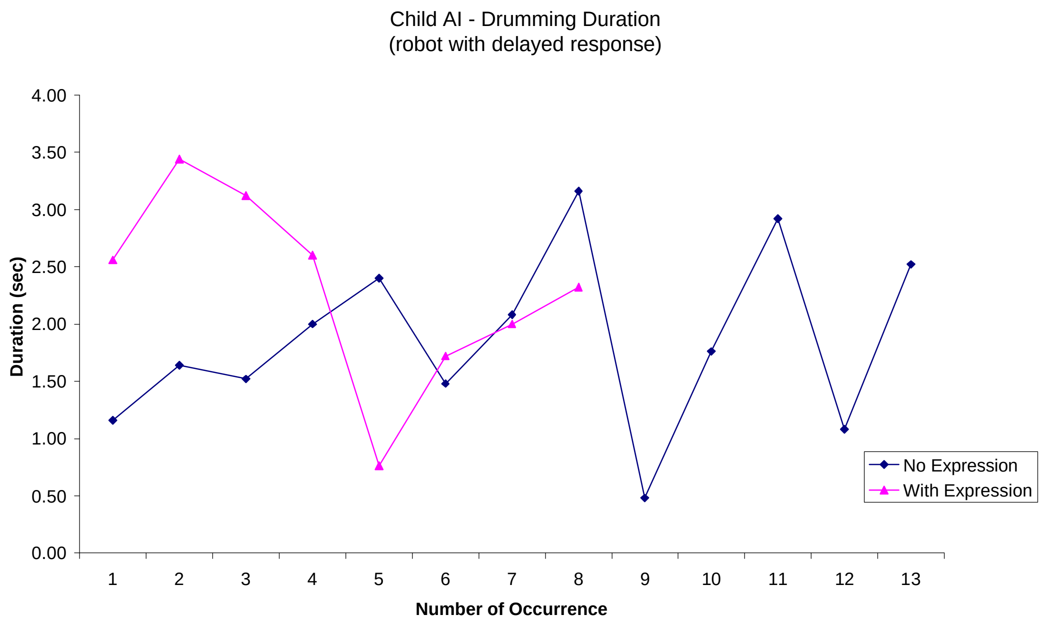
2
3
4
5
6
7
8
9
10
11
Number of Occurrence
No Expression
With Expression


Child AI - Drumming Duration
(robot with delayed response)
Duration (sec)
4.00
3.50
3.00
2.50
2.00
1.50
1.00
0.50
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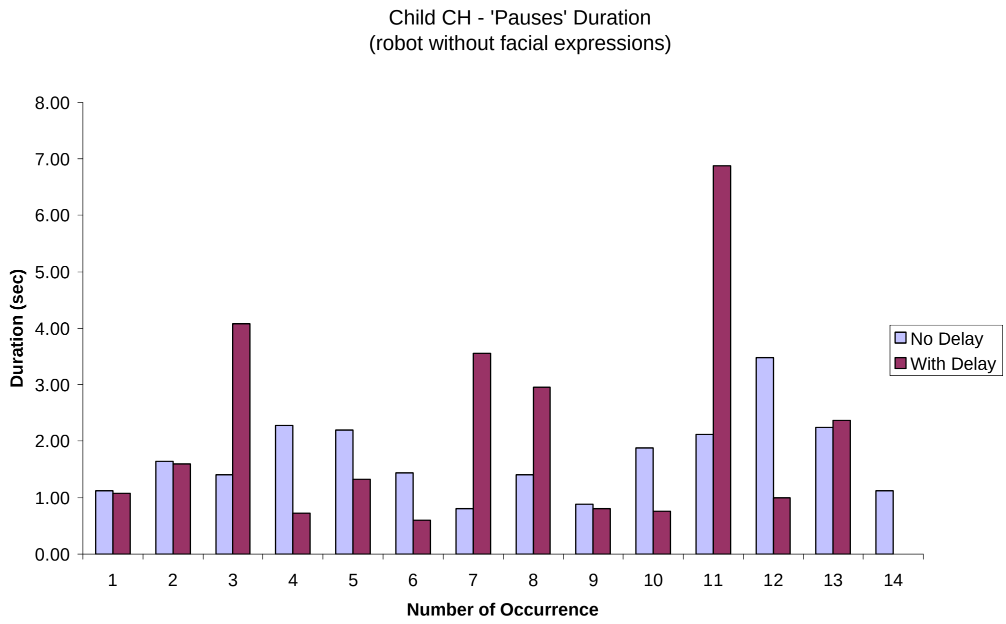
3
4
5
6
7
8
9
10
11
12
13
Number of Occurrence
No Expression
With Expression


