



HAL
open science

Anticipating the terminal position of an observed action: Effect of kinematic, structural, and identity information

Ludivine Martel, Christel Bidet-Ildei, Yann Coello

► To cite this version:

Ludivine Martel, Christel Bidet-Ildei, Yann Coello. Anticipating the terminal position of an observed action: Effect of kinematic, structural, and identity information. *Visual Cognition*, 2011, 19 (6), pp.785 - 798. 10.1080/13506285.2011.587847 . hal-01773530

HAL Id: hal-01773530

<https://hal.science/hal-01773530>

Submitted on 17 Sep 2019

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.

**Anticipating the terminal position of an observed action:
Effect of kinematic, structural and identity information**

Ludivine Martel¹, Christel Bidet-Ildei² & Yann Coello¹

1. URECA, EA 1059, University of Lille-Nord de France
2. CERCA, UMR CNRS 6234, Université de Poitiers, France

Corresponding author: Pr Yann Coello. Email: yann.coello@univ-lille3.fr

Running title: Visual estimate of movement end-point

Keywords: visual prediction, reaching movement, point light display.

Mailing Address:

Pr. Yann COELLO
URECA
Université Charles De Gaulle – Lille3
BP 60149
59653 Villeneuve d'Ascq cedex, France

Tel: +33.3.20.41.64.46
Fax: +33.3.20.41.60.32
Email: yann.coello@univ-lille3.fr

Abstract

The ability to visually identify and anticipate motor actions performed by others is thought to be an essential component of social interactions and possibly requires relating visual information with sensorimotor knowledge. Though motor theory of visual perception received convincing evidence from behavioural, neuropsychological and developmental studies, the nature of the information used for anticipating the terminal location of an observed human action remains still an open issue. In this context, the aim of the present study was to evaluate the role of motor representations on the prediction of the terminal location of an observed manual reaching movement. The stimulus was a 2-D point-light display showing the top-view of a right arm moving along the sagittal plane towards targets positioned at different distances. The task was to estimate the terminal location of the reaching movement after the stimulus vanished following 60% of total movement duration. Characteristics of the point-light display could vary according to movement kinematics (biological motion, constant, inverse or monotonically increased velocity), structural features (all joints visible or only the forefinger tip) and movement identity (self- vs other-generated action). Results showed that spatial performances improved when presenting “self-generated” actions (identity effect) in the biological motion condition (kinematic effect). Furthermore, reducing the visual stimulus to the forefinger did not affect the performance (structural effect). Considered together, these findings provide further evidence for motor-based visual perception of biological motion and suggest that kinematic but not structural information is crucial to give sense to an observed human action and to anticipate its terminal location.

Introduction

Giving sense to actions performed by others is an essential component of social interactions. In this regard, previous studies using point-light displays have revealed that the spatio-temporal characteristics of a biological motion can provide access to not only the content of the observed action, but also the gender (Kozlowski & Cutting, 1977; Troje et al., 2006) or the identity of the actor performing the action (Loula et al., 2005; Troje et al., 2005). More subjective impressions like the emotional state (Atkinson et al., 2004; Chouchourelou et al., 2006; Dittrich et al., 1996) or even the intention of the action performer (Iacoboni et al., 2005) can also be detected through the parameters of the observed performance. This exquisite sensitivity of the visual system to biological motion renders furthermore possible the prediction of the final state of a human action before it was entirely executed. In the context of sequential grasping movement or letters writing for instance, several studies have shown that the forthcoming component of a motor sequence can be predicted from the motion's properties of the ongoing action (Flanagan & Johansson, 2003; Kandel et al., 2000; Louis-Dam et al., 2000; Louis-Dam et al., 1999; Orliaguet et al., 1997).

These visual capacities have been largely interpreted within the framework of motor theory of visual perception¹, suggesting that motor representations contribute to the visual interpretation of observed human actions (Jeannerod 2006; Prinz, 1997; Schütz-Bosbach & Prinz, 2007). As a consequence, observers generally find easier to identify their own motor performance from the dynamical properties of the visual stimulus than the performance of other persons, even when sharing with them their daily life (Beadworth & Buckner, 1981; Loula et al., 2005). Similarly, acquiring a new motor skill in a learning task (Casile & Giese

¹ Different visuo-motor theories have been suggested in the past, including the theory of common representational code (Hommel, Musseler, Aschersleben, & Prinz, 2001; Prinz, 1997), internalized motor simulation triggered by the visual stimulus (Jeannerod, 2001), reciprocal motor and perceptual resonance (Viviani, 2002 ; Shütz-Bosbach & Prinz, 2007), mirror neuron system (Rizzolatti & Craighero 2004). Though these theories diverged in some respects, only the general view of the implication of the motor system in the visual perception of biological movement will be refer to here.

