# We, Robots: Correlated Behaviour as Observed by Humans

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**Abstract.** In this study participants judged on the relationship between two interacting robots, one of them a mobile robot, the other one a stationary, robot arm-based artistic installation with a high flexibility in orienting its anthropomorphic face. The robots' behaviour was either (1) weakly correlated through a loose tracking function, (2) independently random, or (3) independently random, but constrained to the same closely limited area. It was found that the true degree of coupling was reflected on average in the rating responses but that pseudo-random behaviour of one of the robots was judged less random if a relationship between the two robots was present. We argue that such robot-robot interaction experiments hold great value for social robotics as the interaction parameters are under complete control of the researchers.

**Keywords:** Robot-robot interaction, behaviour coupling, agency, Articulated Head.

## 1 Background

When thinking about social robotics and social robots, we appear to have primarily their interaction with humans in mind and pay rarely attention to Robot-Robot Interaction (RRI). Given that the purpose of social robots lies in the interaction with humans, it does not surprise, although with social robots becoming more common place in the near future, it can be expected that they will have to interact with each other and the outcomes of these interactions might have consequences for their human owners. This fact on its own would make experiments in RRI worthwhile, but it is not the primary reason why we are intrigued by RRI. At the centre of our interest is a more fundamental question: Why shouldn't robots socialise with each other in the first place? Social interactions were arguably responsible for the rapid and unique cognitive development of the human species [13,4] and in the same way social robots could be become more sophisticated (e.g., along the lines described in [12]). While an autonomous robotic evolution is still more or less in the realm of science fiction, a more methodologically orientated motivation is already applicable

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and - we would argue - advisable: Human-robot interaction experiments include by definition a human participant who reacts to the robot and can adjust to interactive shortcomings of the robot, possibly even without being aware of the changes in behaviour. Thus, the combined human-robot entity is studied, usually intentionally so, but posing the difficulty to identify clearly the robot's part in the success or failure of the interaction.

Robot-robot interaction is largely under the control of the researcher. The drawback of RRI experiments on the other hand is their low explanatory value with respect to human-robot interaction, though probabilistic methods and machine learning would allow for very valuable insights to be gained nevertheless: If the experiment is situated in an ecologically valid environment, say, a supermarket, the interaction is influenced by the environment and the resulting behaviour of the robots is likely to become complex. The results move from an area of easy predictability to uncharted territory, even if the adaptation ability of the robot control system is severely limited and despite that no human participant is directly involved in the interaction. The emphasis in the previous sentence must be on 'directly' since the two or more robots would act in a environment shaped by humans and intended for human use. Therein lies the specific value of such experiments. In a thought experiment one could have a robotic shopping assistance in a supermarket and the customer to be helped would be a robot, too. As pointed out before, it would be less motivated by the expectation of this being a likely scenario any time soon but more by the advantage of complete control over the parameters that drive the robots. Obviously, the experiment does not need to be a thought experiment; it could be done in reality right now with the current state of art of robots.

Whether or not this line of research belongs in a social robotics conference is an open question. We believe it should. The current study uses an RRI experiment in this way, but with a slightly different focus: it investigates human behaviour relative to robots by removing the human participants from the experiment and making them observers. Our previous work on robotic agency [8] raised questions about the recognition of agency by human interaction partners. We concluded that - at least within the specific work of art at the centre of this research - the impression of agency originated from the human-robot interaction itself, that it was largely attributed due to specific behaviour of the robot that evoked the impression of agency.

The inner workings of this process, however, could not be clarified. One of the simplest assumptions is that any clear 'wilful' relationship between the behaviour of two interacting parties would lead to the impression of agency. For trivial reasons, direct dependency can be ruled out as a plenitude of physical phenomena fall in this category due to cause-effect relationships. Thus, less than perfect correlations become a candidate, e.g., one interaction partner tracking the movements of the other though not constantly, but rather with substantial deviations. The control condition would be random instead of pursuit movements. But would human participants be able to identify loose couplings when looking at machines with doubtful capability for intentional agency and given a tendency to emphasise seemingly meaningful over random behaviour [5]?

