

Biological movement increases acceptance of humanoid robots as human partners in motor interaction

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Abstract The automatic tendency to anthropomorphize our interaction partners and make use of experience acquired in earlier interaction scenarios leads to the suggestion that social interaction with humanoid robots is more pleasant and intuitive than that with industrial robots. An objective method applied to evaluate the quality of human–robot interaction is based on the phenomenon of motor interference (MI). It claims that a face-to-face observation of a different (incongruent) movement of another individual leads to a higher variance in one's own movement trajectory. In social interaction, MI is a consequence of the tendency to imitate the movement of other individuals and goes along with mutual rapport, sense of

togetherness, and sympathy. Although MI occurs while observing a human agent, it disappears in case of an industrial robot moving with piecewise constant velocity. Using a robot with human-like appearance, a recent study revealed that its movements led to MI, only if they were based on human prerecording (biological velocity), but not on constant (artificial) velocity profile. However, it remained unclear, which aspects of the human prerecorded movement triggered MI: biological velocity profile or variability in movement trajectory. To investigate this issue, we applied a quasi-biological minimum-jerk velocity profile (excluding variability in the movement trajectory as an influencing factor of MI) to motion of a humanoid robot, which was observed by subjects performing congruent or incongruent arm movements. The increase in variability in subjects' movements occurred both for the observation of a human agent and for the robot performing incongruent movements, suggesting that an artificial human-like movement velocity profile is sufficient to facilitate the perception of humanoid robots as interaction partners.

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1 Introduction

Humanoid robot technology is developing at an incredible rate (Duffy 2003; Huber et al. 2008) suggesting that in the near future, humanoid service robots may become part of daily lives of ordinary people. Based on the human's instructions and control, humanoid robots might assist humans as “partner robots” in completing a variety of tasks that are physically demanding, unsafe, unpleasant, or

boring. Therefore, the aim of social robot research is to build a robot that can engage in social interaction scenarios with humans in a natural, familiar, efficient, and above all, intuitive manner.

It has been proposed that during interaction with humanoid robots, people tend to anthropomorphize them and to apply experience acquired with human partners in order to explain, understand, or predict their behavior (Duffy 2003). It is traditionally assumed that the obvious strategy for integrating robots successfully into human environments and increasing their acceptance for the majority of non-technical users is building them with a certain degree of anthropomorphic attributes (Duffy 2003). Therefore, it is important to analyze what features of a robot facilitate interaction between a human and a machine in social scenarios and make it enjoyable and which features have less influence on the positive perception of a robot. Although the quality of interaction between humans and humanoid robots has been investigated by some studies (Huber et al. 2008), mostly, only questionnaire-based subjective judgments were used for this purpose (Blow et al. 2006; Goetz et al. 2003; Syrdal et al. 2007). A possibly objective tool, which is based on the phenomenon of motor interference, has been developed only recently (Kilner et al. 2003).

1.1 The cause of motor interference: action–perception coupling

By the means of fMRI (functional magnetic resonance imaging), it has been shown that observation of an action leads to activation of the corresponding motor areas in the human premotor cortex (Buccino et al. 2004; Buccino et al. 2001). In line with this hypothesis goes the finding that there is a significant increase in the motor-evoked potentials from the hand muscles during hand action observation (Fadiga et al. 1995). It therefore seems that perception of an action leads to simulative production of that action on the part of the observer, facilitating its execution and interfering with a different action (Jeannerod 2001). Thus, when the participant observes his partner producing an incongruent movement, the motor program or representation associated with the observed movement should interfere with the outgoing motor output for the movement intended by the observer. Indeed, it has been shown that observing another person perform an action facilitates the execution of a similar (congruent) action and interferes with the execution of a different (incongruent) action (Brass et al. 2001). On the neuronal level, observation of 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 (*motor*

interference) (Jeannerod 2001; Prinz 1997). On the behavioral level, motor interference (MI) is seen as an increase in variance in one's own movement while watching an incompatible movement of a partner. For example, perceiving a horizontal arm movement facilitates the concomitant execution of the same action and curbs the execution of a vertical arm movement (Kilner et al. 2003).

