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An Experimental Investigation of Interference Effects in Human-Humanoid Interaction Games*

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Abstract— **Investigating how people respond to and relate to robots is a multifaceted scientific challenge. This paper reports on an experimental investigation concerning movement interference effects between a human and a robot. We compare results with that obtained by Oztop et al. [1], however, in our study we used a small child-sized robot (KASPAR) with an overall human-like appearance. The experiment was conducted with both child and adult participants who interacted with a small humanoid robot using arm waving behaviours. The experimental setup was designed to be less constrained than in [1] with an emphasis on playful interaction. The experimental results did not show evidence for interference effects. This might be due to a more game-like and less constrained experimental environment or to the specific features of the robot or both. In addition to measurements of the variance of the movements, we investigated a measure for behavioural synchrony between human and robot movements based on the concept of information distance. The results of information distance analysis indicated that most of the human participants were affected by the robot's behavioural rhythms. While our experiments did not show a movement interference effect, we found behavioural adaptation of participants' movement timing to the robot's movements. Thus, the measure of behavioural synchrony that we introduced appears useful for complementing other measures (such as variance) previously used in the literature.**

I. Introduction

As robots move ever closer to our daily lives Human-Robot Interaction (HRI) has become an increasingly important field of research [2]. Modelling human-human interaction is an important approach to HRI, and may provide inspiration to how the communicative and interaction dynamics as well as mechanisms can be realized in human-robot interactions. Human beings commonly interact with each other via actions and language. It is important for humans to understand the underlying meaning when people observe actions and hear speech from others. Many researchers suggest that mirror neurons play a critical role in action and language understanding [3, 4, 5, 6, 7].

Following the discovery of mirror neurons in the premotor cortex of macaque monkeys [8, 9], which discharge when the subject performs an action and when the subject observes a similar action made by another agent, a great deal of research concerning the nature of the mirror neuron system has been carried out [10]. One finding was that a similar mirror neuron system also exists in human brains [1, 10]. It has been suggested that the mirror neurons facilitate the imitation of observed actions, which demonstrates a matching between the perceived action and its execution [11, 12]. There have also been studies of 'interference effects' which are thought to occur as a result of the co-activation of conflicting populations of mirror neurons and are exhibited when a subject is observing and performing incongruent behaviours (illustrated in table 1). These effects have been found in human-human interactions, however, it is thought that they may also occur in human-robot interaction when the robot is more human-like [1, 13, 14, 15]. Recent research also found that interference effects were present when participants were told that a moving dot which they observed was generated by a human and absent when the phenomenon was described as computer generated [16]. Therefore, we may hypothesize that if the interference effects exist in interactions between humans and humanoid robots, it might suggest that humans may perceive such robots as possessing some "human-like" qualities instead of regarding them as simple mechanical machines. Such research may also provide hints at what type of robots may be acceptable as social interaction partners.

TABLE I
Interference Effect Illustration

Agent	Interference Absence		Interference Presence	
Human	Horizontal	Vertical	Horizontal	Vertical
Robot	Horizontal	Vertical	Vertical	Horizontal

In Oztop et al.'s work [1] they describe a human-robot and human-human interaction experiment in which they successfully found an interference effect in human-robot interaction using the mechanically looking, but humanoid robot called DB. Earlier work by Kilner et al. [13] did not find interference effects in human-robot interaction when a robotic arm was used. Thus, it appears from the previous literature that the appearance (and associated movements) of robots may have an impact on the interference effect.

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A starting point for our research was to expand this line of research further and conduct the experiments with a 'social robot[1]' with not only a humanoid shape but a human (child) -like overall appearance.

The main motivations underlying the research presented in this paper were to replicate the interference experiments with a social robot having a human-like appearance in a less constrained and more playful interaction scenario, to investigate whether children and adults would respond differently in such conditions, and finally, to study whether synchronisation of human and robot movements could be observed. The detailed research questions of this experiment are described in section II below.