Child CH - 'Pauses' Duration
(robot without facial expressions)
Duration (sec)
8.00
7.00
6.00
5.00
4.00
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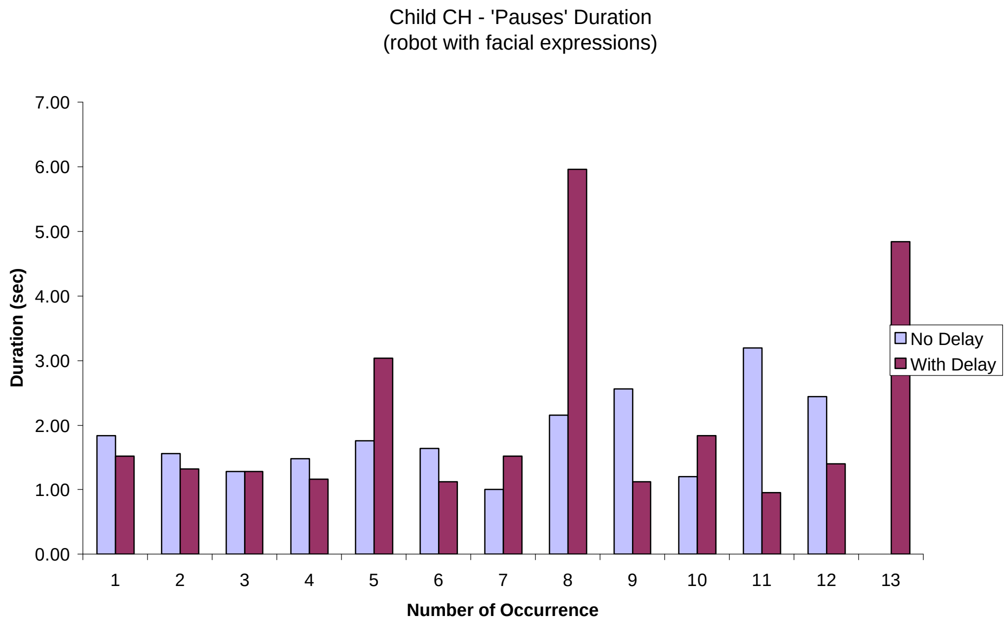
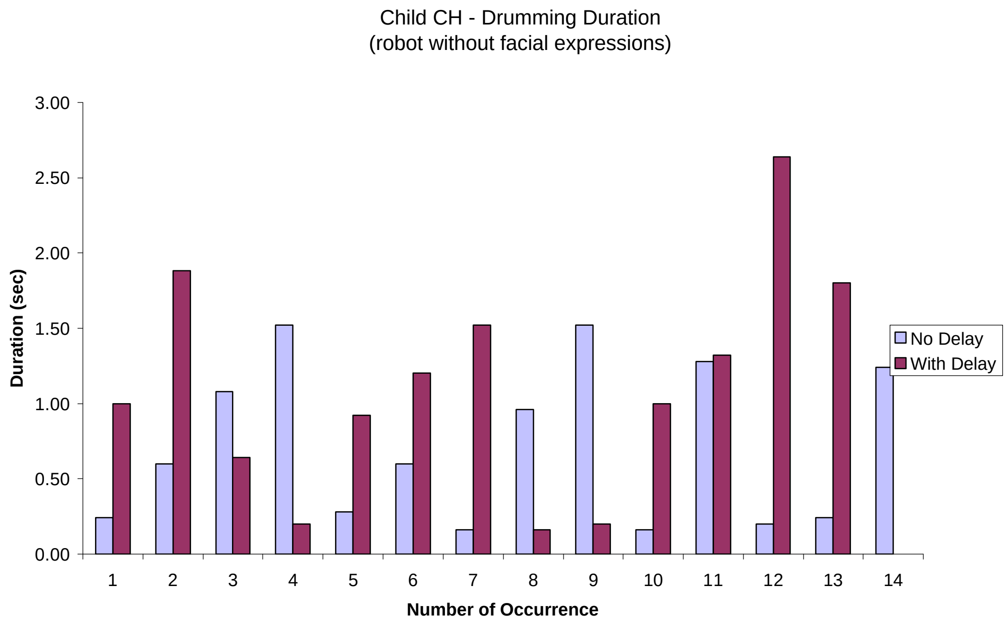
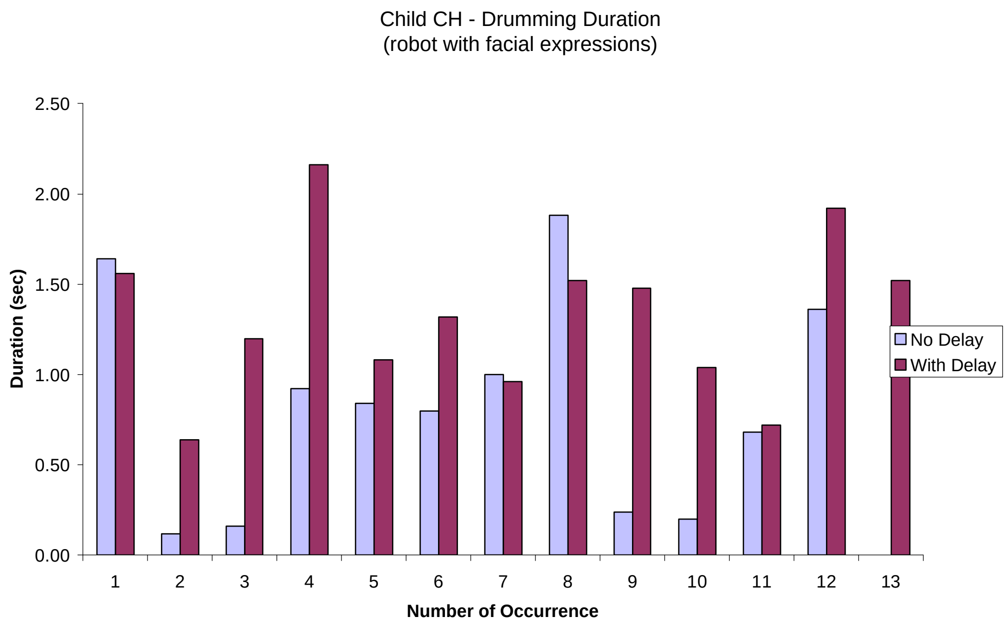
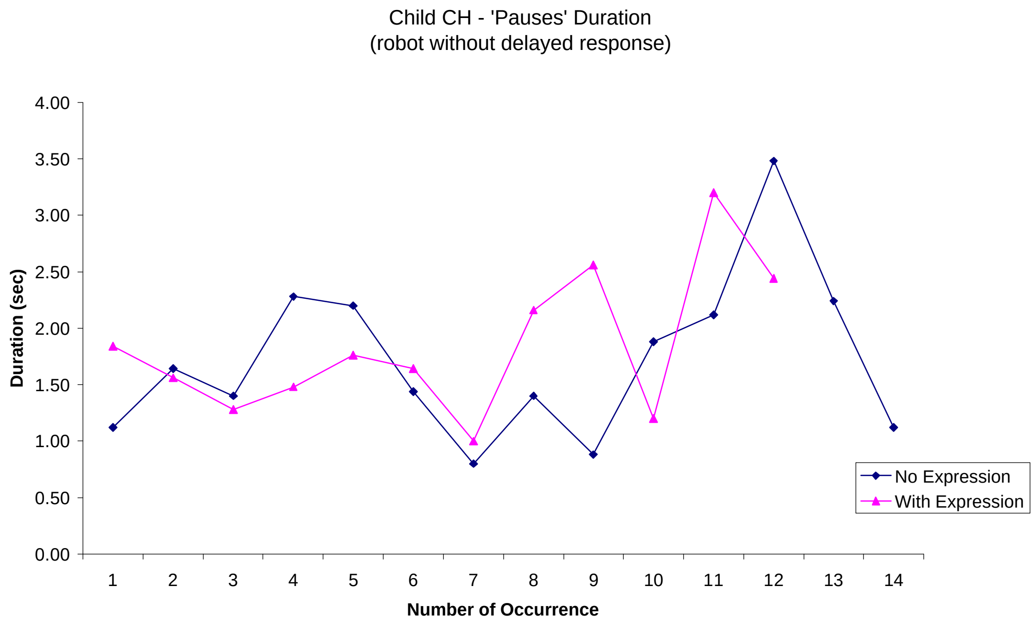
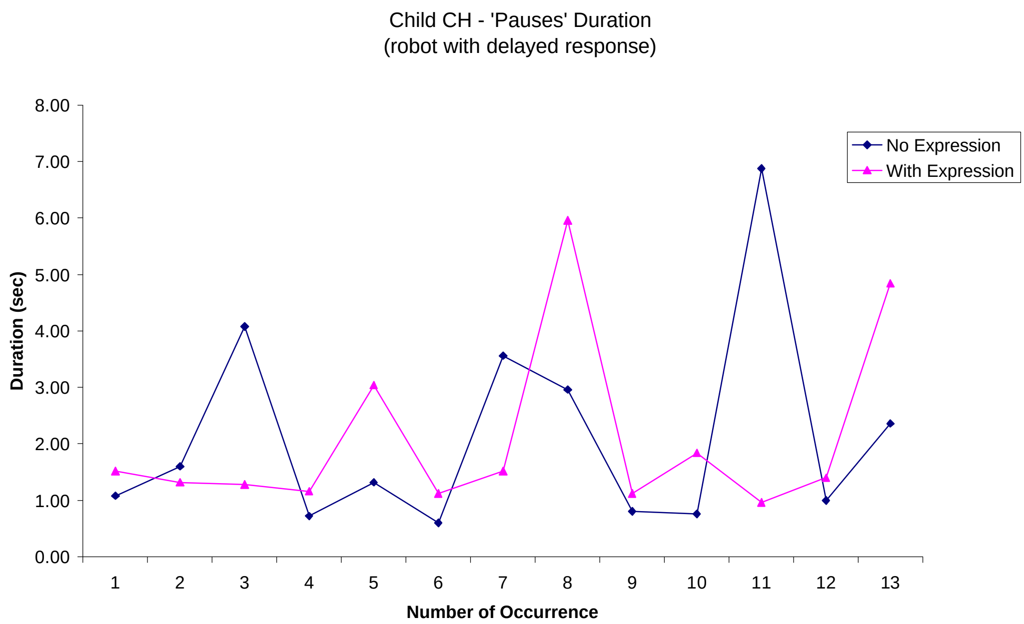
2.00
1.00
0.00
1 2 3 4 5 6 7 8 9 10 11 12 13 14
Number of Occurrence
No Delay
With Delay

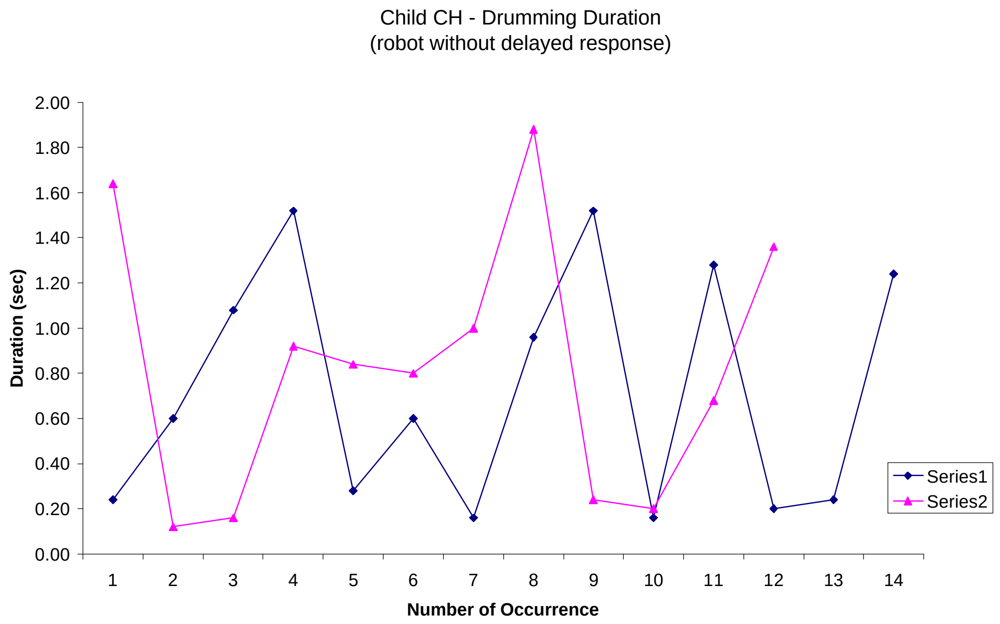

Child CH - 'Pauses' Duration
(robot with facial expressions)
Duration (sec)
7.00
6.00
5.00
4.00
3.00
2.00
1.00
0.00
1 2 3 4 5 6 7 8 9 10 11 12 13
Number of Occurrence
No Delay
With Delay


Child CH - Drumming Duration
(robot without facial expressions)
Duration (sec)
3.00
2.50
2.00
1.50
1.00
0.50
0.00
1
2
3
4
5
6
7
8
9
10
11
12
13
14
Number of Occurrence
No Delay
With Delay

