

Co-representation in a simple task

Bachelor thesis Artificial Intelligence

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Abstract

This thesis is intended to explain some of the results which were obtained in an experiment by Van der Wel, Sebanz, Knoblich (2009). The present study is centralized around the notion of co-representation, by which the sharing of mental representations of a task by two or more people is meant. The type of co-representation which is assumed to take place is based on the Hick-Hyman law, which states that for an increasing number of alternatives to choose from reaction time increases proportionally. This law has its origin in Information Theory and has mostly been applied to Human-Computer Interaction. A better understanding of co-representation may lead to a better understanding of joint action also. Knowing about the mechanisms which underlie social interaction (as studied by the field of joint action) can be useful for designing robots which interact more socially with humans.

Introduction

Even before John McCarthy came up with the term ‘Artificial Intelligence’ in 1956, Grey Walter (1948, 1949) was working on his two ‘social’ tortoise robots named *Elmer* and *Elsie*. The field of robotics was soon related to artificial intelligence because robots required intelligence. A subfield related to both of these is Human-Robot Interaction, for which socially interactive robots are required. Endowing robots with human-like abilities has not been proven easy; Fong, Nourbakhsh, and Dautenhahn (2003) describe the components a social robot should have. Inspiration for solving these issues may be provided by social sciences; principles from humans who interact with each other can be derived and applied to robots. A relevant field to mention here is that of joint action; research on joint action is concerned with people who work together to achieve a certain goal. Still many open questions exist within joint action and this thesis attempts to further elaborate on one of these, namely co-representation. The term co-representation is used to indicate some sort of sharing of mental representations between co-actors. In the remainder of the introduction section I will first introduce joint action and its assumed underlying mechanisms, then introduce co-representation, followed by an influential paradigm (by Sebanz, Knoblich, & Prinz, 2003) for co-representation and some further research on this. At last the work by Van der Wel, Sebanz, and Knoblich (2009) on co-representation and their unexpected results will be discussed.

Joint action

Based on every day experience it is reasonable to conclude people are quite good at working together, whether it is as a football team trying to score or two people dancing together. However, even for simple tasks the underlying mechanisms are far from trivial: two bodies and minds must be coordinated (Sebanz, Bekkering, & Knoblich, 2006). Several mechanisms have been proposed which are thought to play a role in joint action. Joint action here means any form of social interaction whereby two or more individuals coordinate their actions in space and time to bring about a change in the environment (Sebanz et al., 2006). The challenge of joint action is to reach a common ground between two or more people (Clark, 1996).

The first of the four mechanisms underlying joint action is joint attention. Eye gaze studies provide evidence for the role of joint attention in joint action (Richardson, & Dale, 2005). Gaze shifts can automatically direct the attention of another person to an object and with that create a ‘perceptual common ground’ (Frischen, & Tipper, 2004). The second requirement for successful joint action is action observation. Action observation is needed to get an understanding of the goal of the action of another person, which is suggested by some to be the function of mirror neurons (Rizzolatti, & Craighero, 2004). Mirror neurons are neurons which are activated both while performing an action and seeing that same action. Research by Iacoboni, Molnar-Szakacs, Gallese, Buccino, Mazziotta, and Rizzolatti (2005) suggests that premotor mirror neuron areas are involved in both action recognition and the understanding of the intentions of others and thus aid the establishment of a common ground. The third aspect of joint action is action coordination, which means adjusting actions to those of another person in time and space. Experiments by Marsh, Richardson and Baron (2006) show that in an environment with other people, people are aware of actions they can do themselves and actions they can do in conjunction with other people. For instance in the experiment by March et al. (2006) participants were asked to lift planks of different sizes which they could either do alone or together with another person. A relation was found between the size of the plank and the individual and joint arm span. The temporal element of

action coordination was demonstrated in Jordan and Knoblich (2004) who showed that people learn to predict the timing of another person's actions in a tracking task. A fourth mechanism is task sharing. To share a task means knowing what the other's task is or, more precisely, knowing which action another person will perform under which circumstances. Evidence for task-sharing is for instance provided by the finding that individuals form shared representations quasi-automatically (Sebanz, Knoblich, & Prinz, 2005; Atmaca, Sebanz, Prinz, & Knoblich, 2008; Sebanz, Knoblich, Prinz, & Wascher, 2006).

