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**Motor contagion: the contribution of trajectory and end-points**

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### Article

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Trajectory and end-points

1 Title: Motor contagion: the contribution of trajectory and end-points

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4 Running head: Trajectory and end-points

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## Trajectory and end-points

### 1 *Abstract*

2           Increased involuntary arm movement deviation when observing an incongruent  
3 human arm movement has been interpreted as a strong indicator of *motor contagion*. Here,  
4 we examined the contribution of trajectory and end-point information on motor contagion by  
5 altering congruence between the stimulus and arm movement. Participants performed cyclical  
6 horizontal arm movements whilst simultaneously observing a stimulus representing human  
7 arm movement. The stimuli comprised congruent horizontal movements or vertical  
8 movements featuring incongruent trajectory and end-points. A novel, third, stimulus  
9 comprised curvilinear movements featuring congruent end-points, but an incongruent  
10 trajectory. In Experiment 1, our dependent variables indicated increased motor contagion  
11 when observing the vertical compared to horizontal movement stimulus. There was even  
12 greater motor contagion in the curvilinear stimulus condition indicating an additive effect of  
13 an incongruent trajectory comprising congruent end-points. In Experiment 2, this additive  
14 effect was also present when facing perpendicular to the display, and thus with end-points  
15 represented as a product of the movement rather than an external spatial reference. Together,  
16 these findings support the theory of event coding (Hommel et al., 2001), and the prediction  
17 that increased motor contagion takes place when observed and executed actions share  
18 common features (i.e., movement end-points).

19

### 20 *Keywords*

21 Motor contagion; mirror system; observation-execution; trajectory; end-points

22

Trajectory and end-points

## 1 **Introduction**

2           It is well accepted that there is a close link between perception and action, and  
3 accordingly this has been recognised in numerous conjectures on the processes involved in  
4 action-observation: common-coding (Prinz, 1997), theory of event coding (Hommel,  
5 Müsseler, Aschersleben, & Prinz, 2001) and direct-matching (Rizzolatti, Fogassi, & Gallese,  
6 2001). Indeed, the discovery of so-called mirror neurons within the premotor cortex of the  
7 monkey, which are activated during the observation and execution of a reach-and-grasp  
8 action, provides neurobiological evidence to substantiate the commonality between  
9 perception and action (di Pellegrino, Fadiga, Fogassi, Gallese, & Rizzolatti, 1992). A similar  
10 mirror system was subsequently identified within the fronto-parietal regions of the human  
11 brain (Cattaneo, Sandrini, & Schwarzbach, 2010; Hamilton & Grafton, 2006; Iacoboni et al.,  
12 1999), and was postulated to have several behavioural consequences for action understanding  
13 and social imitation (Boria et al., 2009; Chartrand & Bargh, 1999). For instance, automatic  
14 imitation predicts that faster response times are made when a stimulus onset cue corresponds  
15 with the pre-requisite movement response (e.g., a background image of an index finger  
16 movement accompanying an index finger movement response; Brass, Bekkering,  
17 Wohlschläger, & Prinz, 2000). In a similar vein, individuals performing an interpersonal  
18 observation-execution task exhibit involuntary orthogonal arm movement deviation during  
19 the observation of incongruent, as opposed to congruent, human arm movements (Kilner,  
20 Paulignan, & Blakemore, 2003). The latter effect has been referred to as *motor contagion*  
21 (Blakemore & Frith, 2005), and is thought to occur when the observed human stimulus  
22 activates an internal representation that interferes with the efferent motor commands  
23 generated by the observer.

