THE QUARTERLY JOURNAL OF EXPERIMENTAL PSYCHOLOGY
2012, 65 (5), 840–847

Psychology Press
Taylor & Francis Group

Rapid communication

Motor interference and facilitation arising from observed movement kinematics

Robert M. Hardwick[1,2] and Martin G. Edwards[2,3]

[1]Behavioural Brain Sciences Centre, School of Psychology, College of Life and Environmental Sciences, University of Birmingham, Birmingham, UK
[2]School of Sport and Exercise Sciences, College of Life and Environmental Sciences, University of Birmingham, Birmingham, UK
[3]Université catholique de Louvain, Institut de Recherches en Sciences Psychologiques, Louvain-la-Neuve, Belgium

Previous studies demonstrate that observing the movements of others can interfere with concurrent movement execution. This interference effect is attributed to incongruence between the observed and executed movements. The study presented here examined different aspects of observed and executed movement congruency. Participants attempted to trace straight lines in the air using one of two movement tasks while observing an experimenter perform movements varied by their task and spatial congruency. The data revealed that kinematic aspects of the observed movements were incorporated into the observer's own movements. Observing the same kinematics led to interference or facilitation effects depending on whether the direction of the observed movement was congruent or incongruent with the movement the participant performed. These data suggest that low-level properties of observed movements can modulate participant performance.

Keywords: Mirror neurons; Action observation; Interference effect; Motor facilitation; Observed kinematics.

Found in premotor and parietal areas of the macaque brain, mirror neurons have firing patterns that are modulated when a monkey performs an action and also when the primate observes another agent (such as a human experimenter) perform a similar action (for a review see Rizzolatti, Fogassi, & Gallese, 2001). Data from neuroimaging provides evidence of a similar action observation network in the human brain (see, for example, Buccino et al., 2001). There is considerable evidence that the human action observation network is involved in imitation (for a recent meta-analysis see Caspers, Zilles, Laird, & Eickhoff, 2010). Behavioural studies demonstrate that viewing the actions of

Correspondence should be addressed to Robert M. Hardwick, Behavioural Brain Sciences Centre, School of Psychology, College of Life and Environmental Sciences, University of Birmingham, Birmingham, B15 2TT, UK. E-mail: r.m.hardwick@bham.ac.uk
The School of Sport and Exercise Sciences, University of Birmingham, UK, funded this research.

http://www.psypress.com/qjep
http://dx.doi.org/10.1080/17470218.2012.672995

others can modulate the observer's performance of motor tasks (Edwards, Humphreys, & Castiello, 2003; Hardwick & Edwards, 2011). Such effects are present in studies examining interference in the visual coordination of movement (for a review see Blakemore & Frith, 2005). For instance, Kilner, Paulignan, and Blakemore (2003) had participants perform sinusoidal arm movements in either the horizontal or vertical plane, concurrently observing the movements of a human experimenter, observing the movements of a robotic arm, or (in a baseline condition) observing no movement. In the experimenter and robot conditions, the observed agent moved in either a congruent or incongruent (orthogonal) direction to the participant. While observing congruent movements had no effect on participant performance, the spatial error in participants' movements increased when they observed a human experimenter perform incongruent movements. This suggested that observing the incongruent movements of the experimenter interfered with participants' movements. Conversely, the observation of incongruent robotic movements had no effect on participant performance. This suggested that the interference that occurred when observing the incongruent movements of the experimenter was not simply due to increased demands on attention due to observing incongruently directed movement. Instead, it was proposed that the effect may have been due to shared conspecific processes, or the observation of biological motion—due to its inherent variability in contrast to the fixed, repetitive movements of the robotic arm.

Stanley, Gowen, and Miall (2007) examined the effect of manipulating the attributed agency of observed movement kinematics. Participants performed sinusoidal arm movements while observing a moving dot projected on a screen. Dot stimuli depicted either prerecorded (biologically valid) kinematics of a human experimenter, or computer-generated (biologically invalid) movements. Two groups of participants completed the experiment; each group saw both the biologically valid and the biologically invalid stimuli. However, the first group was informed that all the dot stimuli represented prerecorded human movements, while the second group were told that all the dot stimuli depicted computer-generated movements. The results revealed that the dot motion stimuli only interfered with performance when participants believed the kinematics they observed depicted human movements; observing the same stimuli had no effect on participants who believed they depicted computer-generated movement kinematics. Additionally, participant movement variability was greater when they observed human (high variability) movement kinematics than when they observed computer-generated (low variability) movement kinematics. This modulation was, however, present regardless of congruency and agency beliefs and was therefore attributed to a bottom-up effect due to the naturally greater levels of error-plane variability present in the biological movement kinematics (see also Gowen, Stanley, & Miall, 2008).