2006) or losing a particular motor competence due to localised brain lesions (Chary et al., 2004) significantly affects perceptual judgment of human actions. In line with this, neuroimaging studies revealed that the observation of sequential motor actions activates the same brain areas as those involved in the production of similar motor sequences, both in writing and manual reaching activity (e.g. Chaminade et al., 2001).

Considered together, these data strongly argue in favour of common representation for the observation and the production of motor actions. This common representation may contribute to the interpretation of observed human actions on the basis of stimulus properties that are similar to those characterising natural movement productions. Among these properties, kinematics can easily be manipulated (e.g., Viviani & Stucchi, 1989) and is thought to be a crucial component of the visual perception of human actions (Bingham et al. 1995; Muchisky & Bingham, 2002), in particular when stressing on the capacity to predict the final state of an observed action (Kandel, et al., 2000; Stevens et al. 2000). As a consequence, slightly modifying the spatio-temporal properties of an observed action was found to strongly affect the perception of that particular action (e.g., Bidet-Ildei et al. 2006; Blake & Shiffrar, 2006; Jacobs et al., 2004; Pavlova & Sokolov, 2000; Shiffrar & Freyd, 1993; Thornton et al., 2002) or the prediction of its expected final state (Pozzo et al., 2006).

The aim of the present study was to go one step further into this research domain and to investigate whether the structural aspect and the identity of an observed manual reaching action may contribute to the prediction of its final location. More specifically, using a 2-D point-light presentation of a right arm moving towards a visual target, we tested whether viewing the movement of all joints or only that of the extremity of the arm affected the prediction of movement end-point when the stimulus vanished at 60% of total movement duration. The movement presented was that of the observer (self-generated action) or of an unknown person (other-generated action) and could be either realistic (biological motion

condition) or kinematically distorted according to a constant, inverse or monotonically increasing velocity.

Method

Participants

Fourteen right-handed healthy adults (8 females, 6 males) aged between 21 and 29 years (mean age 24.2 years, standard deviation 3.4 years) gave their informed consent and were volunteers to take part to the experiment, which was performed in agreement with the local ethical committee guidelines. None of them reported any sensory or motor deficits and all had normal or corrected-to-normal vision.

Stimuli and apparatus

Participants were seated in a dimly lit room in front of a 17" CRT computer screen (Samsung 171 S, spatial resolution: 1024*768 pixels, sampling rate: 85hz) positioned on a table at a viewing distance of 50 cm. Stimuli were composed of 'avi' format video showing on the vertical screen a point-light display representing the upside-view of a pointing movement performed with the right arm towards a target placed at different distances along the sagittal axis (10 cm, 20 cm or 30 cm, not visible in the video sequence, see Figure 1). Each point-light display consisted of white dots (97 cd/m^2 , Ø : 0.65° of visual angle) presented on a dark background (0.14 cd/m^2).

In a pre-experimental session, pointing movements spontaneously produced by participants with their right hand were registered using a 3D motion capture system (Zebris ultra-sound system, <http://www.zebris.de/>) with markers placed on arm joints (forefinger tip, wrist, elbow and shoulder). This system allowed recording spatio-temporal parameters of the

movement (spatial resolution, 0.5mm; temporal resolution, 100 Hz). Participants were invited to produce five planar pointing movements along their sagittal axis towards the three visual targets. About ten minutes was necessary for each participant to collect the whole movements. From the recording coordinates provided by the Zebris system, one representative exemplar for each distance was chosen. 2D trajectories were then reconstructed using Matlab software routines (<http://www.mathworks.com/>), so as to obtain an avi format movie of 640 * 512 pixels size with a frame rate of 40 frames/s (examples of the stimuli are available at the following address: <http://ureca.recherche.univ-lille3.fr/documents/BiologicalMotion/>). These video sequences represented the biological condition insofar as spatial path and kinematics of the registered dots were alike the natural movements performed by the participant. Three unnatural conditions were also created for each participant and each target distance, which consisted in similar trajectory of similar duration but with a modified kinematics along the path using either a constant velocity, a constant acceleration or an inverse tangential velocity (i.e. with an inversion pattern of the velocity distribution along the trajectory), resulting in four types of movement (biological motion, constant velocity, increasing velocity, and inverse velocity). Moreover, each movement was presented providing information about the whole arm (forefinger, wrist, elbow and shoulder) or only its extremity (forefinger tip). In the latter condition, the whole arm was shown for 300 milliseconds before movement initiation, and then only the forefinger tip remained visible. The movement presented was that of the observer (“self-generated action”) or of an unknown person (“other-generated action”). It is worth noting that the tangential velocity difference between “self-generated” and “other-generated” actions was positive for 7 participants (velocity of the “self-generated” action was higher than velocity of the “other-generated” action) whereas it was negative for the other 7 participants (velocity of the “self-generated” action was lower than velocity of the “other-generated” action).