Co-representation

An important aspect of people co-acting, is co-representation as it is claimed that when people co-act they also take the task of a co-actor into consideration. Results from several different studies have led to the claim that co-representation is an automatic or unintentional process (Sebanz et al., 2005). First evidence comes from results on non-conscious mimicry, such as the finding that individuals unintentionally adopt their posture and mannerism to those of an interaction partner (Bernieri, & Rosenthal, 1991; Chartrand, & Bargh, 1999). A possible explanation for these findings on mimicry is that observing an action increases the likelihood of the observer performing that same action. Further evidence in favor of automatic co-representation is found in a study by Brass, Bekkering, & Prinz (2001) who showed that an action is facilitated when that action is the same as an observed action and interferes when the observed action is opposite to the performed action. This result suggests action observation and action planning have the same underlying representations. The notion of mirror neurons may explain the link between action observation and execution: in macaque monkeys the same neuronal areas are activated when they observe an action and perform this action (Gallese, Fadiga, Fogassi, & Rizzolatti, 1996). Further research suggests humans also possess mirror neurons which are functionally equivalent to those in the macaque monkey (Blakemore, & Decety, 2001).

Previous research has shown the link between action observation and performance of that action (see above). In joint action however, action observation is not always possible, for instance when two people take turns and both focus on their own task. In such a case, no interference or facilitation is expected if the co-actors do not represent the other's task. Sebanz et al. (2003) introduced a paradigm, based on the Simon task (Simon, & Rudell, 1967; Simon, 1969), to see if co-representation takes place in the absence of action observation and what the effect is of actions at the disposal of another agent. The next paragraph shortly discusses the Simon task, followed by the modifications made in the task by Sebanz et al. (2003).

The Simon task

The objective of the Simon task is to determine the relationship between reaction times and the location of the stimulus relative to the response. One of the first experiments was done with an auditory stimulus, presented to the left and right ear of participants (Simon, & Rudell, 1967). The auditory signal consisted of the words 'left' and 'right', randomly presented. Although the location of the auditory stimulus was not relevant for the task, responses were faster on trials in which the location of the auditory stimulus matched the side of the required response. An explanation for the effect of an irrelevant cue in a Simon task, is provided by Simon (1969) who postulates a natural tendency to react toward the source of stimulation. This effect has been shown for several types of Stimulus-Response mappings, such as symbolic compatibility, temporal compatibility and spatial compatibility (Simon, 1990).

Spatial compatibility

A variant of a spatial compatibility task was done by Sebanz et al. (2003) to test whether actions at the disposal of another person influence one's own actions. The experimental set-up consisted of a central monitor and two response buttons on each side of the table. A finger with a ring which can either be red or green, was displayed on the monitor. The left response button corresponded to one color of the ring and the right button to the other color. The irrelevant spatial cue was provided by the finger which can point to the left, middle or right side of the screen. A compatible response occurs when the finger points in the direction of the button that should be pressed and an incompatible response occurs when the finger points in the direction of the button which should not be pressed. When the finger points straight the stimulus is said to be neutral. The performance on this Simon task was measured in three different conditions. The first condition is the two-choice condition in which one participant reacts to both colors of the ring. In the second condition, called 'joint go-nogo', two participants are each responsible for one color of the ring. The individual go-nogo condition required one participant who responded to only one color of the ring.

Results on the spatial compatibility Simon task in the two-choice condition revealed higher reaction times on incompatible than on compatible trials (Sebanz et al., 2003). For the joint go-nogo condition, responses were also faster on compatible trials while no such effect occurred for the same task performed alone (individual go-nogo). This result implies that in the individual condition only one's own action is represented. However the effect of compatibility in the joint condition indicates that the action which is assigned to the other person, is co-represented as if it was part of one's own task. The results in the joint go-nogo condition was similar to those in the two-choice which suggests the actions of another person are represented in a functionally similar way as one's own.

Variants of the finger pointing paradigm

The same finger pointing paradigm (Sebanz et al., 2003) has been used in further research. A variant in which each participant responded to a different dimension of the stimulus, revealed that performance of each co-actor was affected by the task of the other (Sebanz, Knoblich, & Prinz, 2005). Results provide evidence in favor of task sharing rather than action sharing. Similar results were obtained in a second experiment in which action observation was not possible but the participants were informed about the task of the other in advance. Another conclusion based on these results is that shared task representation are also formed in social settings which do not require interpersonal coordination (Sebanz et al., 2005).

Another variant of the experiment by Sebanz et al. (2003) was done with recording ERP alongside reaction times in the individual and joint go-nogo condition (Sebanz, Knoblich, Prinz, & Wascher, 2006). Results suggest that a common representational domain exists which is used to represent one's own and other's actions, and as such activates one's own action representation when observing or anticipating the action of others. The same experiment was done in an event-related fMRI study (Sebanz, Rebbechi, Knoblich, Prinz, & Frith, 2007). Several brain areas are identified which are related to specific parts of the task. First, in the joint go-nogo condition, the ventral premotor cortex was activated when participants responded to their assigned stimuli. It is suggested that knowing about the potential actions of another person increases the relevance of one's own stimuli. Second, increased orbitofrontal activation was found in the joint condition which indicates participants monitored their performance more closely to make sure it was really their turn (Sebanz et al.,

2007).