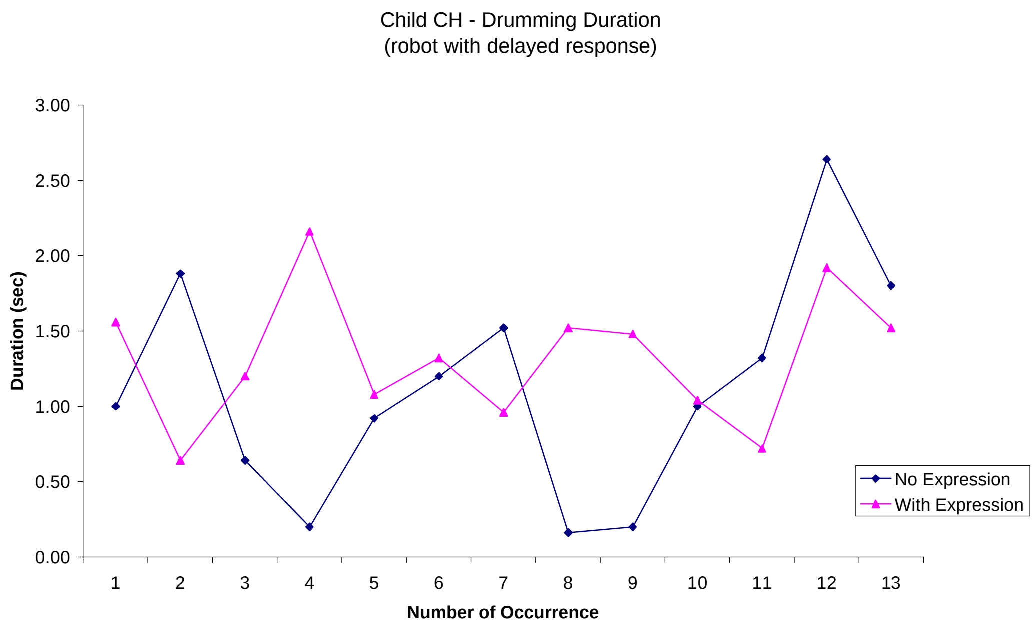

Child CH - Drumming Duration
(robot with facial expressions)
Duration (sec)
2.50
2.00
1.50
1.00
0.50
0.00
1
2
3
4
5
6
7
8
9
10
11
12
13
Number of Occurrence
No Delay
With Delay


Child CH - 'Pauses' Duration
(robot without delayed response)
4.00
3.50
3.00
2.50
2.00
1.50
1.00
0.50
0.00
Duration (sec)
1
2
3
4
5
6
7
8
9
10
11
12
13
14
Number of Occurrence
No Expression
With Expression


Child CH - 'Pauses' Duration
(robot with delayed response)
8.00
7.00
6.00
5.00
4.00
3.00
2.00
1.00
0.00
Duration (sec)
1
2
3
4
5
6
7
8
9
10
11
12
13
Number of Occurrence
No Expression
With Expression



Child CH - Drumming Duration
(robot without delayed response)
Duration (sec)
2.00
1.80
1.60
1.40
1.20
1.00
0.80
0.60
0.40
0.20
0.00
1
2
3
4
5
6
7
8
9
10
11
12
13
14
Number of Occurrence
Series1
Series2



Child CH - Drumming Duration
(robot with delayed response)
Duration (sec)
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2.00
1.50
1.00
0.50
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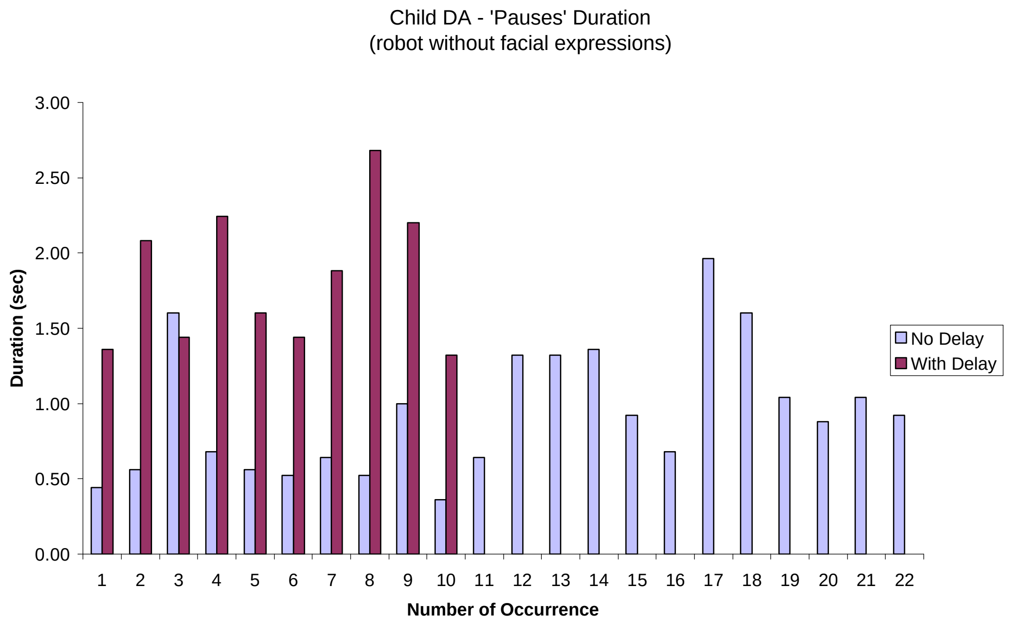
1
2
3
4
5
6
7
8
9
10
11
12
13
Number of Occurrence
No Expression
With Expression



Child DA - 'Pauses' Duration
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Duration (sec)
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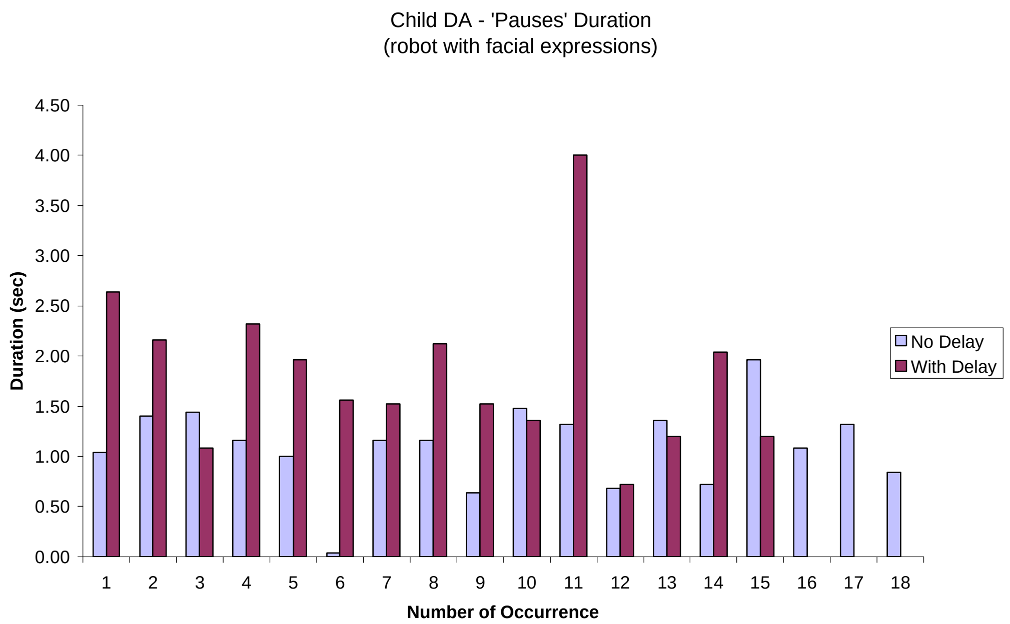
2.50
2.00
1.50
1.00
0.50
0.00
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22
Number of Occurrence
No Delay
With Delay



Child DA - 'Pauses' Duration
(robot with facial expressions)
Duration (sec)
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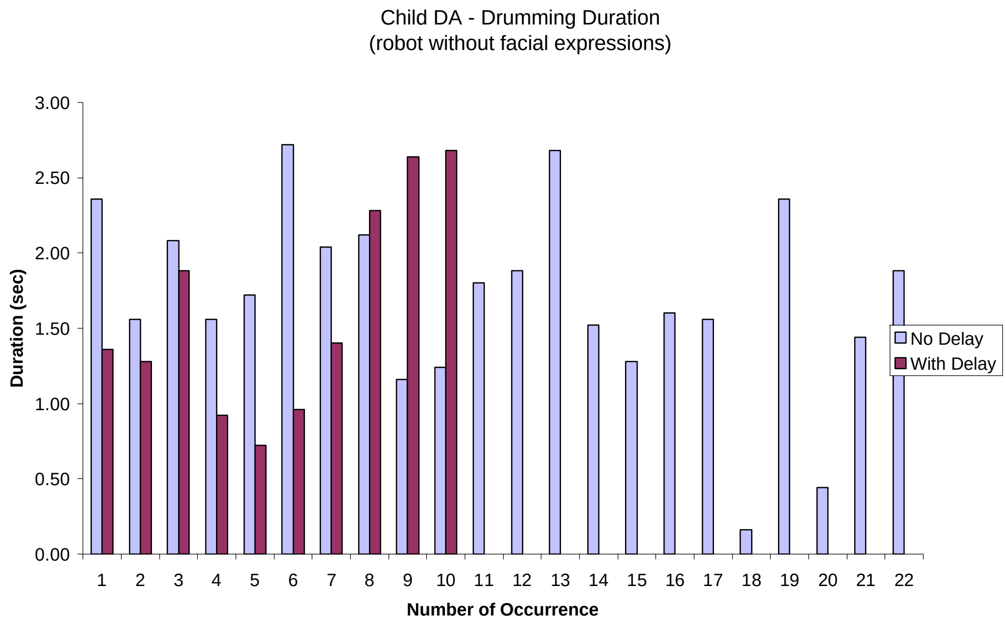
4.00
3.50
3.00
2.50
2.00
1.50
1.00
0.50
0.00
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18
Number of Occurrence
No Delay
With Delay