24           There have been attempts to determine the stimulus (Hardwick & Edwards, 2012;  
25 Kilner, Hamilton, & Blakemore, 2007) and contextual (Stanley, Gowen, & Miall, 2007)

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1 properties underpinning motor contagion. For example, Hardwick and Edwards (2012)  
2 suggested that contagion results from incongruent spatial direction (lateral vs. anterior) when  
3 performing an incongruent goal-directed action (horizontal flexion-extension of the shoulder  
4 vs. flexion-extension of the elbow). Similarly, it has been suggested that arm movement  
5 deviation associated with incongruent stimuli may be influenced by the incongruent end-  
6 points, as opposed to the trajectory (Gowen, Stanley, & Miall, 2008; Stanley et al., 2007).  
7 The implication is that motor contagion, like several other behavioural effects during action-  
8 observation, may be mediated by a mirror system comprising multiple levels of action-  
9 representation (Csibra, 2007; Grafton & Hamilton, 2007; Wohlschläger, Gattis, & Bekkering,  
10 2003).

11 **While not intending to debate the findings of previous empirical or theoretical work**  
12 **on motor contagion**, to date, no single study on motor contagion has directly examined the  
13 combination of observed trajectory and end-point information on the executed action. In this  
14 respect, it is notable that although Stanley et al. (2007) reported that motor contagion may be  
15 related to the incongruent movement end-points, in the same study they found increased  
16 deviation during the observation of biological compared to non-biological motion,  
17 irrespective of the congruency of movement direction. The authors suggested this was a result  
18 of the inherent variability in the observed biological motion, and thus a source of bottom-up  
19 interference related to the trajectory. Thus, our aim was to examine the contribution of  
20 trajectory and end-point information on motor contagion. Specifically, we aimed to determine  
21 the effect of congruence between the executed action and the trajectory and/or end-point  
22 features of the observed stimuli. **Importantly, to minimize the influence of top-down factors,**  
23 **such as human form (Kilner et al., 2007; Press, 2011; Stanley et al., 2007), we presented the**  
24 **stimuli as a non-human agent with biological motion properties.**

25

## 1 **Experiment 1**

### 2 *Introduction*

3       Using a similar experimental design to that of Stanley et al. (2007), here we required  
4 participants to perform cyclical horizontal arm movements across the mid-line of their body  
5 whilst observing a moving dot stimulus representing pre-recorded human arm movement.  
6 Two of the conditions of observed stimuli included horizontal movements similar to that  
7 performed by the participant, or vertical movements featuring incongruent trajectory and end-  
8 points. An additional stimulus was generated that displayed a curvilinear trajectory, and thus  
9 featured movement end-points congruent with the executed action, but an incongruent  
10 trajectory.<sup>1</sup>

11       It was hypothesised that if observed stimuli are primarily coded as a function of their  
12 end-points, limited deviation in orthogonal movement, and thereby motor contagion, would  
13 be present in the horizontal or curvilinear conditions. However, if motor contagion is mainly  
14 a result of incongruence between the executed action and observed trajectory, it can be  
15 hypothesised that there would be increased deviation in both the vertical and the curvilinear  
16 conditions. Alternatively, if both of the action features are coded and act in combination to  
17 influence motor contagion (Hommel et al., 2001), it follows that movement deviation  
18 exhibited in the curvilinear condition will differ from that of the vertical stimulus condition.  
19 More specifically, if the coding of the observed incongruent action features elicits increased  
20 motor contagion due to similarities with the executed action features then we would  
21 anticipate an additive effect when observing the curvilinear stimulus.

22       In addition to the standard measure of motor contagion, we also sought to determine  
23 the mapping of stimulus-motion properties by measuring the spatial congruence between the  
24 observed and executed movement. The idea was to attribute any deviation in the participants'  
25 movement to the unfolding trajectory of the observed stimuli (Dijkerman & Smit, 2007;

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1 Hardwick & Edwards, 2011). To this end, we calculated the mean peak position over a  
2 number of cycles within the orthogonal y-axis. Notably, this dependent measure was much  
3 larger for the curvilinear movement than the horizontal and vertical movement (for an  
4 explanation see Method). Thus, if the deviation in participants' movement were attributed to  
5 the stimulus-motion properties, we would expect participants to exhibit a higher mean peak  
6 position in the curvilinear condition than the vertical and horizontal conditions.

7

## 8 **Method**

### 9 *Participants*

10 Data was recorded from seventeen participants (aged between 18 to 21 years). All had  
11 normal or corrected-to-normal vision and gave written informed consent prior to taking part.  
12 The experiment was designed in accordance with the Declaration of Helsinki and was  
13 approved by the local ethics committee of the host university.