1.2 Motor interference and the quality of dyadic interaction

The main function attributed to motor resonance is action understanding since mirroring the actions of others might help to understand what another person is doing (Rizzolatti et al. 2001; Iacoboni et al. 2005). Thus, simulating other people's actions might allow humans to make predictions about the mental states of others based on the mental states and behaviors that they experience themselves while mimicking others (Breazeal et al. 2005). Further, a high degree of movement synchronization between interaction partners is generally regarded to be a sign of a high level of mutual rapport, involvement, and togetherness (Chartrand and Bargh 1999). Likewise, when people observe other people perform effortful actions, they tend to change their breathing themselves (Paccalin and Jeannerod 2000). Behavioral synchrony during a dyadic interaction has been shown to lead to an increase in attention to the interaction partner and thus enhance memories about his appearance and his utterances (Macrae et al. 2008). In psychotherapeutic counseling, congruent movement of limbs of the therapist and the client were significant contributors to the attributions of rapport (Trout and Rosenfeld 1980). Additionally, it has been demonstrated that while asking for route directions for a certain destination, most subjects synchronized their arm gestures with the person or the humanoid robot, which provided them with instructions (Ono et al. 2001). Another study, investigating body movements in human–robot interaction, has found a positive correlation between the arm movement synchrony and subjective evaluations of the interaction quality (Kanda et al. 2004). All these findings suggest that synchronization of movement during interaction can serve as an indication for a positive and pleasant interaction. Therefore, the more pleasant we find the interaction with a partner, the more we tend to mimic his actions and the more his incongruent movements will interfere with our own action. Likewise, if we enjoy interacting with a humanoid robot, we will have the tendency to mimic its movements that results in deviations from our movement trajectory in case of producing movements different from the robot's movements.

1.3 Movement characteristics facilitating the emergence of motor interference

In the original study, which tested the influence of movement observation on the movement of the observer (Kilner et al. 2003), MI appeared in case of human movement but not in case of movement produced by an industrial robot. However, some recent studies (Chaminade et al. 2005; Oztop et al. 2005) have demonstrated MI when subjects watched a humanoid robot performing movements based on implemented prerecording of a human experimenter. Interestingly, this effect disappeared when the same robot moved with a constant-velocity profile. However, it is still unclear which aspect of human motion, absent in robotic movements, was responsible for evoking MI while observing movements based on human prerecordings. The interference effect in the study by Kilner et al. (2003) might have been triggered by either non-constant velocity (acceleration and deceleration) or variability of amplitude and trajectory (e.g., due to fatigue or constraints caused by anatomy of the human arm) of repeatedly presented movements. A number of results suggest that movement variability is an important factor in differentiating between biological and non-biological movement. Likewise, in a study investigating intention understanding in infants (Premack 1990), the subjects might not have understood the intentionality of a moving box because it repeated exactly the same movements every time. However, implementing variability in the movement trajectory of the box led to goal attribution in 6.5-month-old infants (Gergely 2008). Additional evidence for variability in movement as an important factor for identifying goals comes from preliminary experiments conducted by Gazzola et al. (2007). In their study, the researchers presented subjects with videos of a robot, who performed either five different actions within a block or five times the exact same action. Significant activations in the MNS were found only in the first case.

1.4 Purpose of the study

In our study, we would like to investigate whether the variability of the movement is required to trigger motor interference during observation of movements of a humanoid robot.

We use the MI paradigm described in the study by Chaminade (2008) and Oztop et al. (2005), but replace live presentations with video clips depicting horizontal and vertical movements of either a humanoid robot JAST or a human agent (see Fig. 1). The use of video presentations allows us to control the between-subject variability in the movements of the human agent, which might lead to variability in the subjects' movements. Further, by implementing the

so-called “*minimum-jerk*” velocity profile (Flash and Hogan 1985) into the movements of our robot, we achieve a quasi-biological acceleration and deceleration without having movement variability in them. Similar to a biological non-constant velocity movement, a minimum-jerk movement starts slowly, accelerates smoothly to a peak velocity near the midpoint, and then decelerates slowly. This results in a smooth, bell-shaped velocity profile, where mathematically the derivative of acceleration (jerk) is minimized over the movement. Thus, by preventing abrupt changes in movement velocity, in contrast to the constant velocity profile, minimum-jerk movements look smoother and more natural (Huber et al. 2008). In case that movement variability is less important for triggering MI than non-constant velocity, we expect a higher variability in the observers' movements during observation of incongruent movements of our robot.