Our primary robotic platform, the Articulated Head (see below) has a pursuit behaviour that is driven by an underlying attention model. It exhibits the property of a loose coupling to a moving person or a robot very remotely resembling a human (our secondary robot, a PeopleBot) in its vicinity. Our hypothesis was that observers would notice the relationship despite being rather loose and be able to distinguish it from random movements. Alternatively, participants might consider any random behaviour of the two robots connected because of short accidental movement similarities. As a third hypothesis it could be assumed that a spatial constraint on the movement would be enough to elicit the impression of mutually influenced behaviour. We were then further interested in knowing whether the relationship would influence randomness judgements with respect to either robot.

We included three conditions in the experiment of this study to be able to distinguish between the alternative explanations. In the first condition, the Articulated Head was steered by the attention model (THAMBS, see below) in normal mode. In the second condition, all sensing was switched off and the Articulated Head performed random idle movements as it would normally do if for some time its environment is void of any stimulus able to attract its attention. To create the impression of naturalness, the target values for each joint for these movements are drawn from normal or log-nomal probability distributions following a few simple rules [7]. In the third condition, the Articulated Head was driven by the simulated input of a single (small) person performing a constrained random walk within the area that was in the real world dedicated to the second robot, the PeopleBot. As a consequence, the motion of the Articulated Head was in the height range of the PeopleBot and the orientation of its end effector (the LCD monitor) constrained to point to the area in which the PeopleBot was moving while not following it or only accidentally so.

We recorded the interaction between the remotely controlled PeopleBot (PB) and the Articulated Head (AH) on video and the clips were judged by human participants off-line in the lab. The independent variable was the movement control condition of the Articulated Head with three levels: fully random (FR), constrained random (CR) and tracking with the attention model applied (TR). With regard to the latter see also section 2.1 for more details. The dependent variables were five ratings by the participants. We predicted a linear trend with the order $FR < CR < TR$ of the judgements referring to perceived regularities (correlations) between the behaviour of the two robots (first rating). With regard to two complementary questions, asking about whether the PeopleBot (second rating) or the Articulated Head (third rating) was leading and the respective other robot was following, we expected a linear trend with the order $FR < CR < TR$ for the first question (PB leading) and no statistically significant differences between conditions for the second (AH leading), but a significant deviation from the midpoint of the scale towards ascribing no leading role to the Articulated Head. For the last two questions, asking whether the behaviour of the PeopleBot

**Fig. 1.** The Articulated Head in the Powerhouse Museum, Sydney, Australia

(fourth rating) or the Articulated Head (fifth rating) was considered random, we predicted no significant trend for the first question (PB random) and a linear trend with the order $FR > CR > TR$ for the second (AH random).

## 2 Method

### 2.1 Materials

**Articulated Head.** The Articulated Head is an interactive robot as a work of art designed by the Australian performance artist Stelarc [8]. It was realised by a small team of engineers and cognitive scientists within the Thinking Head project [1] and was displayed for two years in the Powerhouse Museum, Sydney, Australia. It consists of an LCD monitor mounted as the end effector of an industrial Fanuc LR Mate 200iC robot arm (see Figure 1). On the monitor, an animated virtual talking head is shown. For safety reasons the Articulated Head had to be within an enclosure. Multiple input sensors and associated software provided the Articulated Head with situational awareness among them a stereo camera with associated tracking software following people in the vicinity of the Articulated Head (PeopleTracker).

The artistic goal was to create a robotic system that would have a physical, sculptural presence and that would be recognised as a conscious and even intelligent being despite not resembling a human and clearly announcing its machine character. The non-verbal behaviour (the movements of the robot arm) were considered crucial in achieving this goal. Human participants have to be found to attribute animacy, agency, and intentionality to objects dependent on their motion pattern alone [11] and HRI studies confirm that robots are no exceptions though differences remain if compared for instance to the treatment of motor actions of other humans [2,9].

**PeopleBot.** The PeopleBot is a differential drive research robot platform from Adept MobileRobots with a height of 112 cm at the top base where an LCD touch screen is mounted. Its upright slender build adds a certain anthropomorphic quality to it.