14

### 15 *Stimuli*

16 The visual stimulus was a red circle (1.8 cm) displayed on a flat white screen (2.0 x  
17 1.7 m) at a viewing distance of 1.9 m. The stimulus was generated on a host PC (Dell  
18 Precision 670) using the COGENT toolbox implemented in MATLAB (Mathworks Inc), and  
19 was displayed using a CRT projector (Barco Graphics 908) with a spatial resolution of 1024  
20 x 768 pixels and refresh rate of 85 Hz. The stimulus reflected 30 s of pre-recorded, scaled  
21 data from the moving arm of a volunteer. The movements were well practised in order that  
22 the required amplitude and frequency of 1 Hz could be reliably achieved. Scaling of the  
23 stimulus was applied in order that 400 mm horizontal displacement in the recorded data  
24 corresponded to either 400 mm horizontal or vertical displacement on the projection screen.  
25 The movement stimuli consisted of cyclical horizontal and vertical arm movements. In

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1 addition, participants were shown a cyclical curvilinear moving stimulus that displaced 400  
2 mm in the horizontal axis and 200 mm in the vertical axis (from centre to the upper vertex).  
3 Thus, the curvilinear movement end-points aligned with those of the horizontal stimulus (see  
4 Fig. 1). Finally, we included a control condition in which a single red dot was presented at  
5 screen centre for the duration of the trial. Participants were instructed to fixate on the  
6 stationary stimulus while moving their arm at 400 mm horizontal amplitude. No instructions  
7 were given to participants regarding the animacy of the moving stimulus.

8

9

Insert Fig. 1 about here

10

## 11 *Task and Procedure*

12 Participants were instructed to perform 400 mm amplitude horizontal arm movements  
13 across the mid-line of their body in time with a cyclical moving stimulus (or fixating on a  
14 stationary stimulus) observed on the projection screen. The room was otherwise dark and  
15 participants did not have any external cues regarding the location of the stimulus relative to  
16 the screen edge and thus movement reversal. Initially, each participant performed two  
17 practice trials with the guidance of stationary targets located 400 mm apart in the horizontal  
18 axis and an auditory metronome. Participants were instructed to time their movement so that  
19 the end-points, and thus reversals, coincided with the tones. Following practice, the stationary  
20 targets and auditory metronome were removed, and participants completed a trial in the  
21 control condition. Next they completed two trials in each of moving stimulus conditions,  
22 which were randomly ordered with the caveat that no condition could be repeated  
23 consecutively. Finally, they completed a second trial in the control condition. The control  
24 condition was presented as the first and last trials in order to determine if there were  
25 attentional and fatigue effects.



## Trajectory and end-points

1

### 2 *Data collection and analysis*

3       The position of an active infrared sensor attached to the tip of the index finger was  
4 recorded at 200 Hz using a 3D Investigator Motion Capture System (Northern Digital Inc.,  
5 Ontario, Canada). Following data acquisition, the first and last 5 s of data recording were  
6 discarded in order to minimize asynchrony around movement onset and potential attentional  
7 and fatigue effects (Hardwick & Edwards, 2012). The remaining position data were then  
8 filtered at 10 Hz using an autoregressive filter implemented in MATLAB. The same routine  
9 next determined individual movement segments by identifying reversals in fingertip position  
10 of the dominant movement axis (i.e., x-axis; horizontal). For each movement segment (i.e., a  
11 half cycle) the standard deviation of fingertip position within the orthogonal movement axis  
12 (i.e., y-axis; vertical) was calculated to provide a measure of motor contagion. The average  
13 deviation across movement segments within a trial was calculated for each participant. In  
14 addition, the mean peak position within the orthogonal axis was calculated to provide a  
15 measure of mapping the stimulus-motion properties. Peak position was determined as the  
16 extreme most position within the orthogonal axis of each horizontal movement segment  
17 relative to onset, and thus could occur in either the upward or downward direction.