Social facilitation and Ideomotor theory

Two existing theories provide a possible explanation for the results by Sebanz et al. (2003). The first theory is social facilitation theory and the second is the ideomotor theory. Social facilitation theory (Zajonc, 1965) states that the mere presence of another person affects performance on a task. For this theory it does not matter what the other person is doing, their presence will show its impact on an individual's performance. Typically, in simple tasks performance is facilitated and impaired in complex tasks. On the other hand ideomotor theory (Greenwald, 1970), which is extended in the Common Coding theory (Prinz, 2007; Tsai et al., 2006), postulates a common coding or shared representation between perceived events and planned actions. That is, perceiving actions performed by others should activate the same representational structures that govern one's own planning and control of those actions (Knoblich, & Jordan, 2003). Mirror neurons can be thought of as the neural implementation of the common coding between action perception and production.

Even though up until 2003 only experiments in which people performed the same actions had been done, predictions from both theories above can be derived for an experiment in which people perform complementary actions (Sebanz et al., 2003). Complementary actions take place when two people each take care of a different part of a task and as a consequence do not act in parallel. For complementary actions, social facilitation theory predicts a general effect of the presence of another person. This means faster reaction times are expected in the joint go-nogo condition compared to the individual go-nogo condition. No evidence is provided in favor of social facilitation theory in the spatial compatibility task by Sebanz et al. (2003) because no significant difference between reaction times in the joint and individual go-nogo task was observed. Ideomotor approaches predict that the other's actions might become represented and have a specific impact on one's own acting. The finding that a compatibility effect occurred in the joint go-nogo condition and the two-choice condition provides some evidence in favor of the ideomotor theory: the other's actions are represented in a functional similar way as one's own. The compatibility effect accounts for co-representation because the irrelevant spatial dimension activates a response no matter who should perform the corresponding action. This leads to a response conflict when the relevant dimension of the stimulus does not match the irrelevant spatial dimension and thus leads to a higher reaction time.

The Joint SNARC effect

Further evidence is provided which suggests functionally equivalent representations are formed for one's own and other's actions in an experiment which is not based on a spatial compatibility effect. The so-called SNARC effect (spatial numerical association of response codes) defines a relation between numbers and space: small numbers refer to the left and large numbers refer to the right (Dehaene, 1997). Participants reacted faster to small numbers displayed on the left side of the screen than on the right side of the screen and vice versa for large numbers. A same type of experiment as Sebanz et al. (2003) was done with odd and even numbers as relevant stimulus dimension and small and large numbers as irrelevant dimension (Atmaca et al., 2008). The experiment was done with Arabic numbers as a stimulus and with hands depicting a number. In general, results are the same as in previous research: no response conflict occurred in the individual go-nogo task while for the joint go-nogo task there was a response conflict similar to that in the two-choice condition. A conclusion drawn from these results is that not only spatial cues but also symbolic cues affect action

performance. This study provides further evidence that people performing complementary actions not only represent their own part of the task but the whole task.

The present study

Another study, which seeks to find the specifics of co-representation was done by Van der Wel, Sebanz, & Knoblich (2009). For this a new paradigm was developed, in which the irrelevant cue was the number of response alternatives of another person. A law derived from Human-Computer Interaction states that reaction times increase when an individual is given more options to choose from. This law, known as the Hick-Hyman law (Hick, 1952; Hyman, 1953), will be explained further in the next paragraph. The experimental set-up consists of two response boxes containing six buttons which each had a corresponding LED-light above them. Each of the response boxes would receive stimuli on one to three different locations. This way nine conditions were created, each referring to a different combination of response alternatives for both response boxes. Participants performed the task either alone in an individual go-nogo condition or together with another person in a joint go-nogo condition. The experiment was done with complementary actions and with people responding in parallel.