**THAMBS.** The high-level processing of the sensing information and the behaviour control of the Articulated Head, in particular the motor response to visitor movements, is accomplished by the Thinking Head Attention Model and Behavioural System (THAMBS). A detailed description of THAMBS can be found in [7,8].

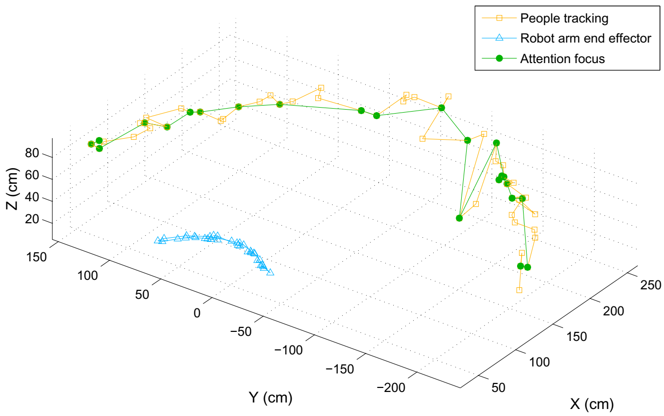


**Fig. 2.** Example of an episode with a person interacting with the Articulated Head. The person walks around the enclosure with varying speed. The input from the People Tracker as received by THAMBS is shown (orange line, square markers), the spatial location of the attention focus over time (green line, circular markers) and the location of the robot arm end effector (light blue line, triangular markers).

Figure 2 depicts a typical instance with tracking results, location of the attention focus and the location of the robot arm end effector shown. As can be seen, the shifting attention focus follows the indicated location of the person, however, not 'slavishly' but with some room to manoeuvre. Often the differences are delays, THAMBS intentionally not reacting to fast, but relatively small movements. This is caused by the previous attention focus being still dominant over other appearing candidates and not decaying rapidly enough. It does not save

THAMBS, however, from paying attention to one of the failures in the tracking, an error in the determination of the person's height.

### 2.2 Stimuli

The stimuli consisted of video clips of the two robots (Articulated Head and PeopleBot) in close proximity at the location of the exhibition of the Articulated Head in the Powerhouse Museum. An area of roughly four by three meters extending from one side of the triangular enclosure of the Articulated Head was used as the movement space for the PeopleBot (see Figure 3). The Articulated Head was set to one of the three conditions and the PeopleBot brought into its dedicated area. Since the PeopleBot moved in the public space of the museum, its movements were for safety reasons controlled by a human operator (none of the authors) who could not see the Articulated Head and was not aware of the tracking condition it was in. The robot operator was instructed to cover the whole area with the movements of the PeobleBot without pursuing any further aims. A Sony HDRFX100 camera was used to record the movements of the Articulated Head and the PeopleBot from a single viewpoint, slightly to the left of a frontal position to minimise occlusions and allow better depth perception with respect to the motion of the Articulated Head.

With the PeopleBot already moving, the camera was started and the scene recorded for 3 min and 10 s. To obtain the final stimuli, clips of the duration of 60 s were excised using Adobe Premiere. The clips were taken from the beginning of the recording or immediately following the end of the previously excised clip, resulting in nine items altogether. No attention was paid to the orientation or location of the two robots. The sound tracks of the clips were erased.

The video stimuli were presented using the experiment control software Alvin [6] and projected on a wall in the HRI lab at the MARCS Institute, University of Western Sydney, Australia. The size of the projection was approximately 210 by 170 cm. The participants were seated in a distance of approximately 320 cm from the projection. A small table in front of them provided the necessary support for a computer mouse used to obtain their responses.