The bottom-up displacement of the extremity of the arm on the screen followed a straight line which was centred according to the width of the screen. The optical size of the stimulus was 10.7° (V) * 10.3° (H) at the starting location and 18.1° (V) * 8.8° (H) at the final location. In all conditions, trajectory vanished when the duration of the movement reached 60% of total movement duration. Stimuli presentation and manual responses registration were under the control of E-prime software (version 2.0, <http://www.pstnet.com/>).

Experimental Procedure

The participants' task was to predict after each presentation the final location of the movement (i.e. target location) as fast and as accurately as possible after visual information was removed at 60% of total movement duration. After each stimulus presentation, participants had to indicate the location corresponding to the judged end-point of the movement by displacing the mouse cursor and using the left click of the mouse. The cursor was invisible during the presentation of the movement and appeared as soon as the stimulus finished. Participants performed 192 randomised trials, resulting in a total duration for the whole experimental session of about 15 minutes. Four trials were performed in each condition depending on the distance (10, 20 or 30 cm), the kinematic information (biological motion, constant velocity, increasing velocity or inverse velocity), the identity of action performer (the observer or an unknown person) and the structural information (the whole arm or only the forefinger tip). A familiarisation task was initially executed which consisted in presenting 10 visual examples of biological movements executed by a person different from those used in the experiment.

/Insert Figure 1 about here /

Data recording and analysis

Participants' spatial error (difference in mm between the cursor position and the actual end-point of the movement) was analysed according to the kinematic properties of the movement (biological motion, constant velocity, increasing velocity or inverse velocity), the structural information (whole-arm / forefinger) and the identity of action performer (observer / unknown person). Negative values indicated underestimations. Data for the different target distances were pooled for statistical analysis (12 trials in each condition and for each participant). The latter was performed using a three-way analysis of variance (ANOVA) with kinematic condition, structural information and identity of action performer as within-participants factors. Student t-tests were used for pairwise comparisons with Bonferroni correction for multiple comparisons. In cases where the sphericity assumption was violated (i.e. Epsilon smaller than 1), Greenhouse-Geisser adjustments of the p-values were reported.

Results

Spatial error (see Figure 2) revealed an overall overestimation (on average: $M = 14.6\text{mm}$, $SD = 59.1\text{mm}$), which was dependent on the kinematic condition ($F(3,39) = 9.57$, $MSE = 597.7$, $p < .01$) and the identity of action performer ($F(1,13) = 6.17$, $MSE = 2526.01$, $p < .05$). Moreover, we found an interaction between the identity of action performer and the kinematic condition ($F(3,39) = 2.88$, $MSE = 298.56$, $p < .05$). The increase of spatial error in the non-biological motion conditions (constant, increasing or inverse velocity) was greater when observers had to judge other's motor performance rather than their own motor performance. Finally, spatial judgment error was not affected by the structural aspect of the stimulus ($F(1,13) = 0.22$, $MSE = 541$).

Concerning the effect of kinematics, participant's judgments were more accurate in the biological motion condition ($M = 1.8\text{mm}$, $SD = 55\text{mm}$) than in the non-biological motion

conditions (constant velocity: $M = 11.8\text{mm}$, $SD = 57\text{mm}$; inverse velocity: $M = 20.4\text{ mm}$, $SD = 61\text{mm}$ and increasing velocity: $M = 24.6\text{mm}$, $SD = 61\text{mm}$, respectively: $t(39) = 2.17$, $p < .03$, $t(39) = 4.04$, $p < .01$, $t(39) = 4.95$, $p < .01$). Spatial error was lower in the constant than in the increasing velocity condition ($t(39) = 2.77$, $p < .01$) and the other comparisons did not reach significance.

