Video observation of humanoid robot movements elicits motor interference

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Abstract. Anthropomorphic "humanoid" robots are suggested to be more competent in social communicative interactions than industrial robots, because humans interact more intuitively with them. It is, therefore, critical to evaluate the acceptance of an agent as possible partner for joint interaction. One possible method is to utilize the phenomenon of motor interference (MI). It claims, that observation of an incongruent movement of another individual leads to a higher variance in one's own movement trajectory. Although this effect has been demonstrated while observing a human agent, the researchers were unable to show increased variance in the subjects' movements if they observed an arm of an industrial robot moving with piecewise-constant velocity. In contrast, in other recent studies, MI was demonstrated when subjects watched a humanoid robot performing biological movements based on prerecording of a human experimenter, even if it was not the case when the same robot moved with constant (artificial) velocity. The purpose of the present study was two-fold: 1) we aimed to replicate these results using video-presentations of the agents, and 2) we asked whether quasi-biological movement trajectories are sufficient to elicit MI. We presented subjects, who were instructed to perform horizontal and vertical arm movements, with videos of a human agent or of a humanoid robot, who performed congruent or incongruent arm movements. Robotic movements were produced with a quasi-biological minimum-jerk velocity profile. We found MI both for the human agent and the robot, suggesting that an artificial human-like movement velocity profile (minimum-jerk) is sufficient to facilitate perception of humanoid robots as interaction partners, and that the measurement of MI using a face-to-face video setup can serve as a tool for objectively evaluating humanoid robots.

1 INTRODUCTION

Humanoid robot technology is developing at an incredible rate [1, 2]. In the near future, humanoid service robots equipped with mechanisms for communication and interaction will become part of daily lives of ordinary people. Based on the human's instructions and control, they will assist humans as "partner robots" in completing a variety of tasks that are physically demanding, unsafe, unpleasant, or boring. They will also assist elderly, individuals with physical impairments and cognitive disabilities in care, therapy and training.

During interaction with a humanoid robot, people tend to anthropomorphise it [1] and to apply their experience with human partners in order to explain, understand or predict its behaviour. Since the interaction with humanoids should be natural, enjoyable and efficient, it is important to analyze how we perceive them and how they affect us.

Although the quality of interaction between humans and humanoid robots has been investigated by some studies [2], mostly only questionnaire-based subjective judgments were used for this purpose [3, 4, 5]. A possibly objective tool, which is based on the phenomenon of motor interference, has been developed only recently [6].

Motor interference - influence of the observed movement on own action

By the means of fMRI (functional magnetic resonance imaging), it has been shown, that observation of an action leads to activation of corresponding motor areas in the premotor cortex [7]. It therefore seems that perception of an action leads to simulative production of that action on the part of the observer, facilitating its execution. The neural basis for the "action-perception coupling" hypothesis has come with the discovery of the mirror neuron system in the premotor cortex of macaques, which is activated both when the monkey performs a specific action and when it passively observes the experimenter perform that same action [8,9]. It is presumed that observing the movement of the partner leads to the activation of the premotor areas that correspond to the production of that movement, irrespective of whether the observed movement is compatible with an intended movement. Thus, when the participant observes the partner producing an incongruent movement, the motor program or representation associated with the observed movement is assimilated or interferes with the outgoing motor output for the intended movement. In line with this hypothesis goes the observation that during action observation there is a significant increase in the motor-evoked potentials from the hand muscles that would be used if making such a movement [10]. Thus, observing a certain action injects bias to the motor controller by activation of modules subserving the observed movement *(motor resonance)* and deactivation of modules controlling incongruent movements [11, 12]. This deactivation leads to *Motor Interference* (MI), defined by an increase of variance in one's own movement while watching an incompatible movement. Indeed, it has been demonstrated that

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while the observation of another person performing an action facilitates the execution of a similar (congruent) action (e.g. the contagion of yawning [13]), it interferes with the execution of a different (incongruent) action [14]. For example, perceiving a horizontal arm movement facilitates the concomitant execution of the same action and curbs the execution of a vertical arm movement [6].

Influence of agency and naturalness of motion on motor interference

It has been shown that although monkey mirror neurons discharge, when it observes an action performed by another individual, these neurons are not activated in the case of mechanical action [15]. However, the question of whether the human mirror neuron system responds to the movements of non-human actors such as robots, is currently controversial. One study [16] suggested that responses in premotor cortex (thought to be the most important part of the mirror neurons network [9]) to observed motion is specific to human action and does not respond to robotic movements. Other data suggest equivalent neural responses to both observed human and robotic action [17].