### 2.3 Participants and Procedure

Twenty-four graduate students and members of the lab (16 female) aged 24-57 (mean: 33.83) participated. They were not familiar with the aim of the study and only 3 participants were accustomed to robotic research. They were instructed to watch the video clip and then respond to five statements about the actions of the robots in the clip by clicking with the computer mouse on the labelled buttons below the area where the video clip was shown. After each clip the text of the first statement appeared on the left hand side and the corresponding set of buttons was activated on the right hand side. After the participant selected a response the next statement and the next set of buttons appeared below. This continued until all five statement were answered and clicking on one of the

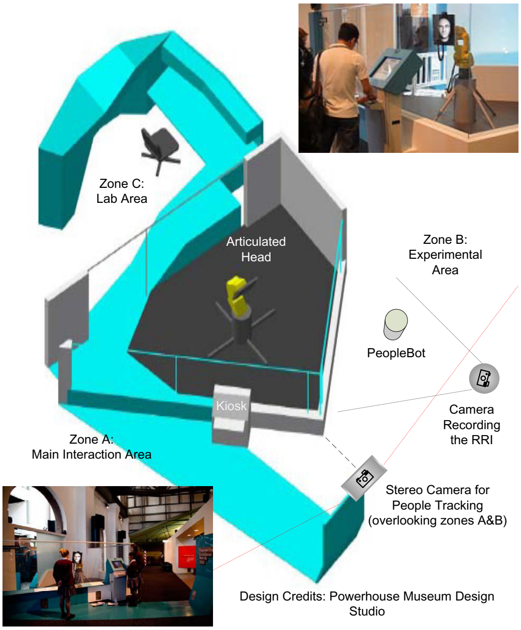


**Fig. 3.** The Articluated Head environment in the Powerhouse Museum and the set-up for the experiment

response buttons of the last statement triggered a new screen and the next video clip to be shown.
The statements were:
[CONNECT] 'There was a connection between the behaviour of the two robots.'
[PB_LEAD] 'The PeopleBot was leading, the Articulated Head was following.'
[AH_LEAD] 'The Articulated Head was leading, the PeopleBot was following.'
[PB_RAND] 'The movements of the PeopleBot appeared random to me.'
[AH_RAND] 'The movements of the Articulated Head appeared random to me.'
The response buttons were labelled:

– '*Strongly disagree*' coded as 1,
– '*Disagree*' coded as 2,
– '*Undecided*' coded as 3,
– '*Agree*' coded as 4, and
– '*Strongly agree*', coded as 5,

implementing a five point Likert scale [10,3].

The nine video clips were repeated three times resulting in 27 clips to be rated by each participant. Thus, altogether 72 ratings for each rating statement were obtained. The order of presentation was fully (pseudo-)randomised.

## 3 Results and Discussion

The rating results were averaged over the three repetitions per participants. Figure 4 shows means and standard deviations of all ratings split by condition. Using the statistics software SPSS a repeated-measures General Linear Model (GLM) was applied to the rating data to test for the predicted trends across the motion conditions. A significant linear trend was found for CONNECT ($F(1,23) = 223.19$; $p = .000$; $\eta_p^2 = .91$) in the predicted direction ($FR < CR < TR$).

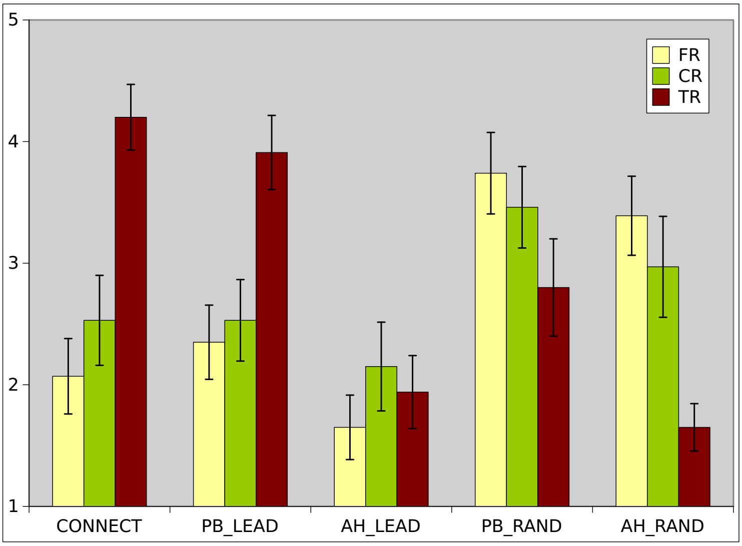


**Fig. 4.** Rating means split by movement condition. FR (fully random): yellow bars; CR (constrained random): green bars; TR (THAMBS tracking): red bars. Error bars denote one standard deviation.