These studies demonstrate that the observation of movement kinematics can interfere with concurrent action execution. This effect relies on observing movement kinematics that can be attributed to another person (even if they are not biologically plausible) that are incongruous with the movement the participant performs. They also demonstrate that low-level properties of observed movement kinematics (i.e., greater levels of movement in the error plane) can exert bottom-up effects on performance. While these interference effects are clearly due to incongruence between observed and executed movements, it has not been established whether they are driven by processes involved in the representation of observed and executed actions, or are due to spatial compatibility effects (Heyes, 2011). For example, the effect may be due to the incongruence between the manner in which the movements were produced (task congruency), incongruence between the relative spatial directions of observed and executed movements (direction congruency), or a combination of these factors (though it should be noted that Brass, Bekkering & Prinz, 2001, have demonstrated effects of task congruency and direction congruency without any interaction in a simple reaction time task). The study presented here examines these issues; varying the task performed by the experimenter and participant allowed the manipulation of task congruency, while varying the position of the experimenter in relation to the participant also allowed manipulation of the relative spatial direction congruency of observed and executed movements. It was hypothesized that observing movements being performed using an incongruent movement task or incongruent movement direction to those being executed would interfere with participant movement performance.

Method

Participants

Twelve participants (seven female) aged 23–35 years participated in the study. All were right-handed with normal or corrected-to-normal vision. The study was approved by the Local Ethics Board, and participants gave informed consent prior to their participation.

Movement tasks and motion capture

During the experiment, participants attempted to trace straight lines in the air with the tip of their right index finger. Participants performed either "anterior" or "lateral" movements in each trial. Anterior movements were performed by moving the arm at both the shoulder and elbow, keeping the index finger in line with the sagittal plane of the body (see Figure 1A). Lateral movements were performed by making sinusoidal movements at the shoulder while keeping the elbow in a fixed position (see Figure 1B). While performing these movements, participants attempted to minimize any movement in the "error direction" (the y-plane during anterior movements, the x-plane during lateral movements). A reflective marker was attached to the tip of the index finger of the participant and experimenter. The position of the markers was recorded at 120 Hz with 0.1-mm spatial resolution using an 8 camera Vicon MX system and was stored for offline analysis.

Following data acquisition, movements from each trial were split into segments (e.g., lateral-movement segments consisted of the fingertip moving from left to right or the fingertip returning from right to left). The standard deviation of the fingertip position in the error direction was calculated for each movement segment, and the mean average of these values was calculated for each trial type (see Stanley et al., 2007).

Design and procedure

In each trial, participants were instructed to perform either anterior or lateral movements. Following familiarization with the movement tasks, participants completed baseline trials in which they performed movement tasks while observing the index finger of a 22-year-old male experimenter who kept his hand in a fixed position.[1] After this, participants completed a series of experimental trials in which the experimenter also performed one of the two movement tasks. *Task congruency* was manipulated by having the experimenter perform either the same or the opposite type of movement to the participant. *Direction congruency* was manipulated by varying the position of the experimenter relative to the participant (see insets in Figures 1C–1D). The experimenter stood either directly opposite the participant at a distance of 2.00 m or to the right of the participant at a distance of 1.75 m (ensuring the approximate midpoint of the experimenter's movements remained at a consistent distance from the participant). During baseline trials, participants performed movements in time with a 1-Hz auditory metronome. In experimental trials, the 1-Hz metronome was played to the experimenter alone through headphones, requiring the participant to pace their movements according to the movements of the experimenter. The experimenter kept their eyes closed in all conditions in order to avoid being influenced by the movements of the participant.