II. Experimental Setup

In July 2008 an experiment similar to that described by Oztop et al. [1] was carried out, but using a less constrained experimental framework. It has been previously found that an interference effect exists in human-human interaction [1, 13], therefore in our experiment we only concentrated on human-robot interaction. In addition, this experiment introduced new variable factors such as the effect of music and a comparison of two different age groups of participants.

A. Research Questions

In this experiment, we investigated the following four research questions:

1. Can an interference effect be found in a playful human-robot interaction experiment using a 'social robot'?
2. Will the use of music affect the participants' behaviour in the interaction experiment?
3. Can we find significant differences between children and adults in terms of their behaviour in the interaction games?
4. Will the rhythm of human behaviour be affected by the rhythm of the robot's behaviour?

The word 'rhythm' in this paper means "a strong, regular repeated pattern of movement or sound" [17].

Our expectations were as follows: As explained in section I the literature suggests an effect of robot appearance on the interference effect. We thus expected that a robot with even more human-like appearance features (compared to DB used in [1]), would elicit a strong interference effect. However, the more playful and less constrained setup of the interaction experiment may influence the outcome. The playfulness of the interaction with the robot was introduced due to their appropriateness for child participants. We expected that music, which emphasizes the robot's movement rhythm would strengthen the interference effect. Since different levels of engagement of children versus adults interacting with a robot could be expected, we hypothesized to find different results for children and adults. Finally, we expected to find that participants would adapt the rhythm of their movements to the robot since previous research with a different version of the same robot has shown that children adapt the timing of their movements to the robot's movements [18]. Our measure of synchrony for human and robot movements in interaction used a previously introduced and experimentally verified method [22].

B. Synchrony Measurement

The method we used for identifying these similar and synchronous actions employed the idea of similarity using *information distance*, previously described by Crutchfield [19] and based on *information theory* [20]. Information distance was used here to capture the spatial and temporal relationships between events.

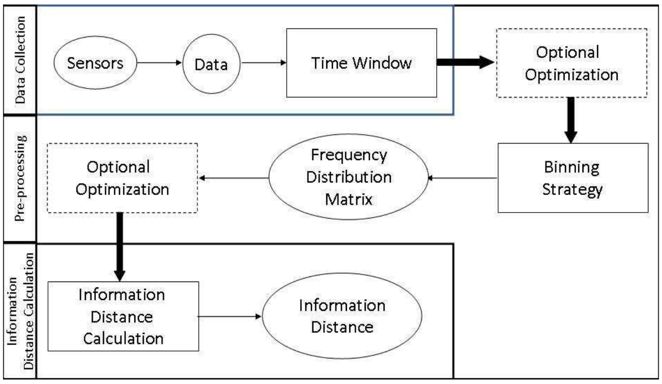


Fig. 1 The Similarity Method General Approach Flow Chart

The similarity identification method calculated the information distance between human and robot body part trajectories to yield an indication of their similarity. The numeric size of the information distance value gave an indication of similarity, the more similar the behaviors, the lower the value. Similarly, a higher value for information distance indicated less similar behaviors.

According to the general approach of this method (shown in Fig. 1), as a first step, the collected 3-D trajectory data of the participants and the robot movements was allocated into different data bins according to its value and the binning strategy. The binning strategy component was then used to extract data distribution features. These features were the critical source of information to conduct the information distance calculation. The calculation of information distance between two data columns, usually a pair of corresponding behavior components from the human and robot behavior respectively (for example, the x co-ordinates of the human forearm position and the x co-ordinates of the robot forearm position), is based on the information metric described by Crutchfield [19]. The information distance between two data columns X and Y is defined as the sum of two conditional entropies of these two columns [21]. It can be calculated using the following formula:

$$d(X,Y) = 2 * H(X,Y) - (H(X) + H(Y)) \quad [21]$$

This similarity identification model was verified using

[1] The term 'social robot' in the context of this paper refers to the humanoid robot KASPAR2 which has been designed by our research group with a number of human-like features and expressions (face, arms etc.) in order to facilitate human-robot interactions in 'social' contexts such as interaction games (as in this paper) or human-robot teaching. URL: http://KASPAR.feis.herts.ac.uk/

random data, artificial data, sine curve data and real human-robot interaction data. The validation results showed that the method was able to correctly identify similarity and synchronous behavior between a human and a robot, see more details in [22].