Concerning the identity effect, spatial error was lower when presenting “self-generated” actions ($M = 6.3\text{mm}$, $SD = 44.38\text{mm}$) than when presenting “other-generated” actions, ($M = 22.98\text{mm}$, $SD = 38.91$). Interestingly, in the biological motion condition we found that the difference between maximum velocity in “self-generated” and in “other-generated” actions correlated with the difference between the spatial errors obtained in the two conditions ($r=0.65$; $t(12)=2.97$; $p=0.01$).

/Insert Figure 2 about here /

Discussion

The aim of this study was to investigate the effects of kinematic, structural and identity information on the ability of human observers to anticipate the terminal location of a point-light reaching movement that vanished at 60% of total movement duration. Considered together, our results showed that predictive spatial judgments about movement end-point were affected by kinematic and identity characteristics, but not by the structural aspect of the observed action.

Spatial error increased when movement was unnatural i.e., when movement kinematics was not in agreement with the spatio-temporal regularities subtending biological motion (constant velocity, increasing velocity or inverse velocity). This accords with previous studies that have shown that kinematic information contributes to the recognition of point-light displays (Chang & Troje, 2009; Viviani & Stucchi, 1989) and represents a crucial

component of action prediction abilities (Kandel et al., 2000; Pozzo et al., 2006). Interestingly, the kinematic effect was dependent on the type of distortion applied to the velocity profile. The worst performance was obtained when presenting a movement with increasing velocity. The fact that accelerating stimuli were more difficult to process than other non-biological stimuli suggests that the end-point of a human action would be difficult to predict when the body segment is still accelerating. This accords with previous studies which have shown that predictions about the forthcoming component of a motor sequence becomes less and less accurate as the initial part of the sequence provided to the observer is reduced (Kandel, Orliaguet & Boë, 2000; Louis-Dam, Orliaguet & Coello, 1999).

It is worth mentioning that the diminution of the performance with non-biological stimuli could be related to the well-known representational momentum, which refers to the tendency of observers to consider the stopping point of a dynamic scene, that was only partially presented, as being farther along in the direction of motion than it is in reality (Freyd & Finke, 1984). Actually, this effect is dependent on movement dynamic, i.e., the overestimation of the final position of an object increases when the velocity of the object increases at the vanishing point (Finke & Shyi, 1988). In agreement with this, we found that spatial errors (i.e., overestimation) increased in the inverse and increasing velocity conditions i.e., in the conditions where the stimulus disappeared when the movement velocity was maximal. Inversely, overestimation was minimal in the biological motion condition, i.e., in the condition where movement velocity was the lowest at the time the visual information was removed. Then, one may speculate that the kinematic effect on spatial performance emerged in the prediction task from the cognitive representation of the unseen part of the trajectory, which was influenced by the representational momentum.

However, this interpretation cannot account for all the effects reported in this study. Indeed, we also found that predictive judgments were more accurate when observers judged

“self-generated” rather than “other-generated” actions. This effect was observed despite the fact that half of the participants showed a higher tangential velocity when performing the action, whereas the other half showed a lower tangential velocity when performing the action according to the tangential velocity characterising the “other-generated” action. Then, biological motion perception was facilitated when the observed performance matched the observer’s motor repertoire (Graf et al., 2007), and this was not due a specifically oriented kinematic difference between “self-generated” and “other-generated” actions. This identity effect accords then with previous works which have revealed higher capacities to recognize a motor action when observers evaluated their own motor performance (e.g., Loula et al. 2005). One of the dominant interpretations for this effect was that observed actions are interpreted through an action-based visual system processing visual information in relation to the motor system. In agreement with this, studies using positron emission tomography (PET) and functional magnetic resonance imagery (fMRI) have revealed overlapping brain activations while performing voluntary actions or simply observing the same actions (Hari et al., 1998; Nishitani & Hari, 2000). This neural network comprises regions extending beyond the extra-striate areas including the mirror neuron system (superior parietal lobe and dorsal premotor cortex, e.g., Filimon et al. 2007) as well as the motor and supplementary motor areas (e.g., Gazzola & Keysers, 2009). Additional evidence came from the measure of magnetic (MEG) or electrical (EEG) brain activity (Cochin et al. 1999; Fadiga et al. 2005) with, for instance, a bilateral decrease of the mu rhythm (8-13hz) in sensory and motor brain areas during both the execution and observation of arm movements (Virji-Babul et al., 2008). In line with the idea of an action-based visual system, behavioural studies revealed that the visual recognition of a human action improves when the observed action is mastered by the observer, even for motor skills learned in absence of any visual information (Casile & Giese, 2006). In the same vein, activations in brain motor areas when passively observing a motor action were reported to be

greater when the observed performance fell within the observer's action repertoire (Calvo-Merino et al., 2005, 2006). Assuming then that biological motion is interpreted according to self-referencing representations, one may expect the perceptual system to be increasingly inaccurate as the observed human actions depart from the internal motor reference. In our study, the correlation observed between the kinematic difference of "self-generated" action relative to "other-generated" action and the terminal spatial errors in the judgment task in the two conditions supports this assumption.