As mentioned in the previous paragraph the Hick-Hyman law defines the relationship between reaction time and the number of response alternatives. Hick (1952) attempted to describe the finding by Merkel (1885; as cited by Hick, 1952) that choice-reaction times plotted against the different number of alternatives resulted in an approximately straight line. For this Hick performed three experiments and applied theorems from Information Theory (Shannon, & Weaver, 1949) to his results. The equation he found based on Information Theory is:

$$R_t = \log(n_e + 1)$$

In this function n_e is the ‘equivalent degree of choice’ or ‘the antilogarithm of the amount of information gained’ or more simply put the n choice-alternatives. Hick demonstrates this function fits his data reasonably well. Later Hyman (1953) provided evidence of a linear relationship between reaction time and number of alternatives (for an overview see Seow, 2005). This law got accepted as the Hick-Hyman law and is defined as follows:

$$RT = a + b \log_2(n)$$

Where n is the number of possible responses which all have an equal chance of occurring, a and b are empirically determined constants. The Hick-Hyman law states that reaction time increases by some constant when the number of response alternatives is doubled. The law has been further applied to several fields of research (Seow, 2005), despite much of the criticisms it received over the years (e.g. Longstreth, El-Zahhar, & Alcorn, 1985).

If no co-representation were to take place in the experiment described above, then there would not be an Hick-Hyman effect in the reaction times for the one person, as a result of the response alternatives of the other person. The results are shown in Figure 1. The left panel of Figure 1 clearly shows Hick-Hyman law holds for one’s own reaction times: for each extra response alternative reaction time increases significantly. The increase in reaction time is present in both the individual and joint condition. In the right panel of Figure 1 the reaction times are plotted in relation to the response alternatives of the other participant. Each point in the graph should be interpreted as ‘my average reaction time over one, two and three responses when the other received either one, two or three alternatives’. A clear trend is especially also visible for the joint condition in the right panel: average reaction times increase when the response alternative of the other person increase. This result suggests that participants co-represented the task of the other person in a detailed manner.

The same task was repeated in which participants responded in parallel. Results are shown in Figure 2. The right panel provides insight in the specificity with which people co-

represent the task of another person. Only a general effect is visible: people responded slower in the presence of another person. Reaction times appear to be only affected by one's own response alternatives and not the response alternatives of the other. The conclusion drawn from these combined results is that the specificity of task co-representation depends on the relative timing of one's own task and the task of the other.

The same experiment was done with two to four different possible stimulus locations for both participants (Van der Wel et al., 2009). The reaction times in these nine condition are expected to show similar relations as in the previous two experiments. So much was true for participants who acted in parallel. For complementary actions, performance did depend on the personally relevant action alternatives. The results for reaction time in relation with the response alternative of a co-actor were surprising: no significant increase or decrease was observed with a varying number of response alternatives for the other. In Figure 3 these results are shown for the individual and joint condition.

The research I performed attempts to explain these contradictory results by manipulating the different number of response alternatives for each of the participants. Instead of assigning the same -varying- number of alternatives to both participants, one participant will always receive their stimulus on one location while the other receives their stimulus in one to four different locations. The reaction times of the participant receiving one alternative will provide useful information about the extent to which the task of the other person is co-represented. I hypothesize that Hick-Hyman law will show its effect again in the data like it did in the initial experiment by Van der Wel et al. (2009).