18       If there were mapping of the stimulus-motion properties to the participant's  
19 movement, it can be expected that movement deviation would occur primarily in the upward  
20 direction with the curvilinear stimulus (Fig. 1f), thus leading to a high mean peak position.  
21 Looking at the vertical stimulus (Fig. 1e), it can be seen that there is deviation away from the  
22 horizontal axis in the upward direction in one segment (positive) and downward direction in  
23 the following segment (negative). Involuntary mapping of this motion by the participants  
24 would lead to a lower mean peak position due to combining positive and negative deviation  
25 from each segment of the movement cycle. For the horizontal stimulus there is very little

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1 movement in the orthogonal axis, and thus mapping should result in a similarly low mean  
2 peak position.

3 A paired-samples t-test on average deviation data was first used to compare the  
4 control trials. Then, to determine the effect of end-point and trajectory information on  
5 participants arm movements, the average deviation and peak position data were submitted to  
6 separate one-way repeated-measures ANOVA. Mauchly's test of Sphericity confirmed no  
7 significant violation of the equal variance of differences assumption ( $p > .05$ ). Significant  
8 effects were decomposed using Bonferroni post hoc procedure ( $p < .05$ ).

9

## 10 **Results and Discussion**

11 For the comparison of control trials, there was no significant difference between  
12 participants' movement deviation in trial 1 ( $M = 6.09$ ;  $SE = .65$ ) and trial 2 ( $M = 7.00$ ;  $SE =$   
13  $1.38$ ),  $t(16) = .62$ ,  $p > .05$ . Thus, there were no significant attentional or muscular fatigue  
14 effects introduced by performing the six 30-second duration experimental trials.

15 ANOVA on average deviation data revealed a significant main effect of stimulus,  $F(2,$   
16  $32) = 15.79$ ,  $p < .001$ , partial  $\eta^2 = .50$  (Fig. 2). Post hoc comparisons indicated lower  
17 movement deviation in the horizontal compared to the vertical ( $p < .05$ ) and curvilinear ( $p <$   
18  $.001$ ) conditions. In addition, average deviation was significantly greater in the curvilinear  
19 condition compared to the vertical condition ( $p < .05$ ). The source of these effects can be  
20 visualised in Fig. 3, which shows more vertical displacement over movement segments for  
21 the vertical condition (Fig. 3b) compared to the horizontal condition (Fig. 3a), and yet even  
22 greater displacement for the curvilinear condition (Fig. 3c). Indeed, the participants'  
23 movement profile in the curvilinear condition was comparable to the observed curvilinear  
24 stimulus (Fig. 1f).

25



## Trajectory and end-points

1 incongruent action features. That is, when the observed stimulus properties are closely  
2 matched (i.e., curvilinear), but not identical (i.e., horizontal) or opposite (i.e., vertical) to the  
3 concurrent executed movement, there is an increase in motor contagion (see Hommel et al.,  
4 2001).

5         Consistent with the theory of event coding, in which an action representation  
6 (observed or executed) comprises a series of codes reflecting individual action features (e.g.,  
7 end-points, duration, trajectory, muscle groups) (Hommel et al., 2001), the greatest contagion  
8 is exhibited when there is co-activation of a single action feature (e.g., horizontal end-points)  
9 represented across multiple action representations (e.g., executed action and observed  
10 curvilinear stimulus). Conversely, less contagion will be exhibited when there is co-activation  
11 of action representations that share fewer action features (e.g., executed horizontal end-points  
12 versus observed vertical end-points). Put simply, the greater the congruence between  
13 observed and executed action features, then the greater motor contagion when presented with  
14 an incongruent trajectory.

15

16

## **Experiment 2**

### *Introduction*

18         The findings from the first experiment of increased contagion in the curvilinear  
19 compared to vertical condition occurred with the observed and executed actions parallel to  
20 each other. In this orientation, participants could move their arm when observing the  
21 curvilinear stimulus such that the maximum shoulder flexion and extension coincided with  
22 the spatial end-points of the observed stimulus. Accordingly, a shared action feature between  
23 the executed horizontal action and observed curvilinear stimulus leading to increased  
24 contagion could have resulted from the representation of external spatial coordinates (i.e., left

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1 and right of centre) and/or movements adopted at the end-points (i.e., horizontal flexion-  
2 extension).