Though our data are consistent with the motor theory of visual perception, one cannot however exclude the possibility that the visual familiarity with the stimuli used may have contributed to the better performance in the biological motion condition (see Prasad & Shiffrar 2009 for a discussion on that issue). However, the fact that the stimuli used in the present experiment were very different from what the visual system regularly experiences in natural visuo-motor conditions suggests that this interpretation can hardly account for the identity effect. Indeed, in our experimental task the movement observed was in some condition the upside view of a single dot moving few centimetres. Moreover, the identity effect was observed while the differences between the various trajectories were not detected at an explicit level, as revealed by post-experiment interviews. Another possible interpretation that may account for the different performances in the "self-generated" and "other-generated" action conditions is that these movements were characterized by idiosyncratic different features which made harder the predictions in the "other-generated" action condition. Though this represents a potential interpretation, it remains however hardly probable. Indeed, as discussed above, post-experiment interviews revealed that performances were not based on the recognition of the action performer, i.e. participants presented a better accuracy for "self-generated" actions without the explicit experience of seeing their own action. Moreover, participants' movements were characterised by a movement tangential velocity higher or

lower than that of the “other-generated” action. A strategy based on a systematic higher or lower velocity of observed action could not then be realistically account for the worse performance observed for “other generated” than self-generated actions. Furthermore, excepted kinematic variables, not other information was available, in particular in the condition where only the forefinger tip was displayed. Finally, the correlation found when comparing the differences between tangential velocity and the differences between spatial performance in the “other-generated” and “self-generated” action conditions showed clearly that the observers’ spatial performance was dependent on the discrepancy between movement velocity in the “self-generated” and “other-generated” action conditions and not to any idiosyncratic difference. The present data stand then more in favour of an action-based perceptual system that account for the observed improvement of spatial judgements in the biological motion condition, in particular when presenting “self-generated” actions (Chary et al., 2004; Jeannerod, 2001; Schütz-Bosbach & Prinz 2007). Furthermore, they corroborate the finding that kinematic information is essential for self-recognition (Daprati et al., 2007; Knoblich & Prinz 2001), though human actions can still be visually interpreted in the presence of kinematic distortions in the biological motion according to self-referencing representations (Bidet-Ildei et al., 2008).

Interestingly, we observed no effect of the structural information with respect to the stimulus on the predictive judgments. Whether the stimulus was a whole arm or only a distal point moving towards the target provided the same accuracy in the prediction task. Though the whole-arm was presented for 300 ms in all conditions before movement onset (which could be sufficient for explicitly recognizing the stimulus presented as a human-related point-light display), this result suggests that visual access to the whole body joints kinematics is not crucial for predicting movement end-point with accuracy. The absence of effect of structural information is compatible with the implicit use of motor representation in the perception of

biological movement, though suggesting that dynamical rather than structural aspects play a crucial role in perceptivo-motor interactions (e.g., Kandel et al. 2000; Méary et al., 2005).

In conclusion, our study supports the motor theory of human movement perception by demonstrating the role of kinematic information and motor repertoire in the perceptual anticipation of the final state of observed actions. Moreover, it shows that structural information does not represent an essential component of perceptual anticipations, which argues in favour of a strong contribution of dynamical motor-related information in the perceptual judgments of human movements. Though further researches are required to investigate the specific effect of unnatural kinematic patterns on perceptual judgments, the present study provides new insight about the content of motor representations and their role in human movement perception.

Acknowledgements

This work was supported by the University Lille 3 and national grant ANR “Concepts systèmes et outils pour la sécurité globale” program from the French Ministry.

References

- Atkinson, A. P., Dittrich, W. H., Gemmell, A. J., & Young, A. W. (2004). Emotion perception from dynamic and static body expressions in point-light and full-light displays. *Perception*, 33, 717-746.
- Beardsworth, T., & Buckner, T. (1981). The ability to recognize oneself from a video recording of one's movements without seeing one's body. *Bulletin of the Psychonomic Society*, 8, 19-22.