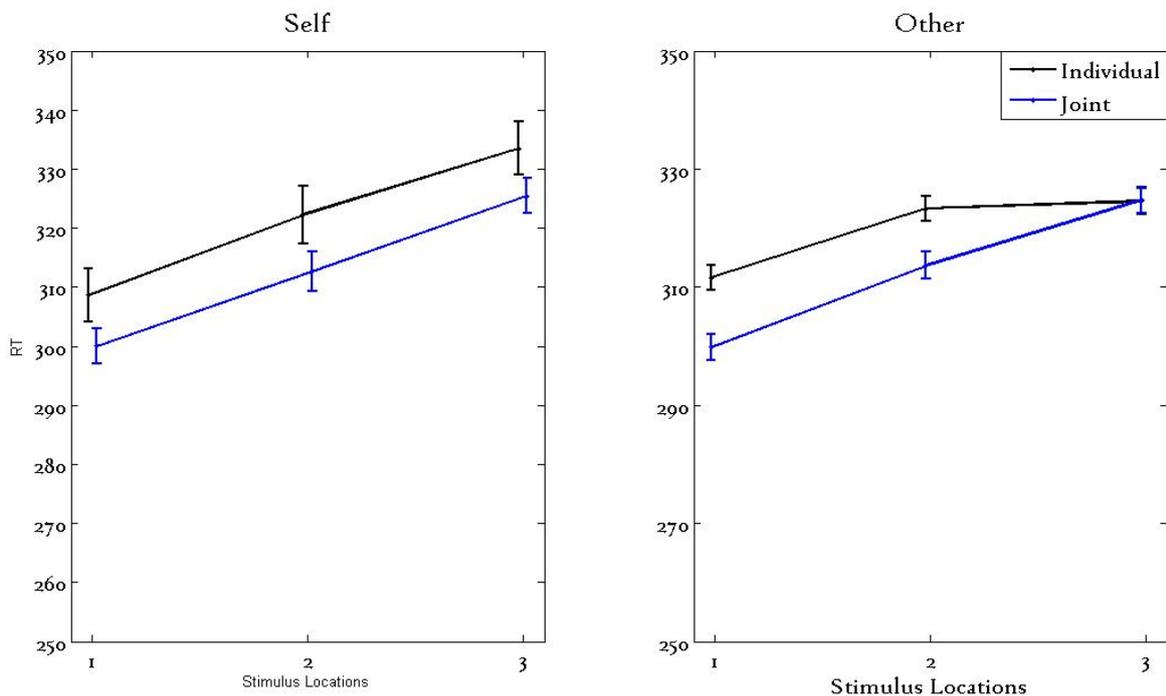


Figure 1. Results by Van der Wel et al. (2009). Participants acted in turns.

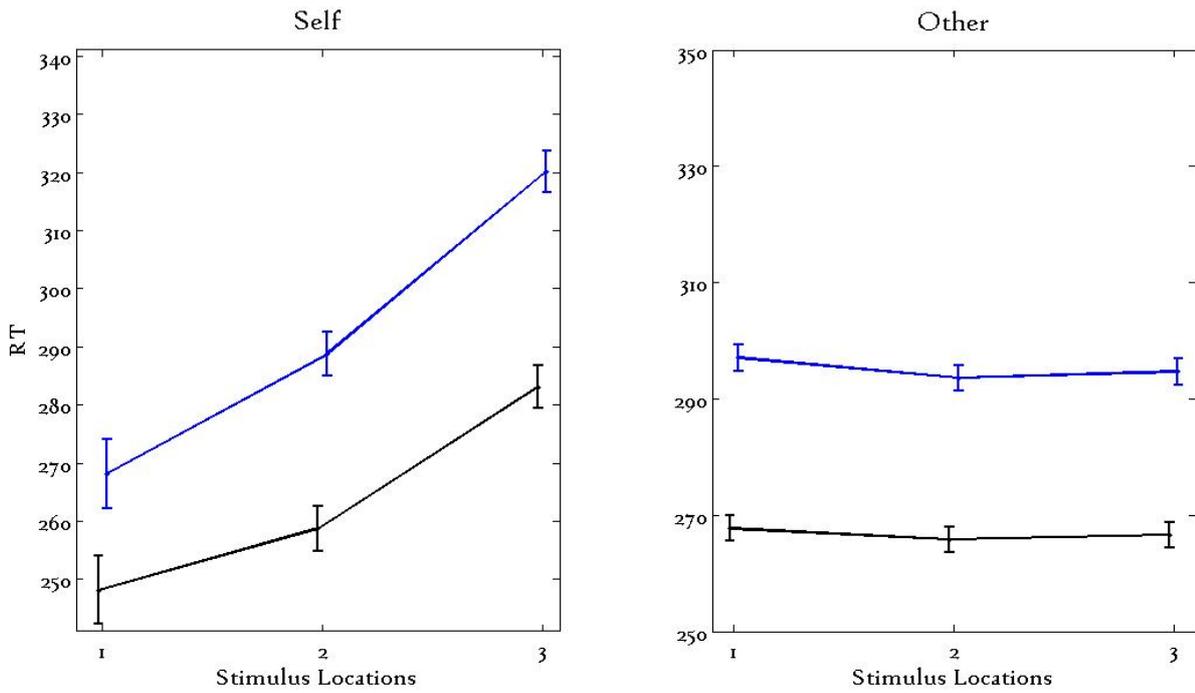


Figure 2. Results by Van der Wel et al. (2009). Participants responded at the same time.