In the original study investigating robotic movement [6], the MI experimental paradigm was adapted to investigate the extent of similarity of the implicit perception of an industrial robot and a human agent. In contrast to observation of a human agent, MI could not be demonstrated for the observation of movement of an industrial robot. However, some recent studies [18, 19] have found MI when subjects watched a humanoid robot performing movements based on implemented prerecording of a human experimenter. Interestingly, this effect could not be shown when the same robot moved with a constant-velocity profile, suggesting that velocity profiles of biological movements might be essential for MI.

Several studies tried to determine what information in the observed movement triggered the MI in the observer's action. These studies investigated continuous movement synchronization of a human observer with a moving dot stimulus [20, 21, 22], ball motion [23], or a point-light figure [24]. In [22] and [23], the variance of the participant’s movements in the incongruent condition was found to be enhanced only with biological motion; in [21], the increase in variance was seen both in biological and in non-biological dot motion; in [24], the biological dot motion led to MI only in subjects with autism in contrast to healthy ones, and in [24], the MI could not be demonstrated neither in human nor in point light figure condition. Although the results of these studies were not uniform, in general they suggest that the brain processes biological and non-biological movements in a different way.

In the experiment reported here, we tried to replicate the results of [18] and [19], by replacing live presentations with video presentations of the human experimenter and the humanoid robot JAST (s. Fig. 1). JAST has an “animal” head and is capable of producing movements with human-like minimum-jerk velocity profiles [2]. The subjects were instructed to produce congruent or incongruent movements while watching the videos projected on a screen.

2 METHODS

Four female and six male PhD students from the local Department of Neurology have been tested in the present experiment. The videos of both JAST and the human agent were rear-projected on a white screen (120cm*160cm) in pseudo-randomized order. The screen was positioned about 1.5 m in front of the participant.

The subjects were instructed to perform 50-cm amplitude horizontal (H) or vertical (V) rhythmic arm movements with their right arms while fixating on the hand of a human agent or JAST (s. Fig 1). The agent performed either spatially congruent (C, same direction) or incongruent (I, perpendicular) movements (frequency: 0.5 Hz). This resulted in a 2*2*2 experiment design with eight experimental conditions and three factors (1) plane of movement (H/V), (2) congruency (C/I), and (3) observed agent (agency; H/R).

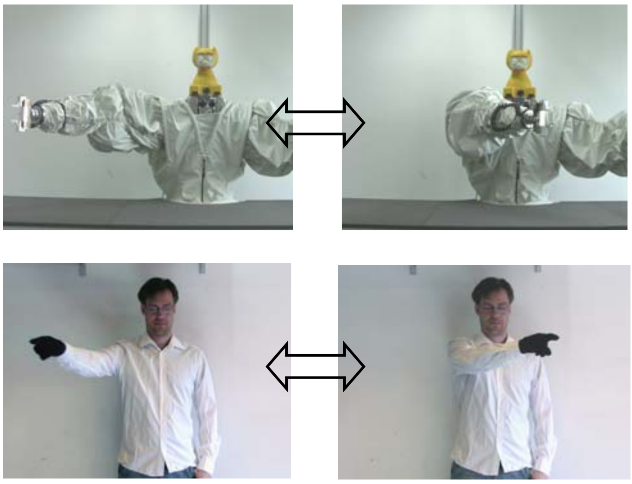

Fig. 1 Screenshots from the videos presented to the subjects. The participants had to make horizontal or vertical movements while fixating on the hand of JAST or a human agent, who performed congruent or incongruent movements.

The robot JAST produced horizontal and vertical movements directed by the shoulder joint. The motion velocity was based on a minimum-jerk profile [25], which, in contrast to the constant velocity profile, makes the movements look smoother and more natural by preventing abrupt changes in movement velocity [2].

One trial (duration: ca. 30s) was performed for each of the eight conditions. At the start of each new condition, the participants were informed (by an instruction appearing on the screen) of the plane in which to move their arm and instructed to keep in phase with the experimenter's and robot's movements. The kinematics of the endpoint of their right index finger was recorded at 240 Hz using the magnet-field based motion tracking system Polhemus Liberty.

After data acquisition, fingertip positions were filtered with a 20-Hz second order Butterworth filter and the data from each trial was split into single movement segments (from right to left and from top to the bottom and vice versa) by finding data points at which the x- and z-values reached their maxima and minima. The standard deviation of fingertip position within the plane orthogonal to the plane of movement was used to quantify the interference. The mean of the deviations of all single movements within one trial was calculated for each subject and then across all the participants.