C. Experiment Design

The experiment described was conducted with both child and adult participants who interacted with a small humanoid robot. In total 14 children and 14 adults participated in the trials. However, following later video investigation, it was found that 4 child participants did not correctly follow the experimental instructions, which affected the data that was collected (e.g. one child tried to find out how fast the robot could move, rather than engaging in an interaction game). Therefore, the experimental data of these 4 children were excluded from the final data analysis. Note, all participants[2] were naive about the experiment.

The robot used in this experiment is called KASPAR2, developed by the Adaptive Systems Research Group at University of Hertfordshire. KASPAR2 is a child-sized humanoid robot with 18 DOF (degrees of freedom). It has 5 DOF in each arm, which enables it to perform some basic human-like waving behaviours. In this experiment, KASPAR2 only used its right arm (consistent with experiments in Oztop et al. [1]).

1) Waving Behaviours: Two basic waving behaviours were used in the experiment: vertical waving and horizontal waving. For both waving behaviours, the upper arm of a subject remained still and the subject used only the forearm, waving vertically or horizontally respectively. Therefore, the hand trajectory of the subject was curvilinear instead of linear, which was more natural and easy for both human and KASPAR2 to produce (note that in the Oztop et al.'s experiment [1] the trajectories were restricted to linear movements).

KASPAR2's waving behaviours were synchronized with a music track, which was the nursery rhyme: "Baa Baa Black Sheep". We chose a nursery rhyme because we expected that people may be more familiar with nursery rhymes and therefore find it easier to get involved in the music rhythm. In addition, many nursery rhymes have a slow and constant rhythm, which may allow better synchronization with KASPAR2's movements. The specified nursery music track had a duration of 30 seconds with a constant rhythm. The time interval between each beat in the music was 1.03 seconds and it took the robot 2.06 seconds to complete one single wave movement. That is, every single wave movement (for example, from left to right) of KASPAR2 took two beats and every complete back and forth wave movement (left to right then to left again) took four beats. During the whole experiment, KASPAR2 was waving at a constant speed. The transition between the with/without music conditions was conducted by simply switching on or off the computer speakers. With the music factor introduced, the participants were expected to synchronize more with the robot's behaviour when the music was on and to synchronize less when the music was off. Besides, music may make human-robot interaction more fun and more enjoyable.

2) Tracking System: A Polhemus Liberty magnetic motion tracking system was used to track the hand trajectories of both the human participant and of KASPAR2. Two magnetic sensors were attached on the waving hands of both human participants and KASPAR2 to collect data. The Liberty system returns the Cartesian coordinates of the sensors with respect to a fixed point (a large magnetic source).

TABLE II
EXPERIMENTAL SETUP COMPARISON

Experiment Setup Items		Oztop et al.'s Experiment	Current Experiment
Waving Behaviour	Direction	Top-Right to Bottom Left/Top-Left to Bottom Right	Vertical/Horizontal
	Frequency	0.5Hz	Not Specified
	Trajectory	Linear	Curvilinear
	Arm Used	Whole Arm	Forearm only
	Instructions Given	Detailed	General
Participants	Age	Adults	Adults/Children
	Distance to the Robot	2m	Around 1m
Agent		Robot/Human	Robot
Music		No Music	Music On/Off
Robot Platform			

3) Participant Instructions: During the experiment, the participants were asked to follow a few instructions. In order to create playful interaction, human participants were not specially trained to perform certain movements and many instructions given were very general instead of specifying every single detail:

1. Each participant was asked to stand facing KASPAR2 within a given distance (around one metre).
2. Each participant was shown the two basic waving movements described above and given a demo by the experimenter before starting the experiment.
3. Each participant was asked to only use their right arm in the experiment. However, the amplitude, speed and rhythm when the participant waved his or her arm was not restricted (from Oztop et al.'s [1] where the participants were explicitly instructed to be in phase with the other agent's movements).
4. Each participant was asked to concentrate on KASPAR2's waving arm when waving his or her arm.
5. Each participant was asked to interact with KASPAR2 for 8 trials.

These trials represented different experimental conditions according to 3 variables (2x2x2 within participant design, randomized order of the experimental conditions):

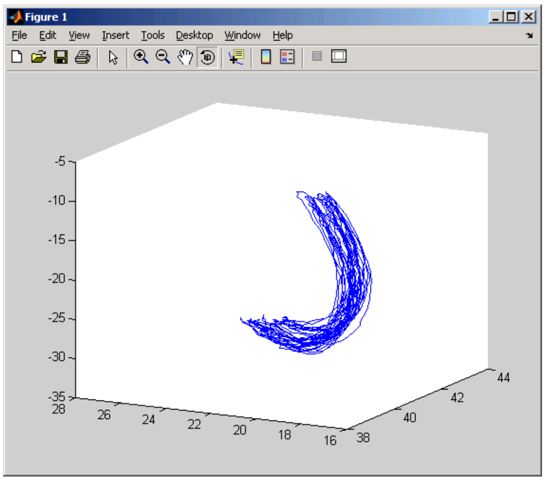
- arm waving direction (vertical/horizontal),

[2] The 10 children were all male and between 11 and 12 years old. The 14 adult participants (4 female, 10 male) were aged 18-52 (10 participants were between 23-26 years old). Thirteen adult participants were university students, one worked for a company.

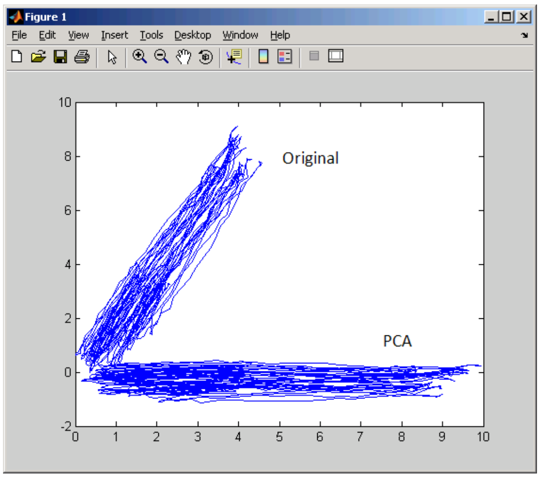
- human-robot behaviour congruency (congruent/ incongruent) and
- music effect (with/without).

Each trial lasted around 30 seconds. Participants were informed when to start before each trial and when to stop after each trial.

The major differences in experimental setup between the experiment described in Oztop et al.'s work [1] and the current experiment are summarised in table 2.



(a)



(b)

Fig. 2 (*a*) illustrates an example of human participant hand trajectory in 3-D space; (*b*) illustrates the mapping of the trajectory in figure *a* and the PCA of the mapping. The PCA is orthogonal to one of the axes.

III. Analysis of Results

A. Measurement Definition

The possible interference effects of human-robot interaction were measured by the variances in the waving movement, as in previous work e.g. by Oztop et al. [1]. In this experiment, the movement variances were defined as the variance orthogonal to a subject's main motion plane. For example, when a subject was waving horizontally, only the variances in the vertical direction (z-axis) were considered.