Participants completed 36 movement segments in each trial. Of these, 30 segments were used in the analysis; five initial segments were discarded to allow the participant to establish consistent timing with the experimenter, and the final segment was discarded as some participants ended the movement prematurely. Each condition was repeated twice in a

[1] *Post hoc* analysis revealed that the average movement of the experimenter's finger during the baseline conditions was 2 mm.

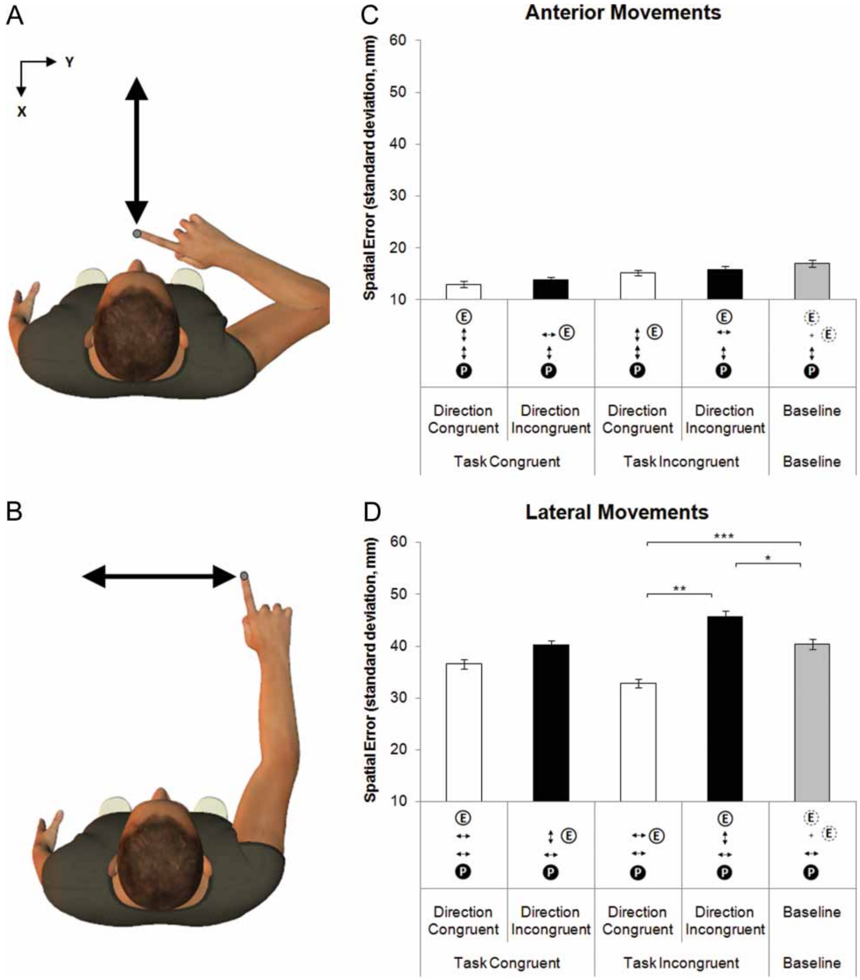

Figure 1. *Movement tasks and experimental results. (A) illustrates the manner in which anterior movements were performed, while (B) shows how lateral movements were made. Each illustrates the starting position and direction of movement for one movement segment. When performing anterior movements, participants moved in the* X *direction while attempting to minimize movement in the* Y *direction, and vice versa for lateral movements. (C) Depicts participant performance when performing anterior movements, while (D) presents participant performance when performing lateral movements. Insets under each bar illustrate the position and movement task performed by the participant (filled circles containing the letter "P") and experimenter (open circles with the letter "E"). For data collection in the baseline condition, one trial was completed with the experimenter in each position, with their hand held in a fixed position (open, dashed circles containing the letter "E"). Error bars present the average within participant standard error for each movement type. *Indicates significant difference from repeated measures analysis of variance (ANOVA;* $p < .05$*). ***Indicates significant difference from* post hoc t *test (*$p < .05$*). Indicates significant difference from* post hoc t *test (*$p < .025$*). To view a colour version of this figure, please see the online issue of the Journal.*

pseudorandom order, resulting in a total of 60 movement segments per condition.