3 RESULTS

The analysis showed that the mean values (across 10 subjects) of the deviations in the plane orthogonal to the movement were generally bigger for the observation of incongruent than congruent movements for both human and humanoid robot observation (s. Fig 2 for an example of movement trajectories projected onto the x-z-plane). The analysis of variance performed on the factors congruency, plane of movement, and agency, revealed only a main effect of congruency [F(1,9)=21.8; p=0.001] (s. Fig 3). There were no other significant main effects or interactions between any of the factors.

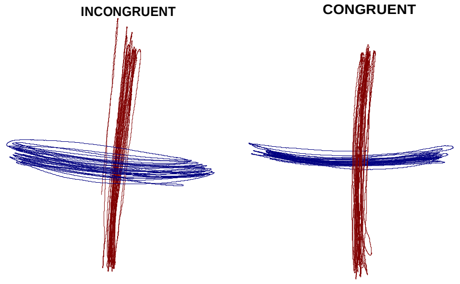

Fig. 2: Individual movements made by a single subject in the XZ- plane. During his movement, the subject observed another human, who performed incongruent or congruent movements.

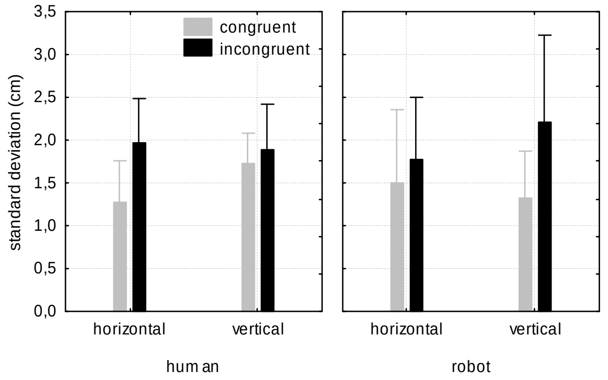

Fig. 3: Standard deviations in the plane orthogonal to the movement plane averaged across ten subjects during observation of a humanoid robot or a human experimenter performing congruent or incongruent movements. Error bars represent 95% confidence intervals.

4 DISCUSSION

While performing everyday activities, individual's limb and body movements are constantly influenced by the observed movements of other individuals [26]. A well-known example of triggering imitation by observing an action is the contagion of yawning [13] by activation of motor systems, which control the observed action. Likewise, the observation of a certain action, different from the own action, can interfere with it.

Movement synchrony enhances intention understanding

Since mirroring the actions of others might help to understand what another person is doing [27], the main function attributed to motor resonance is action perception. Motor resonance might even underlie more sophisticated mental abilities, such as understanding the intentions of others [28]. Thus, simulating another person's actions allows humans to make predictions about the mental states of others based on the mental states and behaviours that they experience themselves while mimicking others [29]. On the neuronal level, it was reported that lesions of premotor cortices involved in the control of action impairs the perception of biological motion presented using point-light displays [30].

The higher degree of movement synchronisation is generally regarded to be a sign of higher degree of mutual rapport, involvement and togetherness [31]. It has been shown, that behavioral synchrony during a dyadic interaction triggers increased attention to the interaction partner leading to enhanced memories about his appearance and his utterances [32]. In psychotherapeutic counseling, congruent movement of limbs of the therapist and the client were significant contributors to attributions of rapport [33]. Additionally, it has been demonstrated, that while asking for route directions for a certain destination, most subject synchronized their arm gestures with the person or the humanoid robot, providing them with these instructions [34]. Another study, investigating body movements in human-robot interaction, has found a positive correlation between the arm movement synchrony of the robot and the human and subjective evaluations of the interaction [35].

Motor interference as objective tool for evaluation of human-robot interaction

As stated in the introduction, motor interference is the direct consequence of motor resonance [13]. Since motor resonance is linked to the sense of togetherness and is observed in a successful human interaction, MI can be used as an objective tool for evaluation of human-robot interaction. Specifically, it can be used to study, what aspects of robot form and motion make it sufficiently human-like and which aspects should be left robotic to display the robot's non-human capabilities. Since the interference effect can be obtained in different planes of movement, the paradigm of MI might be adapted to investigate how naturally other complex robot motions are perceived by humans. However, it might still be helpful to additionally correlate objective findings from the MI experiments with traditional subjective evaluation based on questionnaires.