3 To further examine the action features that influence motor contagion, a second  
4 experiment was conducted in which participants were instructed to perform horizontal arm  
5 movements in time with the vertical or curvilinear movement stimulus, but now facing either  
6 parallel or perpendicular to the stimulus display. In the perpendicular orientation, the end-  
7 points of the executed action were spatially incongruent to those of both the curvilinear and  
8 vertical stimuli. However, the executed action (i.e., horizontal arm movements) required the  
9 same agonist and antagonist muscle groups as those recruited in the parallel orientation. In  
10 this way, the end-points of the executed action when observing the curvilinear stimulus could  
11 be achieved using the same movement (horizontal shoulder flexion and extension) in the  
12 parallel and perpendicular torso orientation. However, for the vertical stimulus, the horizontal  
13 movement adopted at the end-points was incongruent irrespective of torso orientation.

14 A similar procedure in work on automatic imitation indicated priming of upper limb  
15 movements to anatomically congruent movement stimuli (e.g., executed index finger  
16 response coinciding with observed index finger movement) within a spatially incongruent  
17 perpendicular orientation (Heyes, Bird, Johnson, & Haggard, 2005; Press, Bird, Walsh, &  
18 Heyes, 2008). These results were taken as evidence of coding lower-level stimulus  
19 information related to the observed movement itself, as opposed to the spatial coordinates in  
20 which the stimulus moves. Therefore, it is predicted that if the observed end-points are  
21 represented within the underpinning movement dynamics then the increased deviation in the  
22 curvilinear condition should take place in both parallel and perpendicular orientations.  
23 Alternatively, if the end-points are represented in external spatial coordinates then the  
24 increased deviation in the curvilinear condition should be specific to the spatially compatible  
25 parallel orientation.

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## 2 **Method**

### 3 *Participants*

4           Data was recorded from a different group of sixteen participants (aged between 18 to  
5 21 years). All had normal or corrected-to-normal vision and gave written informed consent  
6 prior to taking part. The experiment was designed in accordance with the Declaration of  
7 Helsinki and was approved by the local ethics committee of the host university.

8

### 9 *Task and Procedure*

10           The task and practice procedures were essentially the same as in Experiment 1, except  
11 that participants performed horizontal arm movements while facing parallel or perpendicular  
12 to a display showing a vertical or curvilinear stimulus. Participants looked straight ahead for  
13 the parallel orientation and with the head turned toward the right shoulder for the  
14 perpendicular orientation (Fig. 5). The movement stimuli were randomly ordered with the  
15 caveat that no condition could be repeated consecutively, and the control trials were  
16 presented as the first and last trials. The stimulus conditions in the parallel and perpendicular  
17 orientations were presented in separate blocks, with the order counter-balanced across  
18 participants.

19

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Insert Fig. 5 about here

21

### 22 *Data collection and analysis*

23           The data collection procedures and dependent measures were identical to Experiment  
24 1. A 2 trial (first, last) x 2 orientation (parallel, perpendicular) mixed-design ANOVA was  
25 conducted on average deviation data in the control condition. To determine the effect of

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1 stimulus and orientation, the average deviation and peak position data were submitted to  
2 separate 2 stimulus (vertical, curvilinear) x 2 orientation (parallel, perpendicular) mixed-  
3 design ANOVA. Significant effects were decomposed using Bonferroni post hoc procedure  
4 ( $p < 0.05$ ).

5

## 6 **Results and Discussion**

7 For control trials, there was a no significant main effect of trial,  $F(1, 11) = 1.94, p >$   
8  $.05$ , partial  $\eta^2 = .15$ , indicating no significant attentional or muscular fatigue effects.