Data analysis

The dependent variable of spatial error (mean standard deviation of movements in the error direction, in mm) was calculated using the mean average for each condition. A $2 \times 2 \times 2$ repeated measures analysis of variance (ANOVA) compared experimental conditions, examining the independent variables of participant movement type (anterior or lateral), task congruency (task congruent or task incongruent), and direction congruency (direction congruent or direction incongruent).

Results

Movements performed using the lateral-movement type were affected by action observation. Interference or facilitation effects arose when participants observed the experimenter perform anterior, task-incongruent movements. These modulations of performance depended on the direction congruency of the observed movements.

Figures 1C–1D present the analysis of participant movement error (see Table 1 for detailed results of each condition). Only effects that achieved statistical significance are reported. The analysis revealed significant main effects for movement congruency, $F(1, 11) = 24.12$, $p < .001$, and direction congruency, $F(1, 11) = 18.70$, $p < .01$. This showed that participants performed anterior movements with less spatial error than they did lateral movements (means: anterior movements 15.0 mm, lateral movements, 41.0 mm, *SEM*: 2.7 vs. 4.1) and that participants performed movements with less spatial error when they observed the experimenter perform congruently directed movements than when they observed the experimenter perform incongruently directed movements (means: congruent direction 26.0 mm, incongruent direction 30.2 mm, *SEM*: 2.1 vs. 2.5). The analysis also revealed several significant interactions: between movement type and direction congruency, $F(1, 11) = 20.63$, $p < .001$, between task congruency and direction congruency, $F(1, 11) = 7.83$, $p < .05$, and a three-way interaction between movement type, task congruency, and direction congruency, $F(1, 11) = 6.31$, $p < .05$. The two-factor interactions were analysed using separate ANOVAs, and the three-factor interaction was analysed using separate *t* tests.

The two-factor interaction between movement type and direction congruency was analysed by comparing direction congruency (direction congruent or direction incongruent) for each movement type (anterior or lateral). Only the analysis of lateral movements revealed a significant effect of direction congruency, $F(1, 11) = 31.27$, $p < .001$, with lateral, congruently directed movements showing less error than lateral, incongruently directed movements (means: lateral, congruent direction 37.0 mm, lateral, incongruent direction 45.0 mm, *SEM* 2.2 vs. 2.5). The two-factor interaction between task congruency and direction congruency was also analysed by comparing direction congruency (direction congruent or direction incongruent) for each type of task congruency (task congruent or task incongruent). This revealed no significant differences.

The three-way interaction between all factors was analysed using separate *t* tests. Only the tests for lateral, task-incongruent conditions showed a significant direction congruency effect, $t(11) = 7.47$, $p < .0001$, revealing that participants performed movements with less error when moving in a congruent direction than when moving in an incongruent direction (means: lateral, task incongruent, direction congruent = 35.0 mm, lateral, task incongruent, direction incongruent = 47.4 mm, *SEM* 3.8 vs. 4.0).

As these analyses revealed direction congruency effects in lateral, task-incongruent conditions, *post hoc* analysis was conducted to compare these data

Table 1. *Mean spatial error for each condition*

	Task congruent		*Task incongruent*		
Movement type	*Direction congruent*	*Direction incongruent*	*Direction congruent*	*Direction incongruent*	*Baseline*
Anterior	13.4 ± 1.9	14.2 ± 2.6	16.0 ± 2.7	16.4 ± 3.4	17.7 ± 4.3
Lateral	38.8 ± 4.6	42.7 ± 4.7	35.0 ± 3.8	47.4 ± 4.0	42.3 ± 4.0

Note: Mean values in mm ± standard error of the mean (*SEM*).

with their respective baseline condition. Holm–Bonferroni-corrected *t* tests revealed that lateral-movement, task-incongruent, direction-congruent movements were performed with significantly less error than in the lateral baseline condition, $t(11) = 2.612$, $p < .025$ (means: lateral, task incongruent, direction congruent = 35.0 mm, lateral baseline condition = 42.3 mm, *SEM* 3.78 vs. 3.95). The lateral-movement, task-incongruent, direction-incongruent condition was revealed to be performed with greater error than the lateral baseline condition, $t(11) = 2.21$, $p < .05$ (means: lateral, task incongruent, direction incongruent = 47.4 mm, lateral baseline condition = 42.3 mm, *SEM* 4.0 vs. 4.0).