However, when a subject was waving vertically, it was more complex to locate the variances. This was because, in the experiment setup, the magnetic source was placed diagonally to the participants due to restrictions in the magnetic field generated by the Polhemus device. The range and position of the magnetic field also had to be limited to maintain the accuracy of measurement. Consequently, there was no axis (x, y or z) orthogonal to the subject's main motion plane in the vertical waving condition. An alternate approach applied was to take the mapped trajectory on the horizontal plane (x-y plane) and perform a PCA (Principal Components Analysis) to extract the desired axis. Usually, the first principle component (marked as the new x-axis, x') could be regarded as the mapping of the main motion plane on the horizontal plane. Therefore, the second principal component (marked as the new y-axis, y'), which was orthogonal to the x' axis, was the axis expected (Fig. 2). Through manual inspection, 94.8% of the vertical waving trajectories could use PCA to locate the axis. The axes of the rest of the trajectories were located manually.

In addition, the synchrony and similarity of the robot and participants' behaviours were also measured using an information distance approach [22], which was described in section II.

B. Interference Effect Analysis

A repeated-measures ANOVA was performed on the mean of the movement variances calculated across all trials for each condition (Table 3). Four fixed factors were involved in the ANOVA test: behaviour congruency, waving direction, presence of music and age group. The result showed that there was a significant effect in waving direction ($p < 0.05$) and age group ($p < 0.01$) (Fig.3).

However, there was no significant effect of congruency ($p > 0.1$) found in the experiment. The interaction effect between congruency and movement direction was not significant but very close ($p < 0.08$), which might potentially suggest that the congruent and incongruent behaviours had different impacts on the variability of the human movements in different directions (Fig. 3a).

The significant effect of waving direction was also found in Kilner et al.'s work [13] and Oztop et al.'s work [1], so our results validate their findings. Note, a possible explanation for the fact that we did not find support for the interference effect might be due to the different approaches used in locating the axis that the variance was calculated from.

The significant effect of age group suggested that the children and the adults behaved differently while interacting with the robot. The mean value of the variances in the children's behaviour was significantly higher than the adults' behaviour (Fig.3b). A possible explanation could be that the children adopted a stronger game-like attitude towards the task which lead to less constrained movements. Note, in the earlier work [1,13] higher variances have been interpreted as an indication for interference effects involving the mirror system. Our results did not show an interference effect but still higher variances in children's movements. Thus, future experiments need to investigate this finding further.

There was no significant effect overall in movement congruency. This may be due to the less constrained and more playful set up of the interaction experiment. The interference effect that might occur within a strict experimental setup might be overshadowed in a more relaxed and 'natural' human-robot interaction trial:

1. The type of the waving behaviour in our experiments was more natural (less linear).
2. The participants were not specifically trained to perform particular movements.
3. Only general instructions of how participants should wave their arms were given during the experiment.
4. There were no restrictions imposed on frequency or rhythm in participants' waving behaviours.

Thus, any of the factors mentioned above could have caused the interference effect to remain obscure in our experiments.

TABLE III
TESTS OF BETWEEN-SUBJECTS EFFECTS IN INTERFERENCE EFFECT ANALYSIS

Dependent Variable: Variance

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	54.489[a]	15	3.633	1.467	.122
Intercept	881.119	1	881.119	355.824	.000
Congruency	3.068	1	3.068	1.239	.267
Direction	16.783	1	16.783	6.777	.010
Music	.473	1	.473	.191	.662
Age	17.159	1	17.159	6.929	.009
Congruency * Direction	7.884	1	7.884	3.184	.076
Congruency * Music	4.338	1	4.338	1.752	.187
Congruency * Age	2.205	1	2.205	.890	.347
Direction * Music	.163	1	.163	.066	.798
Direction * Age	.283	1	.283	.114	.736
Music * Age	4.380E-5	1	4.380E-5	.000	.997
Congruency * Direction * Music	.073	1	.073	.029	.864
Congruency * Direction * Age	1.423	1	1.423	.575	.449
Congruency * Music * Age	2.042	1	2.042	.824	.365
Direction * Music * Age	.223	1	.223	.090	.764
Congruency * Direction * Music * Age	.159	1	.159	.064	.800
Error	435.824	176	2.476		
Total	1353.994	192			
Corrected Total	490.313	191			