2 Methods

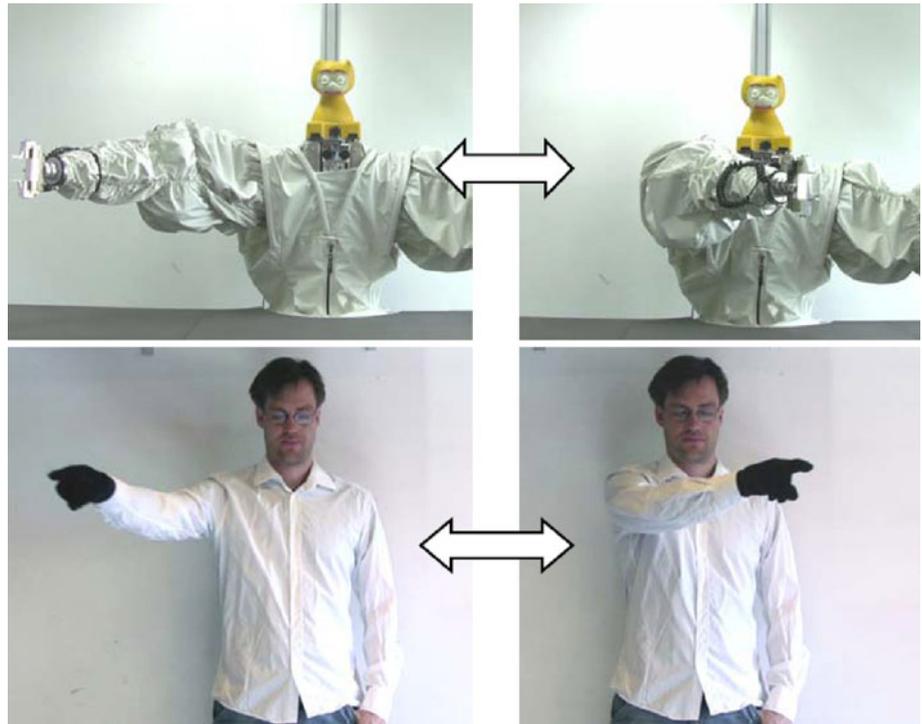
Eleven female and fourteen male graduate students from the local Department of Neurology have been tested in the present experiment. The videos of both the robot “JAST” and the human agent were rear-projected on a white screen (120 × 160 cm, located ca. 1.5 m in front of the participant) in a pseudorandomized order. JAST has an “animal” head and is capable of producing movements with human-like minimum-jerk velocity profiles directed by the shoulder joint (Huber et al. 2008).

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 or robotic agent (see Fig. 1). The agent performed either spatially congruent (C, same direction) or incongruent (I, perpendicular) movements (frequency: 0.5 Hz) with their right arm. 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).

One trial (duration: ca. 30 s) 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 (a small 1 × 1 cm sensor was fixed to the tip of the participant's index finger).

After data acquisition, fingertip positions of subjects were filtered with a 20-Hz second order Butterworth filter, and the data from each trial were split into single movement segments (from right to left and from top to the

Fig. 1 Screenshots from the videos of the human and robot agents performing horizontal movements. The participants were instructed to perform horizontal (congruent) or vertical (incongruent) movements while fixating on the hand of JAST or the human agent



bottom and vice versa) by finding data points at which the x - and z -values reached their maxima and minima, respectively. The standard deviation of fingertip position in the direction 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 of variance (repeated measures ANOVA) was performed on “movement plane”, “congruency” and “agent” as within-subjects factors and “gender” as between-subject factor. This analysis revealed a main effect of congruency [$F(1, 23) = 23,74; p < 0.000$]. The mean values (across 25 subjects) of the deviations in the plane orthogonal to the plane if movements were generally bigger for incongruent than for congruent movements during observation of both human and humanoid robot (see Fig. 2). There were no other significant effects for other factors or interactions between any of the factors.

4 Discussion

Our results demonstrate that observing non-goal directed human and robotic arm movements significantly interferes with ongoing executed movements if the observed

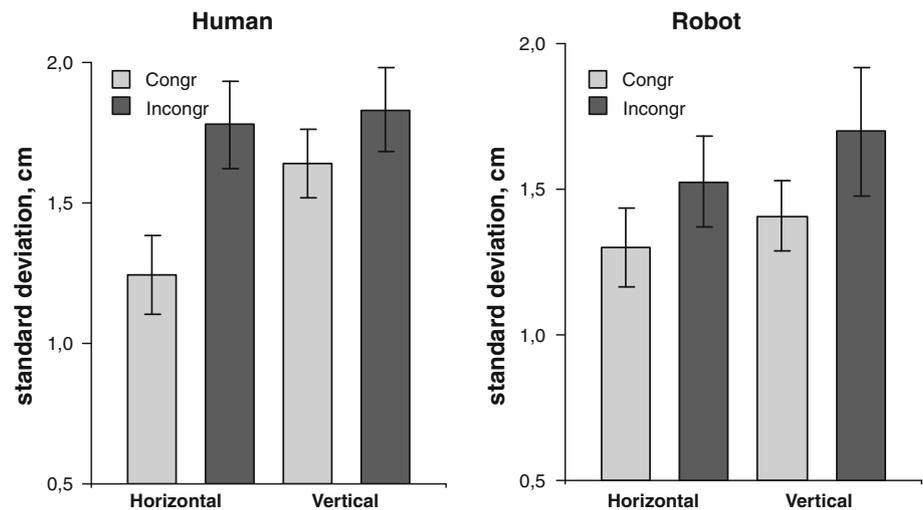
movements are qualitatively different from the movements being made. This is not surprising, since while performing everyday activities, our limb and body movements are constantly influenced by the observed movements of other individuals (Sebanz et al. 2006). A well-known example of triggering imitation by observing an action is the contagion of yawning (Chaminade 2008). Since we found no difference in movement variability for men and women, it seems that the strength of motor interference does not depend on social factors such as gender differences in observing subjects and familiarity with the robot (which might be higher for men than for women).