9 Although there was a significant main effect of orientation,  $F(1, 11) = 15.89, p < .01$ , partial  
10  $\eta^2 = .59$ , there was no significant trial x orientation interaction,  $F(1, 11) = 1.02, p > .05$ ,  
11 partial  $\eta^2 = .08$ .

12 For the analysis of movement deviation, there was a significant main effect of  
13 stimulus,  $F(1, 15) = 12.66, p < .01$ , partial  $\eta^2 = .46$  (Fig. 6). As per Experiment 1, there was  
14 increased movement deviation in the curvilinear condition compared to the vertical condition.  
15 There was a significant main effect of orientation,  $F(1, 15) = 6.73, p < .05$ , partial  $\eta^2 = .31$ ,  
16 indicating increased movement deviation in the perpendicular compared to parallel  
17 orientation. There was no significant stimulus x orientation interaction,  $F(1, 15) = .15, p >$   
18  $.05$ , partial  $\eta^2 = .01$ . Thus the effect of stimulus was independent of any influence of  
19 orientation.

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Insert Fig. 6 about here

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23 For the analysis of peak position, ANOVA revealed a significant main effect of  
24 stimulus,  $F(1, 15) = 22.54, p < .01$ , partial  $\eta^2 = .60$  (Fig. 7). Peak position was significantly  
25 higher in the curvilinear compared to vertical condition. The main effect of orientation

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1 approached conventional levels of significance,  $F(1, 15) = 3.41, p = .09$ , partial  $\eta^2 = .18$ ,  
2 indicating a higher peak position in the parallel compared to perpendicular orientation. There  
3 was no significant stimulus x orientation interaction,  $F(1, 15) = .26, p > .05$ , partial  $\eta^2 = .08$ .

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Insert Fig. 7 about here

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### 21 **General discussion**

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Previous studies have shown an increase in involuntary orthogonal arm movement deviation during the concurrent observation of incongruent human arm movements (Kilner et al., 2003; Kilner et al., 2007), which has been attributed to the trajectory and/or end-points within the observed movement stimuli (Gowen et al., 2008; Stanley et al., 2007). Here, we



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1 examined more directly the contribution of these action features on movement deviation  
2 during an interpersonal observation-execution task.

3         In the first experiment, we found motor contagion, as evidenced by average deviation  
4 in the orthogonal axis, was greater when observing a vertical compared to horizontal  
5 stimulus. There was even greater motor contagion in the curvilinear condition, which featured  
6 congruent end-points but incongruent trajectory. In accord with the theory of event coding  
7 (Hommel et al. 2001), we interpret these findings as evidence that motor contagion occurs  
8 through co-activation of action representations (observed stimulus or executed action)  
9 consisting of shared action features. A similar explanation was given for data showing that  
10 partially incongruent action stimuli increased contagion (as indicated by slowed response  
11 times) compared to identical and opposing action stimuli (Ocampo, Painter, & Kritikos,  
12 2012). In the current study, the representations for the observed curvilinear stimulus and  
13 executed horizontal movement were incongruent in terms of trajectory, but shared common  
14 action features related to end-points.

15         In the second experiment we showed that end-points of the observed stimulus do not  
16 have to be located in the same orientation as the executed action (for similar effects on  
17 automatic imitation, see Heyes et al. 2005). Therefore, it would seem that this action feature  
18 (i.e., horizontal end-points) contributes to motor contagion because it is represented across  
19 multiple lower-level representations (executed action and observed stimulus), and not an  
20 abstract representation of the external spatial coordinates. This is consistent with the idea of  
21 motor contagion being underpinned by a bi-directional perceptual-motor process involving  
22 the co-activation of a particular action feature within incongruent action representations  
23 (Blakemore & Frith, 2005).