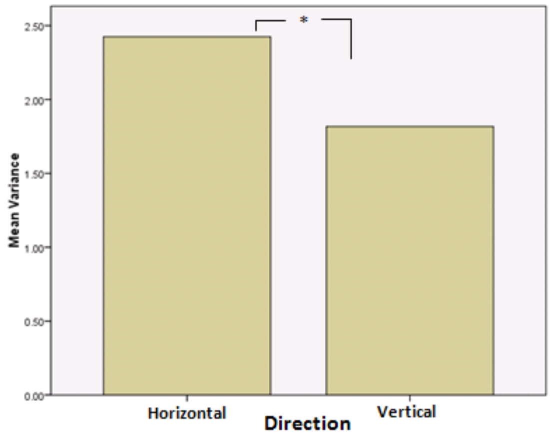
a. R Squared = .111 (Adjusted R Squared = .035)

Besides, we did not find any significant effects for the music condition, which suggests that in our experiments music did not affect the variability of the human movements in human-robot interaction. Note, a possible explanation for this result could be that nursery rhymes may not have been suitable for either age group. However, we decided to chose one and the same music for both age groups, due to consistency purposes, and had assumed that both groups of participants may be familiar with such rhymes (e.g. via younger siblings or own children).

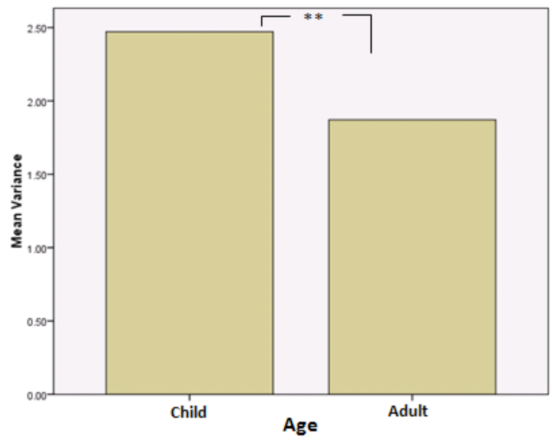
C. *Information Distance Analysis*

An ANOVA test was performed in the information distance analysis which was similar to the previous ANOVA test except the dependent variable was changed to information distance (Table. 4).

Significant effects were found in age group (p < 0.01), which validated the similar result in the variance interference effect analysis. Figure 5 shows that the mean value of information distance for children was much lower than the value for adults, suggesting the rhythm of waving in children's behaviour was more synchronized with the robot's rhythm than the adults' rhythm.



(a)



(b)

Fig. 3 figure *a* and *b* showed the effects of waving direction and age group. (a) The mean value of the variances that occurred in horizontal waving was much higher than the value of vertical waving. (b) The mean value of the variances that occurred in the behaviours of the children was much higher than the value in adults' behaviours. The significances of the ANOVA test are also shown in the figure (*: p <.0.05; **: p < 0.01).

A further statistical analysis of information distance values showed that the rhythm of waving behaviour of human participants was synchronized with the rhythm of the robot in over 81% of the trials (the information distance value of these trials were below 1.5, which was an empirical value indicating synchronization obtained in earlier research [22]). Note, that during the experiment, the participants were not instructed to wave with a particular rhythm or imitate the robot, instead, they were instructed to decide their behaviour rhythm by themselves. Therefore, the results show that the participants were affected by the robot's behaviour rhythm in the human-robot interaction experiments and adapted to it, which confirms previous results on timing adaptation in human-robot interaction experiments [18].