Discussion

This study examined the effects of observing simple movements on the execution of similar actions. Using two distinct types of movement (anterior and lateral movements), we modulated observed task congruency and direction congruency in order to examine the effects these factors had on movement execution. The data revealed that movements performed using the lateral-movement task were affected by action observation, with interference or facilitation effects arising when participants observed the experimenter perform the incongruent, anterior-movement task.

The significant main effect of movement type revealed that participants made less error when performing anterior movements than when performing lateral movements. The level of error when participants performed anterior movements was similar across all conditions, suggesting that a ceiling level of performance was achieved, preventing action observation from modulating their movements. This can be attributed to the greater level of control allowed when articulating using two joints (anterior movements) as opposed to only one (lateral movements).

When participants were performing lateral movements, the observation of anterior (task-incongruent) movements interfered with participant performance. The increase in error (compared to baseline) when participants performed lateral movements and observed task-incongruent, direction-incongruent movements was in accordance with that in previous studies (Blakemore & Frith, 2005). When participants performed lateral movements, the observation of task-incongruent, direction-congruent movements led to a significant *decrease* in error compared to baseline. Such facilitation effects have not previously been revealed using this paradigm; the effect examined has often been labelled "the interference effect" (Gowen et al., 2008; Stanley et al., 2007). Furthermore, no performance modulation effects occurred when participants observed the corresponding lateral-movement conditions during their own performance of lateral movements (i.e., lateral-movement, task-congruent conditions). This indicates that the effects revealed in the lateral, task-incongruent conditions were not simply due to disparities between arm and eye movements, or because participants were able to monitor their movements to different extents in different conditions; had this been the case, corresponding effects would have been expected in the lateral, task-congruent conditions. This indicates that the effects revealed here were due to specific attributes of the anterior-movement type. Previous studies demonstrate that increasing the variability of observed movement stimuli can lead to increased error in participant performance due to bottom-up effects of stimulus content (see Gowen et al., 2008; Stanley et al., 2007). A *post hoc* analysis was conducted examining the movements of the experimenter, revealing that their anterior movements showed significantly lower levels of spatial error than their lateral movements.[2] This explains why effects were only revealed during the observation of anterior movements; they showed less movement in the error direction, providing a more compelling stimulus than lateral movements, and thus modulated participant performance.

[2] The experimenter's anterior movements ($M = 9$ mm, $SD = 3.27$ mm) showed significantly less spatial error than their lateral movements ($M = 28$ mm, $SD = 5.13$ mm) when analysed using a paired-samples *t* test, $t(11) = 28.23$, $p < .001$.

Heyes (2011) has previously noted that the "interference effect" may arise due to motor simulation effects, or could derive from spatial compatibility effects. Results from the present study seem to support only the latter suggestion; no task congruency effects were found, and the three-way interaction revealed that the spatial direction congruency of observed movements was a critical factor that determined whether interference or facilitation effects occurred. It is of note that participants in the presented study were instructed to observe the fingertip of the experimenter throughout their performed movement; an instruction to observe the movement of the hand has been provided in studies using similar experimental tasks (see, for example, Kilner et al., 2003). It is likely that maintaining fixation on the experimenter's fingertip may have been a key factor in driving the effects revealed, as previous data suggest that spatial attention is required for action observation effects to occur (Bach, Peatfield, & Tipper, 2007). Therefore, in the study presented here it can be assumed that focusing attention on the manner in which the observed movement was performed (movement type, task congruency) was deemed to be of lower priority than focusing attention on the observation of the trajectory and relative spatial direction of the observed finger (direction congruency), explaining why no significant effects of task congruency were apparent in the analysis. This would also explain the apparent contradiction between our results and the results of a previous study (Brass et al., 2001) that found that both movement congruency and movement direction modulated simple reaction time when participants observed finger movements. It is, however, important to consider that observers naturally tend to focus on the movement of the hand during the observation of arm movements (Mataric & Pomplun, 1998). This suggests that our experimental instruction would only serve to reinforce the natural behaviour of the participant, and that direction congruency effects would therefore be the primary source of modulations of performance when observing arm movements.