As hypothesised, the participants rated the degree of connectivity between the behaviour of the two robots according to the real relationship if one considers being confined in orientation and location to the same area as a weak but yet existing link. The mean of 2.53 in the CR condition close to the midpoint of the scale (at 3) indicates that the participant detected, maybe subliminal, some relationship but were not confident about it. The difference between FR and CR is - though statistically significant (post-hoc comparisons as part of the GLM model - FR vs CR: diff = .46; $F(1,23) = 5.62$; $p = .026$; $\eta_p^2 = .20$) - very small compared to the difference between CR and TR which is at 2.13 and thus substantial given a 5 point scale.

A significant trend in the predicted direction ($FR < CR < TR$) was also detected for PB_LEAD ($F(1,23) = 94.89$; $p = .000$; $\eta_p^2 = .81$). Contrary to our predictions a significant trend in the same direction was found for AH_LEAD

($F(1,23) = 4.99$; $p = .035$; $\eta_p^2 = .18$). Thus, unexpectedly, both trends for a leading role of any of the robots reached significance. However, when considering ratings in each condition separately and comparing Articulated Head and PeopleBot, the PeobleBot was rated significantly higher as the leader in the FR and TR condition (paired-sample t-test; FR: $t(23) = 4.59$; $p = .000$; TR: $t(23) = 8.76$; $p = .000$) but not in the CR condition ($t(23) = 1.98$, $p = .60$). The difference is very pronounced in the TR condition which is of course in line with the factual circumstances in this condition.

In line with expectations a significant trend in the predicted direction ($FR > CR > TR$) was confirmed for AH_RAND ($F(1,23) = 113.48$; $p = .000$; $\eta_p^2 = .83$). Contrary to expectations a significant linear trend ($FR > CR > TR$) for PB_RAND was also attested ($F(1,23) = 30.30$; $p = .000$; $\eta_p^2 = .57$).

The degree of randomness in the behaviour of the Articulated Head is reflected in the trend found for AH_RAND. For FR and CR the ratings are distributed close to the midpoint of the scale indicating that the participants were on average not sure whether or not the behaviour of the Articulated Head was random. This points toward the tendency mentioned in the Section 1 to mistake randomness for intentional behaviour. In the TR condition, however, the rating result clearly indicates that the participant were confident about the lack of randomness in the behaviour of the Articulated Head. The difference between CR and TR is strong (1.31). Note that the difference can only originate from the recognition of the stronger coupling between the two robots' behaviours, since it was the only pronounced discrepancy between the CR and TR condition.

The trend found for PB_RAND is indeed surprising since there was no change in the behaviour of the PeopleBot in the three conditions. Post-hoc comparisons as part of the GLM model revealed that the trend is primarily due to condition TR (FR vs CR: diff = .28; $F(1,23) = 2.75$; $p = .11$; $\eta_p^2 = .11$; CR vs TR: diff = .65; $F(1,23) = 13.84$; $p = .001$; $\eta_p^2 = .38$). It suggests that if a relationship between the behaviour of two robots is present, it biases the perception of both robots towards attesting meaningful behaviour to both of them. Indeed in an unexpected way, this is in line with the original conjecture that the impression of agency arises - at least partially - from the interaction itself.

Given that humans of course see themselves always as intentional agents, there might be a tendency to attribute agency to any entity that shows some loose coupling of its own behaviour to the one of the human. It can be speculated that it does not require a robot for this impression to be evoked let alone a humanoid robot but rather that it applies to all kinds of physical phenomena unless an effect-cause relationship can be established. One's own shadow, for instance, is typically characterised through a tight coupling that makes it easy to assert a cause-effect relationship. If the correlation of the movement of the shadow to the movements of the body, however, is lowered, the cause-effect explanation might become doubtful and the impression of an uncanny agency might arise. In the same way some of what is typically considered by cultural believes to fall into the realm of magic and the paranormal might be the impression of agency without a home, that is, without a proper explanation. Social robots could both profit from the phenomenon and suffer in acceptance - dependent on circumstances. Obviously, much more research is needed.

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