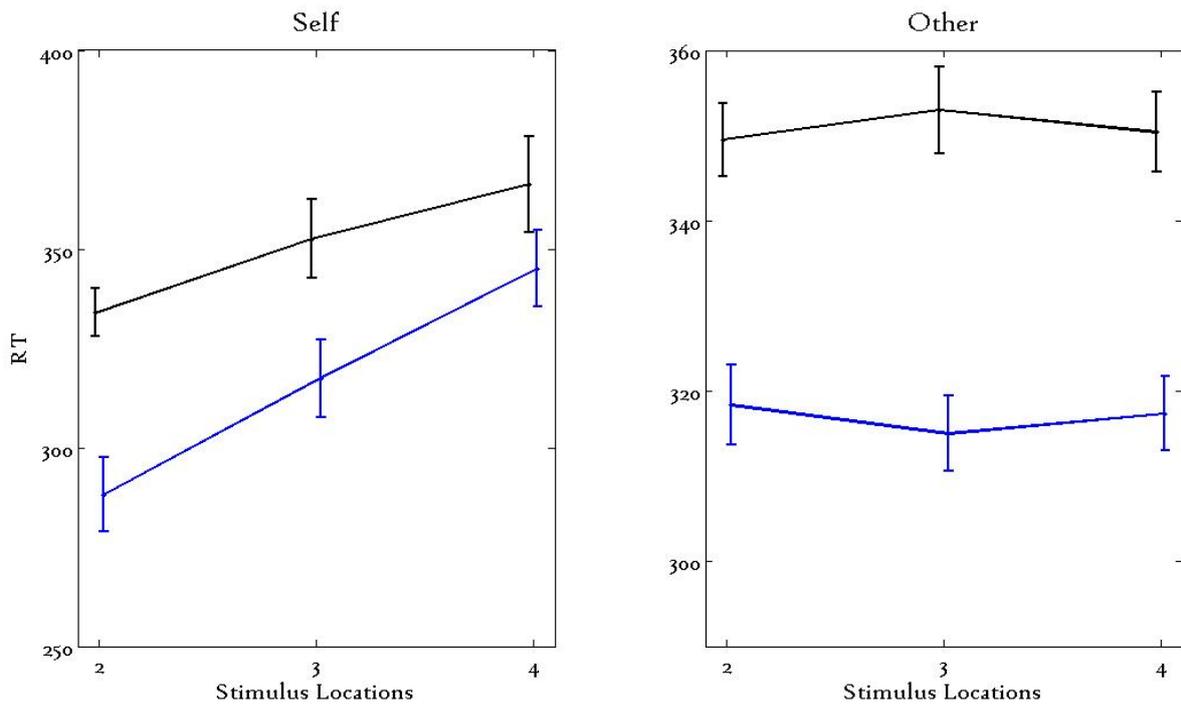


Figure 3. Results by Van der Wel et al. (2009). Participants performed complementary actions with two, three or four different stimulus locations.

Methods

Participants

Twenty-four participants were recruited for this study in the Radboud Sona System, an online participant recruiting system for students of the Radboud University Nijmegen. The age of the participants ranged from 18 to 30, with an average age of 21.00 and standard deviation of 2.93. All but one participant had corrected or correct to normal vision (no-one suffered from color-blindness). Out of 24 participants five were male. Participants received either a reward of 10 euros for their participation or 1 "participation credit".

Materials

The experiment was done with ioLab response boxes which were connected via USB to a Macintosh computer running Matlab was used to control the boxes. The response boxes had six colored buttons on top, each with a controllable red-colored LED light above them. Response boxes were affixed to the table with Velcro so they could not be moved easily by the participants. They were oriented such that it was not easy for the participant to ignore the other response box (as can be seen in Figure 4).



Figure 4. ioLab response boxes.

Procedure

Participants were instructed to press the corresponding button when a red LED light appeared above a button on their response box. In the individual part participants were told the lights on the other box would disappear automatically and in the joint part the other participant would take care of the other response box.

Participants always performed the same task alone and alongside another participant. To achieve this, pairs of participants were formed, so 24 participants formed 12 pairs. For each pair, the first participant performed the task alone and then the second participant was brought in. Thus, the second participant always performed the joint part of the task first. One participant always received a stimulus in only one location in each condition of the individual and joint part of the experiments. The other participant of a pair responded to a different numbers of stimulus locations, ranging from one to four, in different conditions. The side at which the single responses occurred was counterbalanced across pairs. Four conditions were created, each corresponding to a different number of response alternative for one of the participants. The order of conditions was counterbalanced across pairs. Each condition was run twice in the individual and twice in the joint part so each part consists of eight blocks of

trials. Each block consisted of 180 trials. The order of stimuli was random and equally probable between the response boxes and the stimuli appeared such that at any time only one response box required a response.

Before each condition participants received a preview of the relevant buttons for that condition by showing all the corresponding LED lights that would appear. The location of the required buttons for a block was randomized such that participants used a randomly picked set of the four response buttons that corresponded to the required number of response locations for the particular condition. Participants always used one fixed hand throughout the experiment to press the response buttons to respond to the stimuli.

All participants finished within 50 to 55 minutes after starting.