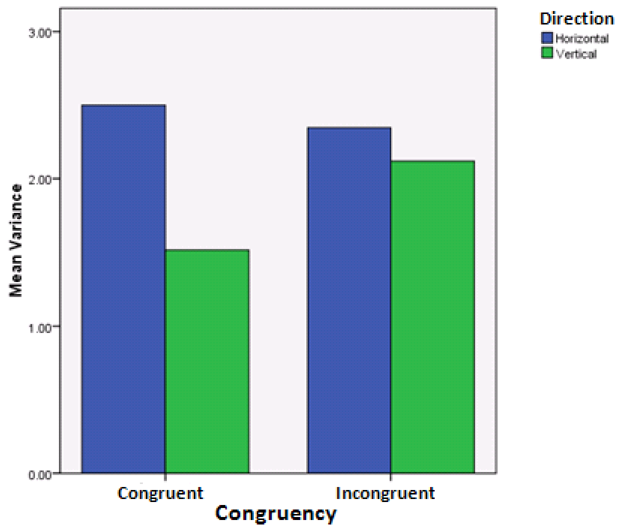


Fig. 4 The interaction effect between congruency and direction might potentially suggest that the congruent and incongruent behaviours had a different impact on the variability of the human movements in different directions

TABLE IV
TESTS OF BETWEEN-SUBJECTS EFFECTS IN INFORMATION DISTANCE ANALYSIS

Dependent Variable: InfoDist

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	3.643[a]	15	.243	1.534	.097
Intercept	280.766	1	280.766	1773.551	.000
Congruency	.059	1	.059	.371	.543
Direction	.000	1	.000	.001	.976
Music	.137	1	.137	.864	.354
Age	1.844	1	1.844	11.647	.001
Congruency * Direction	.014	1	.014	.090	.765
Congruency * Music	.046	1	.046	.291	.590
Congruency * Age	.000	1	.000	.002	.967
Direction * Music	.001	1	.001	.009	.925
Direction * Age	.248	1	.248	1.569	.212
Music * Age	.019	1	.019	.118	.732
Congruency * Direction * Music	.019	1	.019	.122	.728
Congruency * Direction * Age	1.176	1	1.176	7.431	.007
Congruency * Music * Age	.001	1	.001	.005	.943
Direction * Music * Age	.010	1	.010	.066	.798
Congruency * Direction * Music * Age	.055	1	.055	.344	.558
Error	27.862	176	.158		
Total	328.146	192			
Corrected Total	31.505	191			

a. R Squared = .116 (Adjusted R Squared = .040)

Note, Oztop et al. [1] relate their finding of the movement interference effect to the participants' perception of the robot as 'human'. In our experiments we did not find an interference effect, but we found behavioural adaptation of participants' movement timing to the robot. Thus, the measure of behavioural synchrony introduced above (section II) appears useful for complementing other measures (such as variance). This approach may offer a different route towards the multifaceted scientific challenge of understanding how people respond to and relate to robots.

There was no significant effect involving music in the information distance analysis. This may be because the rhythm of the music was the same as the behaviour rhythm of the robot. Thus, the facilitation effect of music could not be revealed even if it did exist.

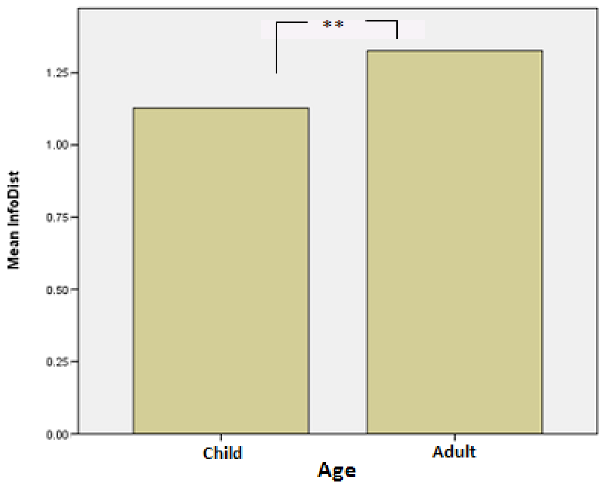


Fig. 5 This figure showed that the mean value of information distance of children was much lower than the value of adults. The significance of the ANOVA test is also shown in the figure (*: $p < 0.05$; **: $p < 0.01$).