Child DA - Drumming Duration
(robot without facial expressions)
Duration (sec)
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2.00
1.50
1.00
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0.00
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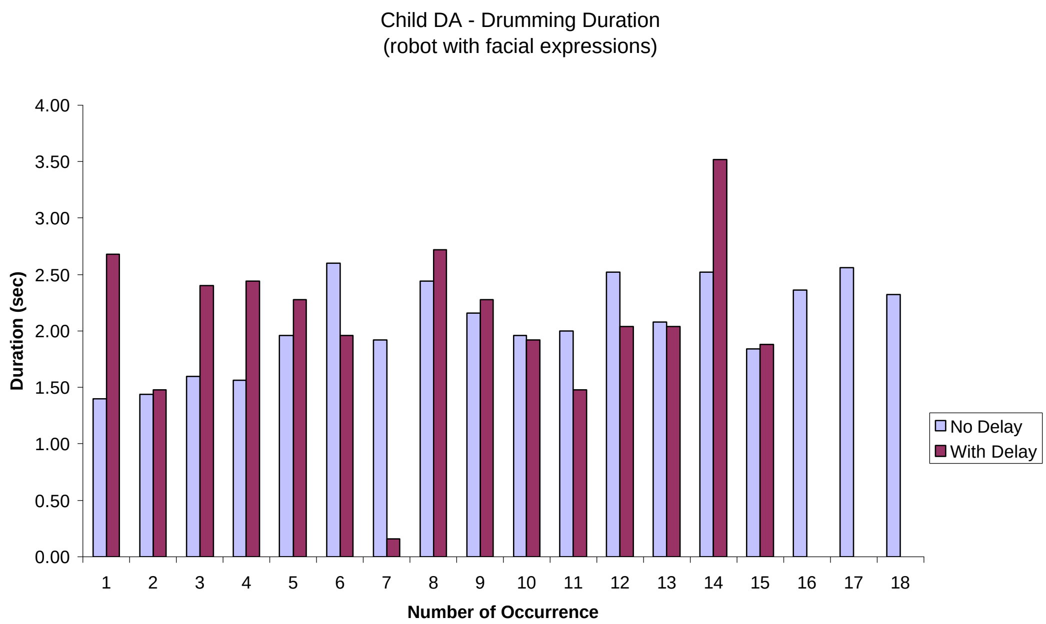
Number of Occurrence
No Delay
With Delay


Child DA - Drumming Duration
(robot with facial expressions)
Duration (sec)
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3.00
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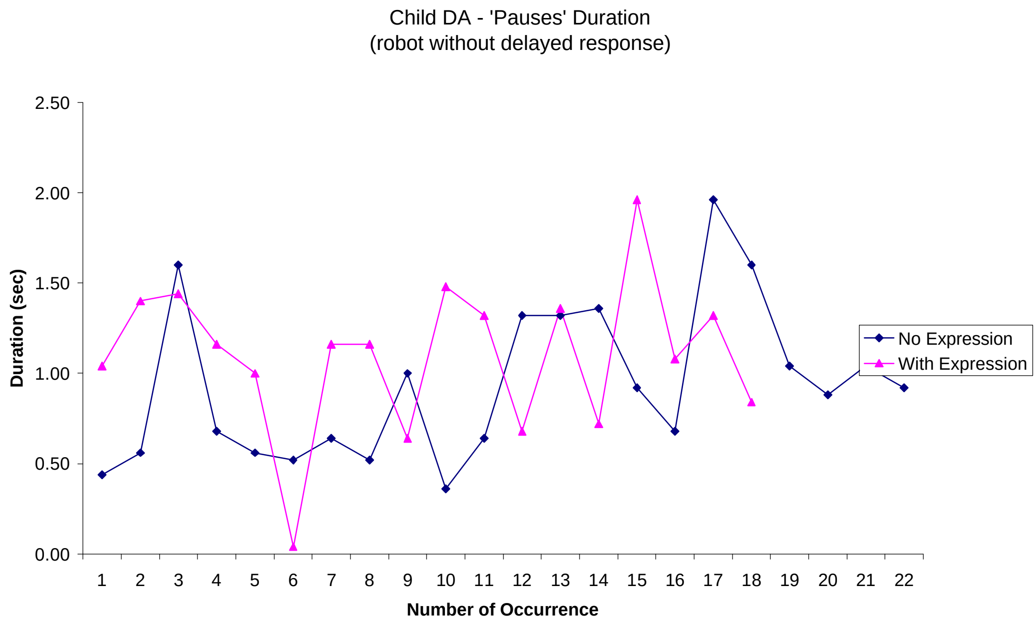
0.00
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18
Number of Occurrence
No Delay
With Delay


Child DA - 'Pauses' Duration
(robot without delayed response)
Duration (sec)
2.50
2.00
1.50
1.00
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0.00
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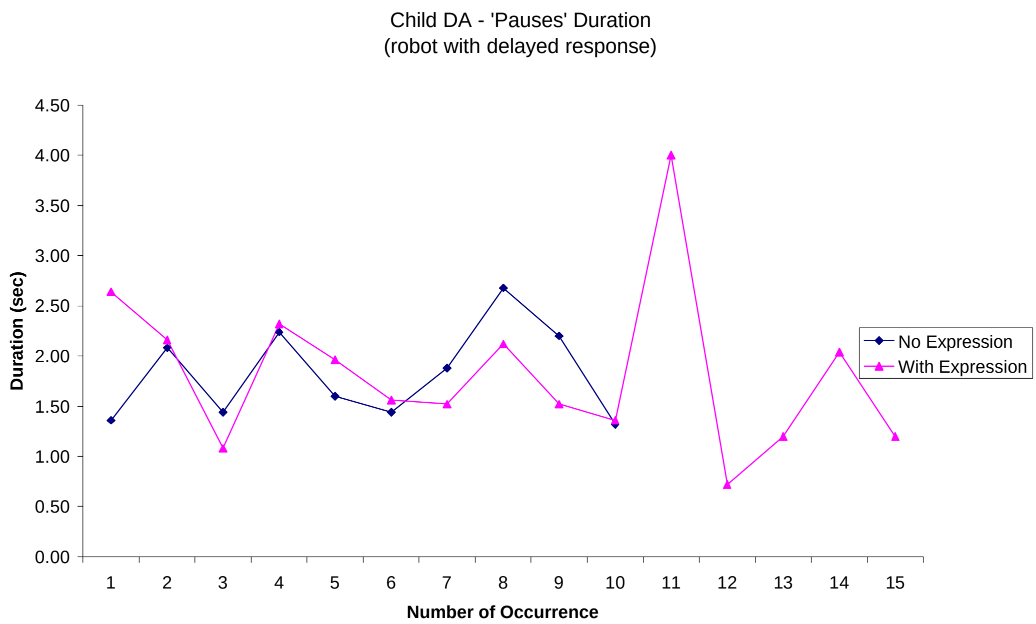
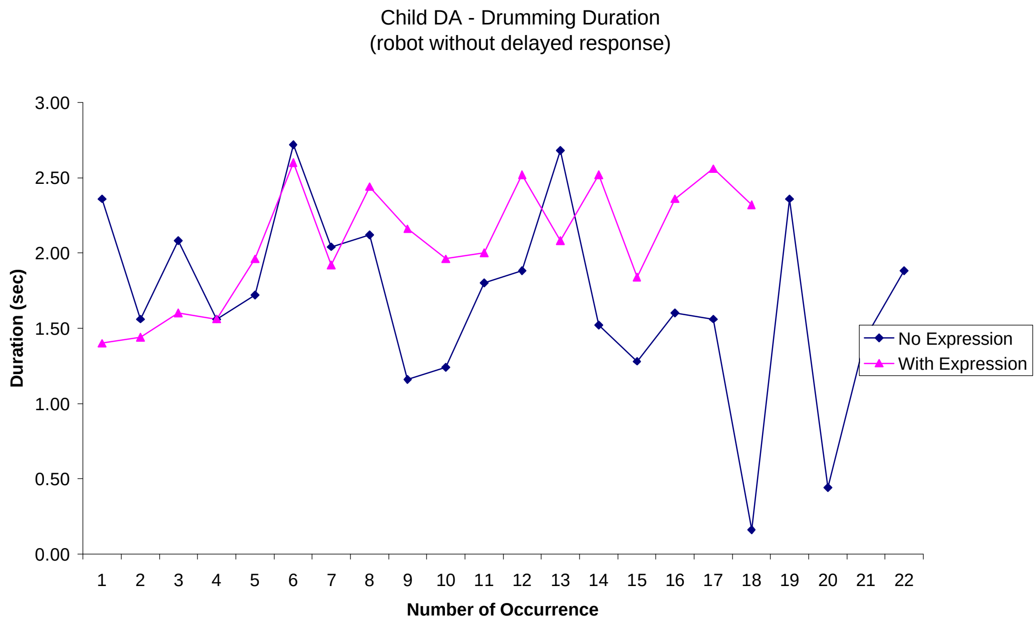
Number of Occurrence
No Expression
With Expression