Results

Reaction times were measured for each button press. Incorrect responses were also recorded but discarded from the data. Reaction times below 100ms and above 650ms were coded as invalid. Then a within-subjects ANOVA with the factors Condition (individual or joint) and Alternatives¹ (one to four) was used to analyze the reaction times. No main effect was present for Condition ($F(1, 11) = 0.370, p = .555$) which means that on average there is no difference between the reaction times in the individual and the joint part of the task (the mean and standard errors are 281.1 and 6.7, 278.5 and 7.7 respectively). A main effect of response alternatives was found ($F(3,33) = 3.046, p = .042$). So the average reaction times for the different number of alternatives does differ (for one to four alternatives the average and mean are, 274.440 and 6.207, 280.628 and 6.792, 282.048 and 7.960, 282.360 and 7.612 respectively). The Condition x Alternatives interaction was not significant ($F(3,33) = 0.353, p = .788$) which shows that the increase in reaction time in the joint and individual condition is not significantly different. The mean reaction times and standard errors are shown in Table 1. A graphical representation of this data is shown in Figure 5.

Alternatives	1	2	3	4
Condition				
Individual	276.2 6.7	283.2 7.7	283.4 7.9	281.7 6.9
Joint	272.6 6.8	278.0 6.7	280.6 9.6	282.9 8.8

Table 1. Mean Reaction Time (top line in each cell) and standard errors (bottom line)

Further analyses was done on the response alternatives of the other because the size of this effect is large ($\eta^2 = 0.217$) and these difference are also significant (see above). Two separate ANOVA's are done for the joint and individual condition. For the data in the joint condition the differences fall just outside the significance level of $p < .05$ ($F(3,33) = 2.646, p = .065$). This non-significant result might be due to the small number of participants in the joint condition ($N = 12$) as the effect of the response alternatives is pretty strong ($\eta^2 = .194$). The ANOVA done on the individual data does not show a significant effect ($F(3,33) = 0.965, p = .421$).

¹ Alternatives in this section refers to the number of response alternatives the other response box received. In the individual condition this refers to the nogo-stimuli and in the joint condition to the other participant. Different formulations will be used interchangeably.

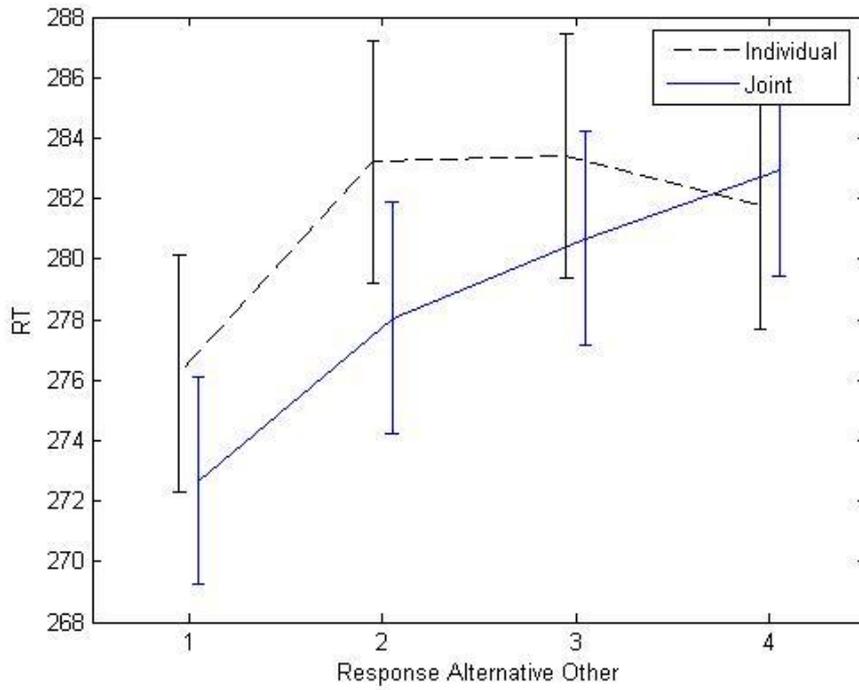


Figure 5. Analysis of reaction times in the joint and individual condition. Response alternatives of the other range from one to four.

Discussion

Results do not provide a clear explanation for the contradictory results by Van der Wel et al. (2009). The general trend for the reaction time plotted against the different alternatives of a co-actor is much more similar to the initial results by Van der Wel et al. (compare Figure 5 to the right panel of Figure 1) than to the contradictory results (compare Figure 5 to the right panel of Figure 3). The slope of a fitted line on the data from the present study (approximately 2.5ms) however is much less steep than the slope of a fitted line on the initial results (approximately 7.5ms). A possible explanation for this can be provided by the effect of Stimulus-Response Compatibility (SRC) on the slope of the Hick-Hyman law; Seow (2005) concluded from several studies that the slope of reaction times relative to the number of alternatives, diminishes with an increasing SRC. Arguably, SRC is the same in each of the experiments, because SRC is defined as the degree to which a stimulus and response are naturally related to each other (Simon, 1990).