Present results in light of other studies

The variability of the subjects' arm movements in the orthogonal plane of movement was significantly increased while observing incongruent vs. congruent movements of a human agent (Fig. 2). This was also the case for the humanoid robot. Additionally, there was no interaction effect between the factors "agency" and "congruency". These results support the notion that, during observation of non-goal directed action, the specific neural networks subserving that particular movement are already tuned for action [11], thus interfering with a different action.

The current findings are similar to [18] and [19], who also reported MI for the observation of incongruent action of both human and humanoid robot and strengthen the conclusion, that biological motion velocity might be essential for MI. However, our results extend these previous studies by showing that MI is present in observation of video presentation as well. Furthermore, MI did not depend on accurate biological movement profiles such as used in previous studies: the minimum-jerk movements used in our study, which only approximate biological motion, were sufficient to elicit strong MI.

Together with previous findings [18], our results indicate that the phenomenon of MI is not only limited to observation of human action. A humanoid robot with a limited human-likeness in its appearance may trigger the same type of implicit perceptual processes as a human agent, given that it moves with a quasi-biological velocity. In contrast to that, in the original study [6], MI could not be shown when subjects were observing an industrial robot performing the actions. However, this discrepancy can be explained by the fact that the robot used in the earlier study did not have any humanoid facial features and moved with an artificial constant velocity.

The influence of anthropomorphism on the motor interference

It is traditionally assumed, that building robots with humanoid appearance is the obvious strategy for integrating them successfully into human environments and increasing their acceptance for the majority of non-technical users. However, the question is, whether we need a fully anthropomorphic synthetic human or if a certain degree of form realism is sufficient for social acceptance. A popular theory about the perception of robots [36] states that as a robot increases in humanness, it becomes more susceptible to failures in its functionality and design ("The Uncanny Valley"). This results from the fact that the more human-like the robot appears, the higher are the expectations of people interacting with it. This hypothesis predicts, for example, that a prosthetic limb covered with skin-colored rubber, which imperfectly, albeit extremely closely, reproduces the texture and the motion of real limbs would be more repulsive than a less realistic limb with a mechanical appearance. Therefore, to meet the users' expectations, there must be an appropriate match between physical familiarity with a human and cognitive abilities of the robot.

6 CONCLUSIONS & FUTURE WORK

The present experiment replicates the results of recent studies, claiming that observing incongruent arm movements made by a humanoid robot with a biological velocity, may have a significant interference effect on simultaneously executed human movements. MI also remains stable if the live presentations of the robots are substituted by videos, which are projected on a screen in life-size.

The currently used robot head "iCat" had a zoomorphic appearance with movable eyebrows, eyelids, eyes and lips [37]. This animal-like form might have resulted in the higher acceptance by humans by decreasing the probability of getting into the "uncanny valley, since our expectations of animals' capabilities are lower than of human. The presence of detailed face feature might also have had a positive effect on the emergence of the MI, since it has been shown, that the four features that increase the perception of humanness the most are the eyes, nose the eyelids and the mouth [38].

Initially, MI has been demonstrated in the robot DB, facial features of which are merely suggested, but which, on the other hand, has more degrees of freedom in his joints than JAST and thus a higher capability for biological motion [18, 19]. Therefore, the importance of using a humanoid form in interactive robots is still an assumption that has yet to be proven. Also, the exact aspect of biological motion, which is the trigger for interference, and which is absent in robotic movements (e.g. non-constant velocity, curved trajectory, increased movement variability), remains unknown [39].

Therefore, in the next step, we would like to use the MI paradigm (combined with the subjective evaluations) in order to separate the relative contributions of form and motion to the effect of MI. The question whether humanoid form is essential to elicit a motor response similar to human movement observation can, for example, be investigated by comparing JAST with an industrial robot such as JAHIR [40], which can also be programmed to produce minimum-jerk velocity movements.

Although the MI paradigm is an easy and cheap method for the evaluation of humanoid robots, its applications may be limited to mobile humanoid robots provided with torso and at least two upper limbs. Therefore, it might be helpful to expand the results obtained my MI using additional objective and subjective (questionnaires) methods. Possible objective tools for evaluation of human-robot interaction might include measuring a) physical proximity between the interaction partners, b) number of human approaches towards the robot, c) effectiveness of the jointly completed work, d) success in the solution of mutual tasks, amount of shared attention, e) quality of emotional response to the robot or f) recording heart rate and skin conductivity as measures of arousal.

Together with previous studies, our results will provide a test bed for analyzing human-robot interaction and thus principles for developing guidelines for the future design of assistive robots. These interactive robots will facilitate social competence and support appropriate and pleasant human-robot interaction.

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