IV. DISCUSSION AND FURTHER WORK

With respect to the research questions formulated in section II.A the results can be summarised as follows:

We did not find evidence for the movement interference effect in our experiments. This might be due to the less constrained and more playful experimental environment.

Alternatively, the specific robot used in the experiment could be an important factor. Recent research from neuro-imaging and neuro-psychological studies indicates that there are at least two routes of imitation: one is a goal-directed route and the other is a non-goal directed (the waving behaviours described in this paper can be regarded as non-goal directed behaviours as the participants were not informed of any particular goal during the interaction). The non-goal directed imitation appears to require from the imitatee greater reliance on effector selection (e.g. hand) and movement execution [7, 23]. Press et al.'s work [14, 15] may support this finding, which suggests that robotic stimuli have an impact on humans' mirror neuron systems if the robotic stimuli are similar to the human stimuli in visual properties. This implies that the limitations in robots can contribute to the absence of interference effects, which gives another possible explanation as to why there was no interference effect found in this experiment. There were some limitations in KASPAR2, which may affect the participants' concentration or behaviours during interactions:

1. The robot's servos were noisy.
2. The robot was in a sitting posture when the participants were standing, which caused differences in height between the robot and the participants. The participants were not instructed to sit on a seat because the seat would restrict the freedom of their behaviours.
3. There were temporary limitations in the robot neck servos. Therefore, it could not raise its head enough to face the participants.

An alternative explanation for the lack of the interference effect in the data is that the appearance of the robot is in the danger of falling into the 'uncanny valley' [24], which may be a factor in explaining whether robotic stimuli are effective or not. The "uncanny valley" is a theoretical idea that suggests that as robots become more human-like, they become less appealing to a real human. Only when true human-like features and movements appear does the "appeal" factor rise from the valley [24]. Although some robotic stimuli are very similar to human stimuli, if these stimuli fall into the uncanny valley and give humans a negative impression, then the mirror neuron system may not respond to them.

The experimental results indicated that the waving direction had significant impact on the human participants' behaviour, which validated similar results in Kilner et al. [13] and Oztop et al.'s work [1]. Our results also showed differences in movement variances between children and adults. In addition, the results of an information distance analysis indicated that most of the human participants were affected by the humanoid's behaviour rhythm, which may potentially suggest that the robot was regarded as an interaction 'partner'. We did not find any significant effect involving music. A possible explanation was that the rhythm of the robot's behaviours, which was the same as the music rhythm, are shadowed the effect of the music. Alternative, the choice of the music may have influenced the result.

Research into robot appearance suggests that an appropriate match between a robot's appearance and its social functionality can facilitate human acceptance and cooperation in interactions [25]. In this experiment, the servo noise and occasional shaky movements of KASPAR2 may have impaired its social functionality.

Moreover, some researchers found that children prefer interaction with a more machine-like robot over a more human-like robot [26, 27]. After the experiment, some participants, including children, reported that the rubber face of KASPAR2 looked scary. All of the feedback mentioned above indicated that KASPAR2 had very likely fallen into the uncanny valley, which may explain why KASPAR2 could not achieve responses from human participants' mirror neuron systems, although it looked more human-like (i.e. possessed more human-like appearance features) than e.g. the robot used in Oztop et al.'s work.

One may argue that the behavior rhythm could be affected by other simple rhythmic movements, e.g. caused by a pendulum or a moving dot on a screen instead of physical robots. That is, although the participants' behaviour rhythm was affected by the robot this may not necessarily mean that the participants treated the robot as a potential interaction partner. Our future work will try to validate this point by replicating the experiment using other visual stimuli instead of a robot. Further work may also change the rhythm of the music to further validate the impact of the music.

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