In contrast, no obvious differences are observed in the present study with regard to the individual condition compared to the [2, 3, 4]-responses (compare the right panel of Figure 3 to Figure 5). Results from the present study on one to four levels of the nogo-stimuli may link the observations from Van der Wel et al. (2009) as shown in the right panel of Figure 1 to those in Figure 3. An apparent trend in all three graphs is that reaction time for one alternative is lower than for two, three or four alternatives and even more so, the differences between two, three and four alternatives is no more than a few seconds. It is tempting to speculate that the lack of differences between these three levels of alternatives of a nogo-stimuli indicate that nogo-stimuli are not represented in the individual condition. Further investigation of the lower reaction time for one alternative would be needed though.

Two theories were discussed in the introduction on which Sebanz et al. (2003) based their hypothesis. These were social facilitation theory and ideomotor theory, and will now be discussed in the light of the present study. Recall that for social facilitation theory a general effect of a co-actor would take place. In Sebanz et al. (2003) no such effect was found as in fact reaction times in the individual go-nogo condition were faster than in the joint condition. The results in Figure 5 however do show reactions were faster in the joint condition (although no significant difference was found), which may imply facilitation. In the analysis of the data a significant main effect of response alternatives of the other was found which means more specific co-representation takes place. The social facilitation theory fails to provide an explanation for these differences between alternatives.

Ideomotor theory on the other hand predicted a specific stimulus-response effect in the joint condition. In Sebanz et al. (2003) a comparison is made between the joint go-nogo and the two-choice condition. The present study however did not include a two-choice condition because the task is not suitable for such a condition. In contrast to Sebanz et al. (2003) stimuli for any response were not presented on a shared screen and thus it would not be easy for participants to monitor all stimulus locations. On top of that, no spatial compatibility effect is assumed, only an effect of the number of response alternatives the other response box received, so a two-choice condition would not be meaningful. But as Tsai et al. (2006) pointed out, to test the assumptions of the ideomotor theory, an effect in the joint condition which is absent in the individual condition is sufficient. As mentioned in the results section, in the joint condition no significant differences were present between the different response alternatives which implies ideomotor theory does not provide an explanation for the results for the current study. However the eta-squared for the number of response alternative in the joint condition is quite strong which means that despite the non-significant difference a large part of the variance can be explained by the number of alternatives. In this light, a

recommendation for future work would be to add some extra participants to the experiment because a larger number of participant might yield a significant difference in the joint condition. No significant difference was found in the individual condition and as opposed to the joint condition it is doubtful that any significant difference will be found with more participants. Taking these considerations in mind, it is reasonable to accept the ideomotor theory based on the results from the present study.

For future work I would recommend to put the use of the Hick-Hyman law in perspective, despite the rather promising results by Van der Wel et al. (2009) that significant differences between the response alternatives are present for both the own stimuli as the stimuli of the other. Typically it is assumed that for every extra bit of information, that is for every $\log_2 n$ alternatives, an increase of approximately 150ms in reaction time occurs (Hyman, 1953; in later papers this observation appears to be accepted as a fact). The left panels of Figure 1-3 do not show differences of that magnitude. Longstreth et al. (1985) also found much smaller values for the slope of the function of reaction time against different alternatives (which was typically around 15ms). It would be interesting to explore the variables of which the slope of the Hick-Hyman effect in this task is depended on (for instance the relative timing between response and a new stimulus). After all, the Hick-Hyman law was defined based on Information Theory and not so much on psychological data. Also for Human-Computer Interaction it might be more valuable to have heuristics which are not purely theoretical and are also thoroughly tested on humans.

In conclusion, although there were no clean-cut results significant results found in the present study it does not mean research on co-representation in the paradigm by Van der Wel et al. (2009) is not useful. In fact, the paradigm already showed that the specificity with which people co-represent the task of another person may depend on the relative time of their tasks. Also for the understanding of joint action, results from these types of tasks can help to adjust or specify current theories. And with a better understanding of the mechanisms required for humans to work together, the design of social robots can be improved also. For the Human-Robot Interaction to be successful the robot's presence must be accepted as being natural. The ultimate test for a robot is to 'survive in the wild', that is to not just interact with its creators but also people with any prior knowledge of robotics (Sabanovic, Michalowski, & Simmons, 2006).

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