Child DA - 'Pauses' Duration
(robot with delayed response)
Duration (sec)
4.50
4.00
3.50
3.00
2.50
2.00
1.50
1.00
0.50
0.00
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15
Number of Occurrence
No Expression
With Expression


Child DA - Drumming Duration
(robot without delayed response)
Duration (sec)
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2.50
2.00
1.50
1.00
0.50
0.00
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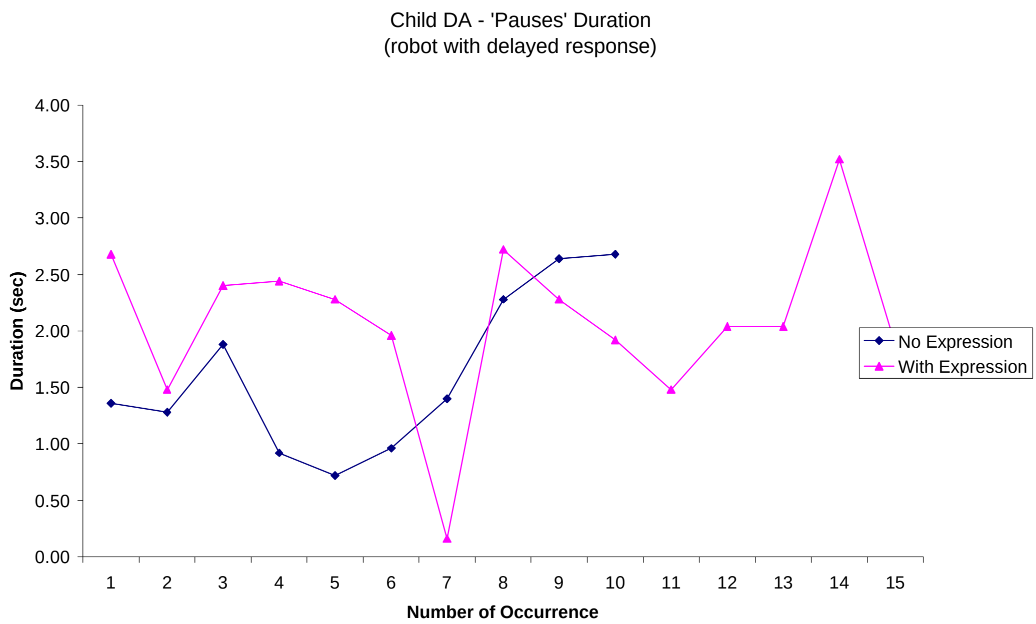
Number of Occurrence
No Expression
With Expression


Child DA - 'Pauses' Duration
(robot with delayed response)
Duration (sec)
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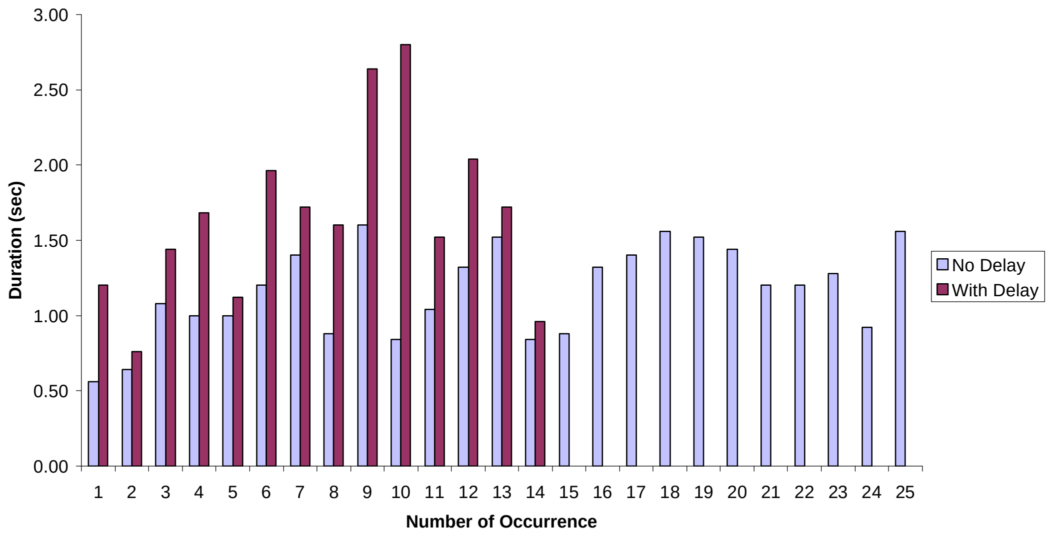
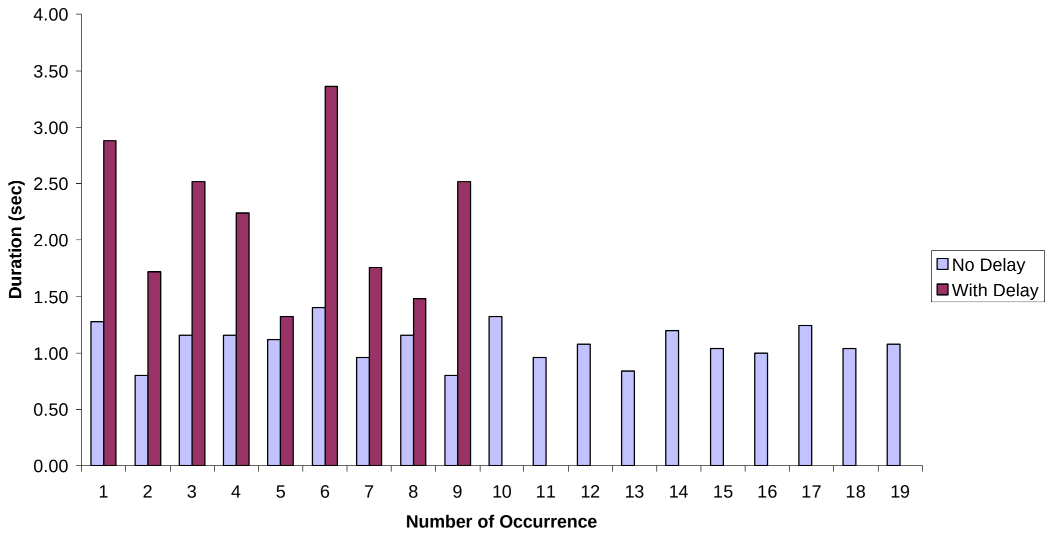
3.50
3.00
2.50
2.00
1.50
1.00
0.50
0.00
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15
Number of Occurrence
No Expression
With Expression

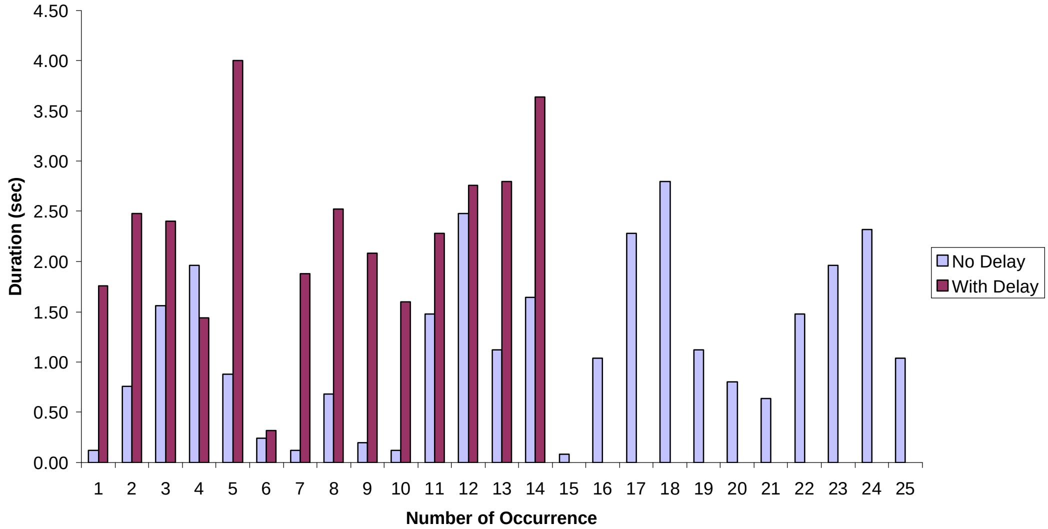
Child GE - 'Pauses' Duration
(robot without facial expressions)