Further, we could show that quasi-biological movement velocity is sufficient for triggering MI, even if the movement variability is absent in the observed movement.

4.1 Biological motion velocity is required for intuitive interaction

The ability to distinguish biological from non-biological motion might be useful for recognizing the movements of other animate beings and for the prediction of their future actions and making an appropriate response. Some studies have suggested that perception of biological motion plays a role in social cognition more broadly (Dakin and Frith 2005) including the discrimination of living from non-living entities (Johnson 2006; Troje and Westhoff 2006) or gender (Troje et al. 2006) or individuals from one another (Jacobs et al. 2004). The fact that perception of biological

Fig. 2 Standard deviations in the direction orthogonal to the movement plane averaged across 25 subjects during observation of a humanoid robot or a human experimenter performing congruent and incongruent movements. *Error bars* represent the standard error of the mean



motion plays a role in social understanding is supported by developmental findings in Autism Spectrum Disorder and Williams Syndrome—two developmental disorders demonstrating more or less complementary social abilities. Autistic children, who show a variety of symptoms including poor social cognition, impaired face, and emotion processing, have deficits in joint attention abilities and attributing mental states (Hadjikhani et al. 2007), also have deficits in the processing of biological motion of point-light displays (Blake et al. 2003). Conversely, children with Williams syndrome, who exhibit relatively preserved social cognition including intact face recognition (Paul et al. 2002), were shown to have intact processing of biological motion (Jordan et al. 2002).

4.2 Present results in light of other studies

Several studies used video observation to investigate what information in the observed movement triggered MI in the action of the observer. These studies investigated continuous movement synchronization of a human observer with a moving dot stimulus (Bouquet et al. 2007; Gowen et al. 2008; Stanley et al. 2007), ball motion (Kilner et al. 2007), or motion of a point-light figure (Jackson et al. 2006). In the study by Bouquet et al. (2007) and Kilner et al. (2007), the variance of the participant's movements in the incongruent condition was enhanced only by biological dot motion; in the study by (Stanley et al. 2007), the increase in variance was observed in both biological and non-biological dot motion; in the study by (Gowen et al. 2008), the interference effect was greater in the biological dot movement profile than in the non-biological dot movement profile, and in the study by (Jackson et al. 2006), MI could 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. Together with (Chaminade et al. 2005), who also reported MI for the observation of incongruent action of a humanoid robot moving with biological, however not constant velocity, our findings strengthen the hypothesis that biological motion velocity might be essential for MI.

Additionally, MI did not depend on the variability of movement trajectory or accurate biological movement velocity profiles such as used in previous studies. The minimum-jerk movements, which only approximate biological motion, were sufficient to elicit strong MI. Thus, it seems that given that the velocity of the movement is biological, the variability in movement trajectory is not crucial for triggering motor interference.

5 Conclusions and future work

The present experiment provides additional evidence for the fact 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.

Together with previous findings, our results further 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 (Kilner et al. 2003), MI could not be shown when subjects were observing an industrial robot performing the actions. However, this could also 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 velocity.

The currently used robot head “iCat” had a zoomorphic appearance with movable eyebrows, eyelids, eyes, and lips (Hegel et al. 2007). This animal-like head might have led to a higher acceptance by humans, since our expectations of animals’ capabilities are lower than those of humans. The presence of detailed facial features might also have had a positive effect on the emergence of the MI, since the presence of eyes, nose, eyelids, and mouth has been shown to increase the perception of humanness the most (DiSalvo et al. 2002). 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 can perform biological motion in a more optimal way (Chaminade et al. 2005, Oztop et al. 2005). Thus, more detailed facial features of JAST might have compensated for a less realistic body (which consists of two industrial arms with grippers instead of fingers (Reinhart et al. 2007)) when it comes to MI.

Since both robots (JAST and DB), using which MI was demonstrated, had a humanoid shape, the relative contribution of appearance for eliciting this phenomenon still remains unclear. Therefore, in the next step, we would like to use the MI paradigm (combined with subjective evaluations) for separating the effect of humanoid shape and biological motion velocity in the emergence 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 (Reinhart et al. 2007), which can also be programmed to produce minimum-jerk velocity movements.

Together with previous studies, our results will provide 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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