24         An alternative interpretation for the finding of increased movement deviation in the  
25 curvilinear compared to vertical (and horizontal) condition is that it could be reflective of a

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1 random disturbance related to motion saliency (Jansson, Wilson, Williams, & Mon-Williams,  
2 2007). However, we know of no reason why curvilinear motion should be more salient than  
3 vertical motion, which in turn would be more salient than horizontal motion. Indeed, we  
4 found evidence for the mapping of stimulus-motion properties, which would not be predicted  
5 by some random disturbance. Visuomotor mapping is consistent with previous evidence  
6 indicating imitation of the movement direction of observed upper-limb movements  
7 (Dijkerman & Smit, 2007; Hardwick & Edwards, 2011). Further, it is coherent with the  
8 acquisition of novel motor skills through action-observation, where the mapping of stimulus-  
9 motion properties specifically relate to movement direction (Hayes, Ashford, & Bennett,  
10 2008; Mattar & Gribble, 2005).

11 **Another difference between the curvilinear and vertical (and horizontal) conditions is**  
12 **that the former had somewhat greater resultant velocity. This was an unavoidable**  
13 **consequence of preserving primary (horizontal or vertical) movement amplitude and cycle**  
14 **duration. In this respect, it is relevant to note that similar levels of movement deviation in the**  
15 **orthogonal axis have been reported when the frequency of an incongruent stimulus movement**  
16 **was varied between 0.5, 0.71 and 1.25Hz (Richardson, Campbell, & Schmidt, 2009).**  
17 **Therefore, simply trying to match horizontal arm movements to a faster moving incongruent**  
18 **stimulus should not influence orthogonal movement deviation. In the current study, however,**  
19 **there was incongruence between arm movement velocity in the primary horizontal axis and**  
20 **resultant velocity of the curvilinear stimulus. It will be interesting in future work to determine**  
21 **more precisely, albeit with biologically plausible stimuli, the incongruent factors between an**  
22 **executed action and observed trajectory that contribute to increased orthogonal deviation.**

23 In summary, observing a curvilinear movement stimulus, featuring an incongruent  
24 trajectory, but end-points congruent with the executed horizontal arm movements, resulted in  
25 increased motor contagion compared to congruent horizontal or incongruent vertical stimuli.

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- 1 Increased motor contagion when observing the curvilinear stimulus was found in both a
- 2 spatially congruent (parallel) and incongruent (perpendicular) orientation. These contagion
- 3 effects were reflected by the mapping of stimulus-motion properties related to the precise
- 4 direction of the movement stimuli. Together, these findings support the theory of event
- 5 coding (Hommel et al., 2001), which posits that the extent of motor contagion is determined
- 6 by the stimulus action features shared with the executed action (i.e., movement end-points).

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### **Footnote**

1. In this instance, congruency of trajectory was defined by movement differences in the vertical axis. The additional movement in the vertical axis for the curvilinear stimulus was clearly different from the horizontal stimulus, and thus was conceived as an incongruent trajectory.

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### Figure captions

**Fig. 1** Pictorial representation of the horizontal (a), vertical (b) and curvilinear (c) stimuli.

The dashed line in each panel indicates the direction of motion followed by the target dot.

Movement traces of individual movement segments of the horizontal (d), vertical (e) and

curvilinear (f) stimuli are included for comparison. Black and grey traces represent

movement in the two segments that comprise a cycle

**Fig. 2** Standard deviation within the orthogonal axis of movement during the observation of horizontal, vertical and curvilinear stimuli. Error bars show the within-group standard error

**Fig. 3** Left (black) and right (grey) movement traces in the x- and y-axis taken from a single participant during the observation of horizontal (a), vertical (b) and curvilinear (c) stimuli

**Fig. 4** Mean peak position within the orthogonal axis of movement during the observation of horizontal, vertical and curvilinear stimuli. Error bars show the within-group standard error

**Fig. 5** Schematic representation of the parallel (a) and perpendicular (b) orientations. Thick black lines represent the projector screen; double-ended arrows represent the instructed horizontal movement direction, and dotted lines represent the equivalent viewing distance across orientation conditions

**Fig. 6** Standard deviation within the orthogonal axis of movement during the observation of vertical and curvilinear stimuli in the parallel and perpendicular orientation. Error bars show the within-group standard error

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**Fig. 7** Mean peak position within the orthogonal axis of movement during the observation of vertical and curvilinear stimuli in the parallel and perpendicular orientation. Error bars show the within-group standard error