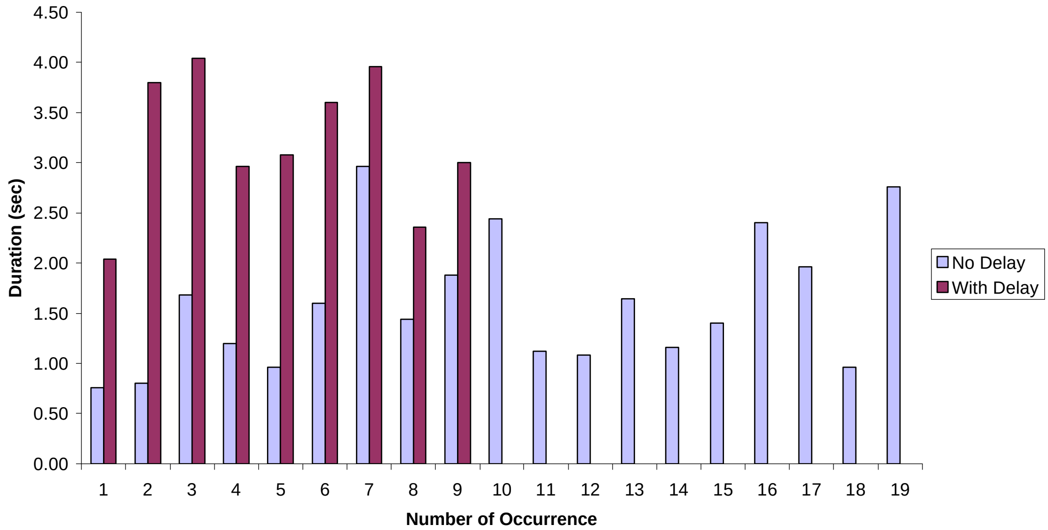
Child GE - 'Pauses' Duration
(robot with facial expressions)



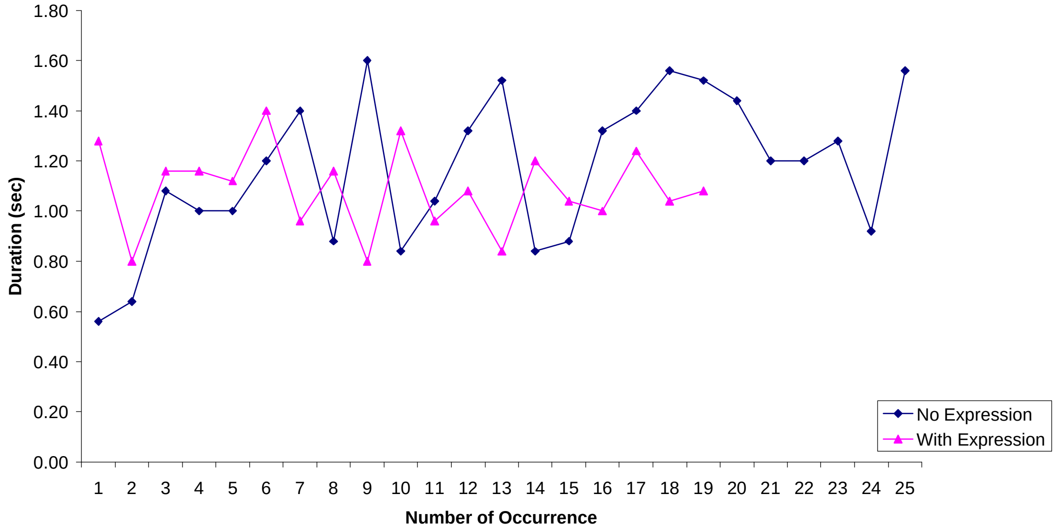
Child GE - Drumming Duration
(robot without facial expressions)



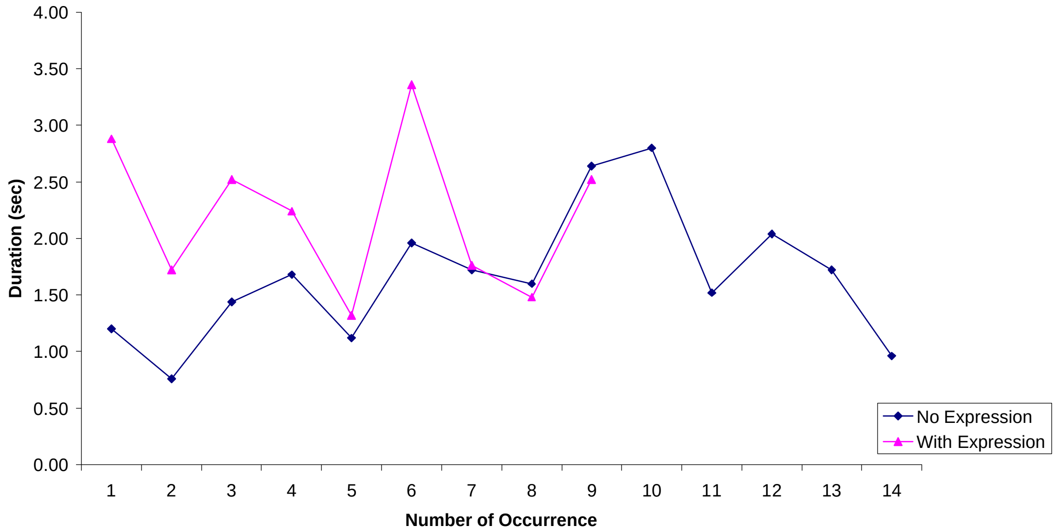
Child GE - Drumming Duration
(robot with facial expressions)



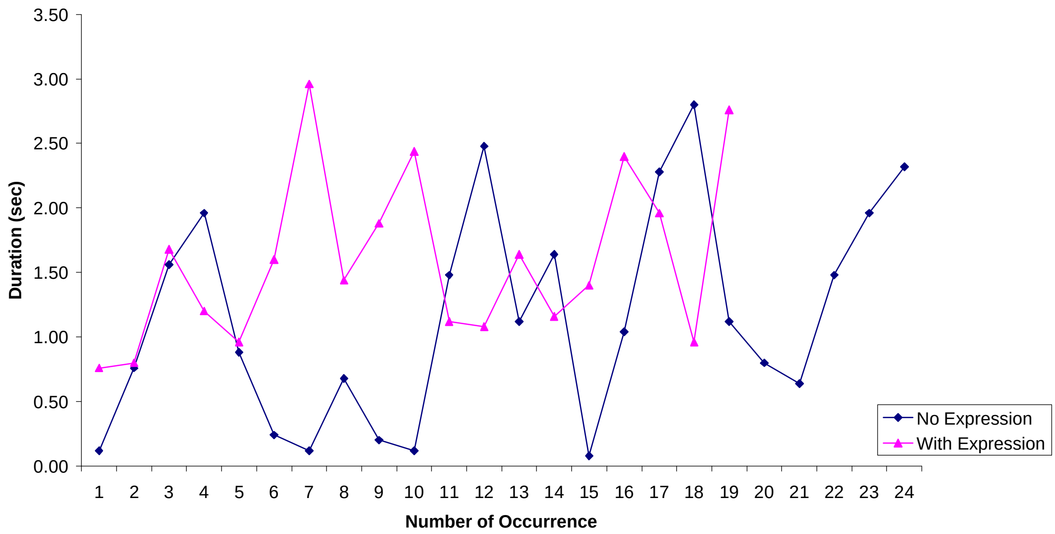
Child GE - 'Pauses' Duration
(robot without delayed response)