Schmidt, Carello, and Turvey (1990) provided evidence that the relative phase in which movements were performed can lead to interference effects due to phase transitions. Using cyclic leg movements, they demonstrated that interference effects occurred when participants attempted to perform cyclic antiphase movements (i.e., when movements were performed with directly opposing patterns of agonist/antagonist activity, such as when one participant extends their leg while watching the other flex their leg), leading participants to switch to performing more stable, in-phase movements (i.e., participants switched to performing the task using matching patterns of agonist/antagonist activity). The study here did not attempt to examine the effects of congruency relative to the muscles used to perform the different tasks, and the exact phases of the motor programmes used to execute actions were not matched. However, in Kilner et al. (2003), a comparison of horizontal movements (effectively performed out of phase) and vertical movements (performed in phase) revealed no differences when movements were performed in and out of phase. Previous studies also suggest that effects are more reliable when observed actions are presented out of phase than when they are presented in phase; only observing horizontal (out of phase) movements revealed interference effects in Stanley et al. (2007). A final point is that Schmidt et al. (1990) found that such interference effects only occurred when participants performed movements at relatively high movement frequencies (between 1.4 and 2.2 Hz), while participants in the study presented here moved only at a frequency of 1 Hz. This relatively low frequency of movement would therefore make it unlikely that phase transition effects would have contributed to the interference effects during the present study.

In conclusion, the study here revealed that observing an experimenter perform the same movement in different directions modulated concurrent movement execution. This was driven by the spatial direction and kinematics of the movement, as opposed to the manner in which the movement was performed (movement type) or the congruency between the observed and executed movement tasks (task congruency). Observing the same movement being performed in different directions led to either facilitation or interference of performance, depending on the direction congruency of the observed movement.

Original manuscript received 16 July 2011
Accepted revision received 23 February 2012
First published online 12 April 2012

REFERENCES

Bach, P., Peatfield, N., & Tipper, S. (2007). Focusing on body sites: The role of spatial attention in action perception. *Experimental Brain Research*, *178,* 509–517.

Blakemore, S. J., & Frith, C. (2005). The role of motor contagion in the prediction of action. *Neuropsychologia*, *43,* 206–267.

Brass, M., Bekkering, H., & Prinz, W. (2001). Movement observation affects movement execution in a simple response task. *Acta Psychologica*, *106,* 3–22.

Buccino, G., Binkofski, F., Fink, G., Fadiga, L., Fogassi, L., Gallese, V., et al. (2001). Action observation activates premotor and parietal areas in a somatotopic manner: An fMRI study. *European Journal of Neuroscience*, *13,* 400–404.

Caspers, S., Zilles, K., Laird, A., & Eickhoff, S. (2010). ALE meta-analysis of action observation and imitation in the human brain. *NeuroImage*, *50,* 1148–1167.

Edwards, M. G., Humphreys, G. W., & Castiello, U. (2003). Motor facilitation following action observation: A behavioural study in prehensile action. *Brain and Cognition*, *53,* 495–502.

Gowen, E., Stanley, J., & Miall, R. C. (2008). Movement interference in autism spectrum disorder. *Neuropsychologia*, *46,* 1060–1068.

Hardwick, R. M., & Edwards, M. G. (2011). Observed reach trajectory influences executed reach kinematics in prehension. *Quarterly Journal of Experimental Psycho*logy, *64,* 1082–1093.

Heyes, C. (2011). Automatic imitation. *Psychological Bulletin*, *137,* 463–483.

Kilner, J., Paulignan, Y., & Blakemore, S. J. (2003). An interference effect of observed biological movement on action. *Current Biology*, *13,* 522–525.

Mataric, M., & Pomplun, M. (1998). Fixation behaviour in observation and imitation of human movement. *Cognitive Brain Research*, *7,* 191–202.

Rizzolatti, G., Fogassi, L., & Gallese, V. (2001). Neurophysiological mechanisms underlying the understanding and imitation of action. *Nature Reviews Neuroscience*, *2,* 661–670.

Schmidt, R., Carello, C., & Turvey, M. (1990). Phase transitions and critical fluctuations in the visual coordination of rhythmic movements between people. *Journal of Experimental Psychology: Human Perception and Performance*, *16,* 227–247.

Stanley, J., Gowen, E., & Miall, R. C. (2007). Interference in performed movement during observation of a moving dot stimulus. *Journal of Experimental Psychology: Human Perception and Performance*, *33,* 915–926.