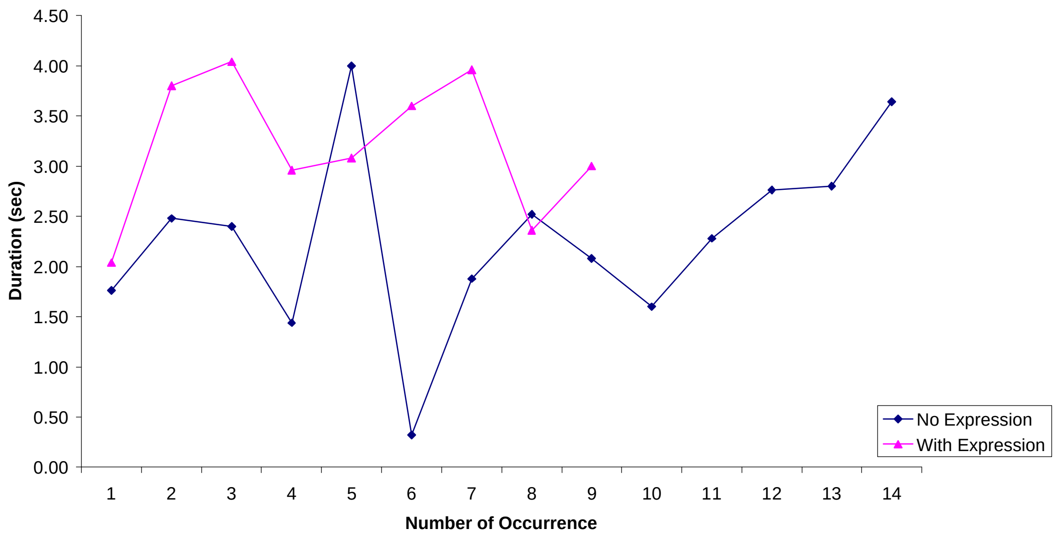
Child GE - 'Pauses' Duration
(robot with delayed response)

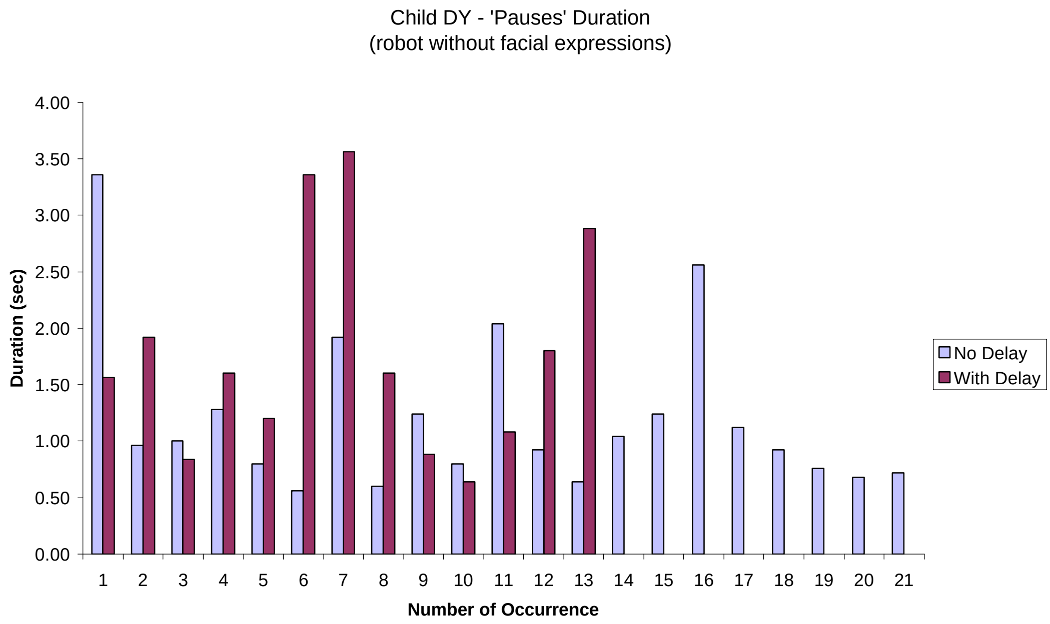


Child GE - Drumming Duration
(robot without delayed response)

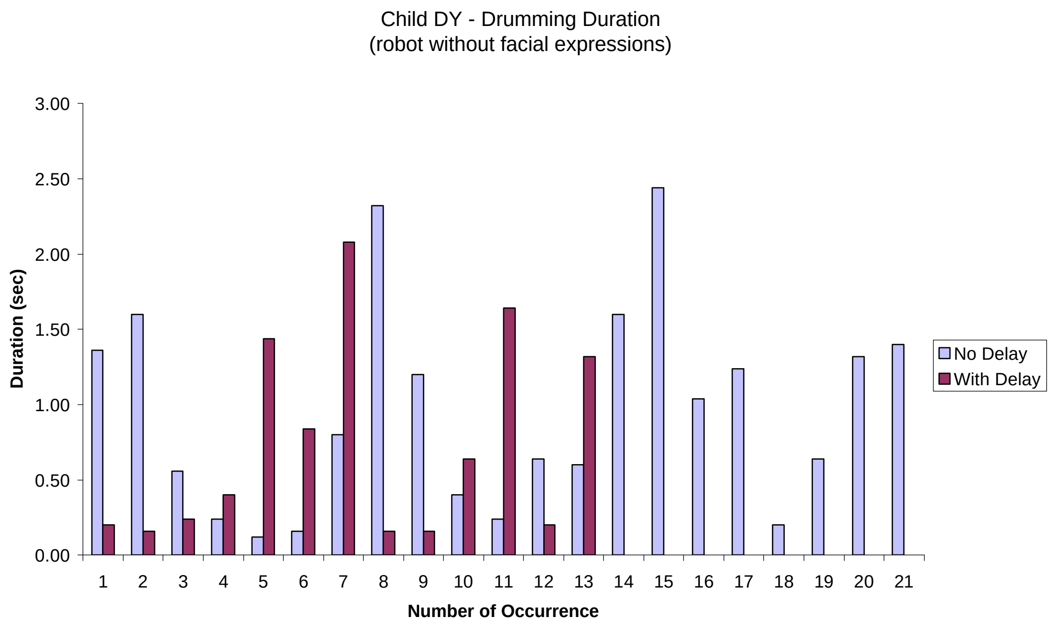


Child GE - Drumming Duration
(robot with delayed response)



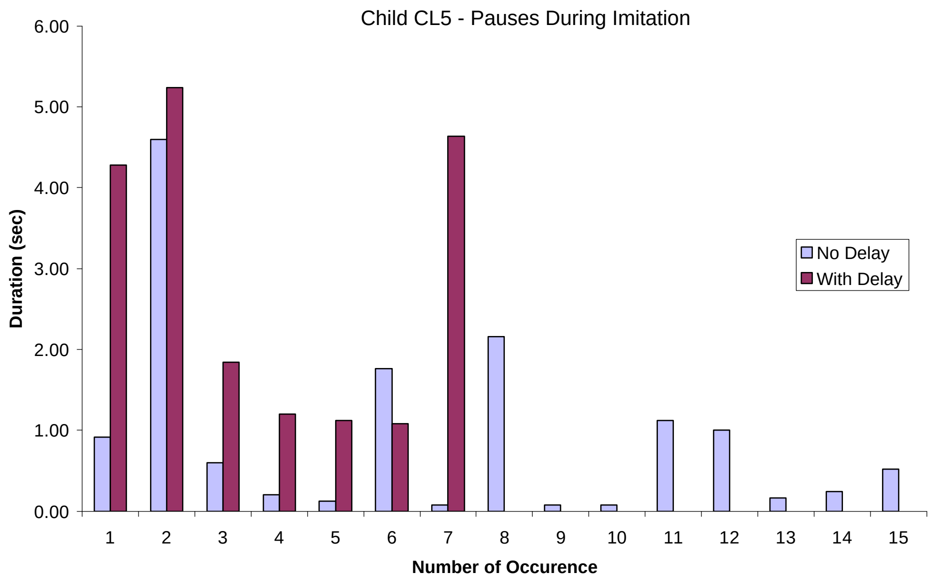


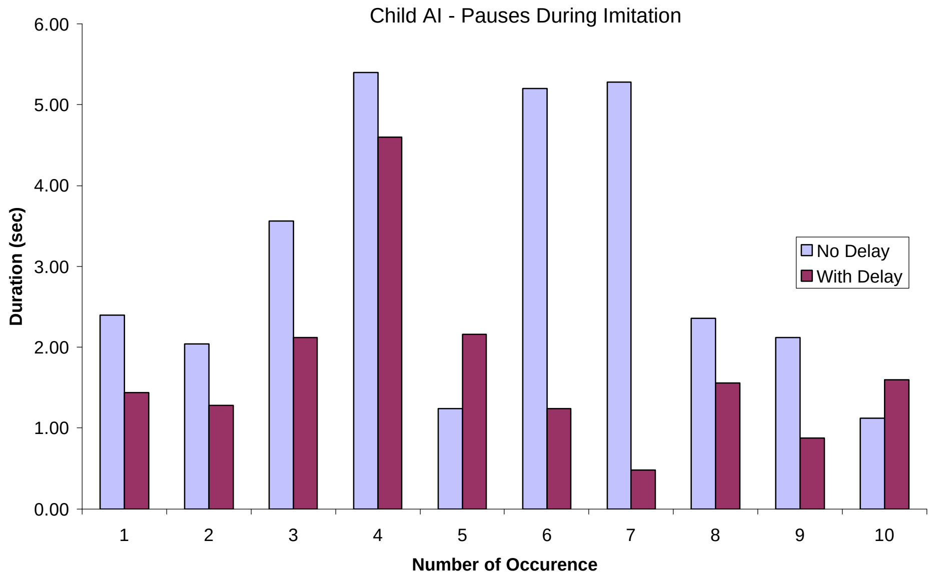
Child DY - 'Pauses' Duration
(robot without facial expressions)
Duration (sec)
4.00
3.50
3.00
2.50
2.00
1.50
1.00
0.50
0.00
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21
Number of Occurrence
No Delay
With Delay

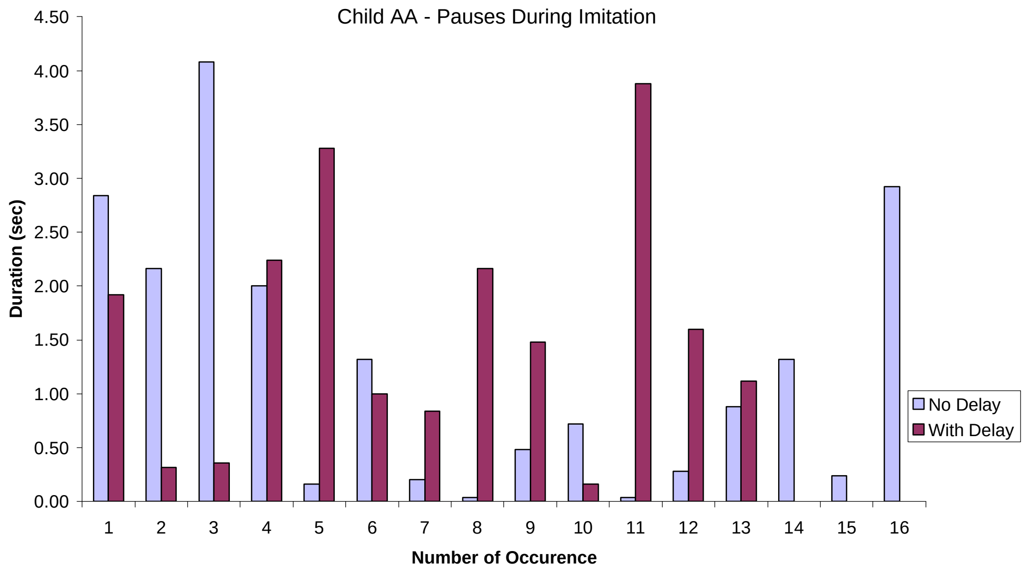


Child DY - Drumming Duration
(robot without facial expressions)
Duration (sec)
3.00
2.50
2.00
1.50
1.00
0.50
0.00
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21
Number of Occurrence
No Delay
With Delay

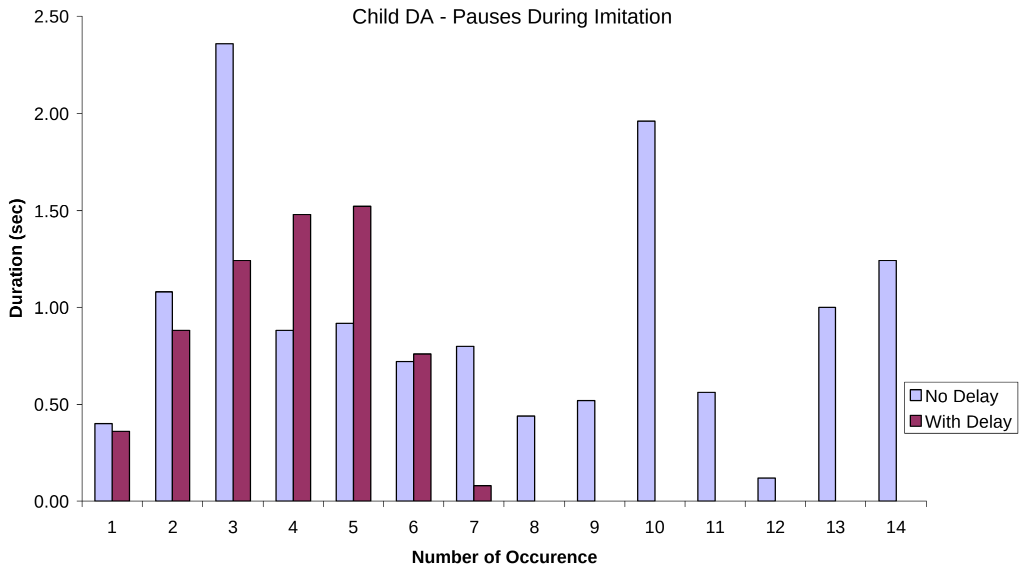
APPENDIX B – Imitation game - Charts



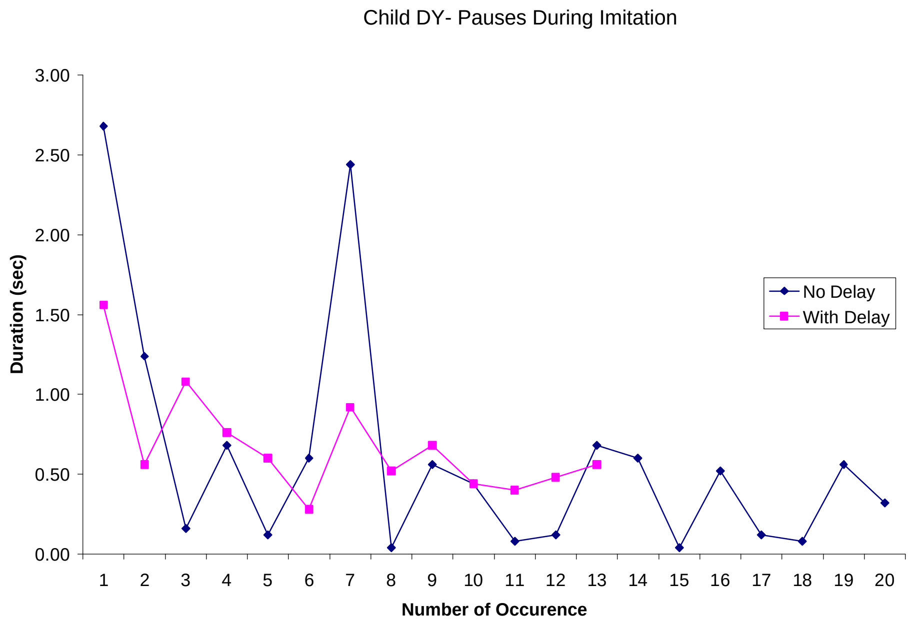




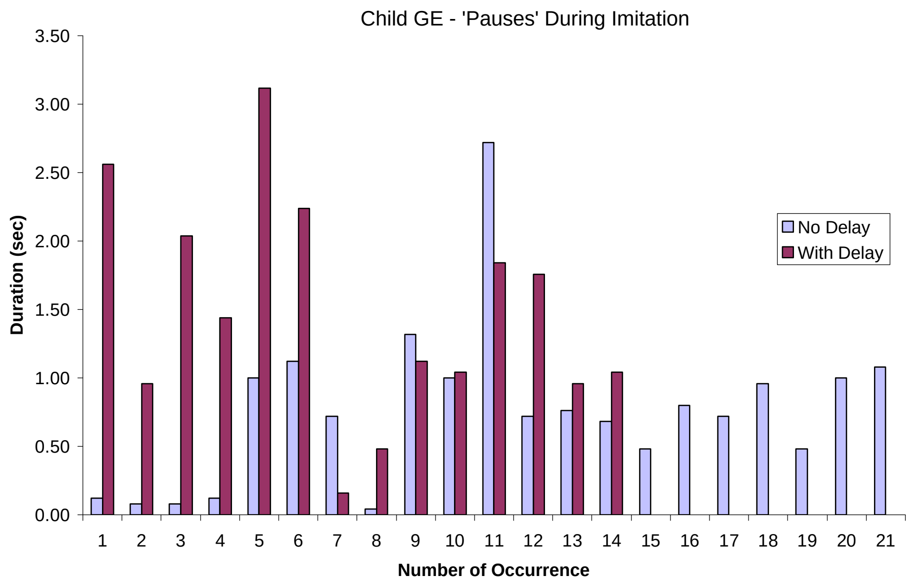
Child AA - Pauses During Imitation
Duration (sec)
4.50
4.00
3.50
3.00
2.50
2.00
1.50
1.00
0.50
0.00
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16
Number of Occurence
No Delay
With Delay



Child DA - Pauses During Imitation
Duration (sec)
2.50
2.00
1.50
1.00
0.50
0.00
1 2 3 4 5 6 7 8 9 10 11 12 13 14
Number of Occurence
No Delay
With Delay



Child DY- Pauses During Imitation
3.00
2.50
2.00
1.50
1.00
0.50
0.00
Duration (sec)
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
Number of Occurence
No Delay
With Delay



Child GE - 'Pauses' During Imitation
3.50
3.00
2.50
2.00
1.50
1.00
0.50
0.00
Duration (sec)
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
Number of Occurrence
No Delay
With Delay