- Bidet-ildei, C., Méary, D. & Orliaguet, J-P (2008). Visual preference for isochronic movement does not necessarily emerge from movement kinematics: A challenge for the motor simulation theory. *Neuroscience Letters*, 430, 236-240.
- Bidet-Ildei, C., Orliaguet, J.-P., Sokolov, A., & Pavlova, M. (2006). Perception of biological motion of elliptic form. *Perception*, 1137-1147.
- Bingham, G. P., Schmidt, R. C., & Rosenblum, L. D. (1995). Dynamics and the orientation of kinematic forms in visual event recognition. *Journal of Experimental Psychology: Human Perception and Performance*, 21, 1473-1493.
- Blake, R., & Shiffrar, M. (2006). Perception of Human Motion. *Annual Review of Psychology*, 58,47-73.
- Calvo-Merino, B., Glaser, D. E., Grezes, J., Passingham, R. E., & Haggard, P. (2005). Action observation and acquired motor skills: an fMRI study with expert dancers. *Cerebral Cortex*, 15, 1243-1249.
- Calvo-Merino, B., Grezes, J., Glaser, D. E., Passingham, R. E., & Haggard, P. (2006). Seeing or doing? Influence of visual and motor familiarity in action observation. *Current Biology*, 16, 1905-1910.
- Casile, A., & Giese, M. A. (2006). Nonvisual motor training influences biological motion perception. *Current Biology*, 16, 69-74.
- Chaminade, T., Meary, D., Orliaguet, J. P., & Decety, J. (2001). Is perceptual anticipation a motor simulation? A PET study. *Neuroreport*, 12, 3669-3674.
- Chang, D. H. F., & Troje, N. F. (2009). Acceleration carries the local inversion effect in biological motion perception. *Journal of Vision*, 1(9), 1-17.
- Chary, C., Meary, D., Orliaguet, J. P., David, D., Moreaud, O., & Kandel, S. (2004). Influence of motor disorders on the visual perception of human movements in a case of peripheral dysgraphia. *Neurocase*, 10, 223-232.

- Chouchourelou, A., Matsuka, T., Harber, K., & Shiffrar, M. (2006). The visual analysis of emotional actions. *Social Neuroscience*, 1, 63-74.
- Cochin S, Barthelemy C, Roux S, Martineau J (1999) Observation and execution of movement: similarities demonstrated by quantified electroencephalography. *European Journal of Neuroscience*, 11, 1839-1842.
- Daprati, E., Wriessnegger, S., & Lacquaniti, F. (2007). Kinematic cues and recognition of self-generated actions. *Experimental Brain Results*, 177, 31-44.
- Dittrich, W. H., Troscianko, T., Lea, S. E., & Morgan, D. (1996). Perception of emotion from dynamic point-light displays represented in dance. *Perception*, 25, 727-738.
- Fadiga L, Craighero L, Olivier E (2005) Human motor cortex excitability during the perception of others' action. *Current Opinion in Neurobiology*, 15, 213-218.
- Filimon F, Nelson JD, Hagler DJ, Sereno MI (2007) Human cortical representations for reaching: mirror neurons for execution, observation, and imagery. *Neuroimage*, 37, 1315-1328.
- Finke, R. A., & Shyi, G. C. (1988). Mental extrapolation and representational momentum for complex implied motions. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, 14, 112-120.
- Flanagan, J.R., Johansson, R.S. (2003). Action plans used in action observation, *Nature*, 769-771.
- Freyd, J. J., & Finke, R. A. (1984). Representational Momentum. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, 10, 126-132.
- Graf, M., Reitzner, B., Corves, C., Casile, A., Giese, M., & Prinz, W. (2007). Predicting point-light actions in real-time. *Neuroimage*, 36, T22-32.

- Gazzola, V. & Keysers, C. (2009). The observation and execution of actions share motor and somatosensory voxels in all tested subjects: Single-subject analyses of unsmoothed fMRI Data. *Cerebral Cortex*, 19, 1239-1245.
- Hari R, Forss N, Avikainen S, Kirveskari E, Salenius S, et al. (1998) Activation of human primary motor cortex during action observation: a neuromagnetic study. *Proceedings of the National Academy of Sciences-USA*, 95, 15061-15065.
- Hommel, B., Musseler, J., Aschersleben, G., & Prinz, W. (2001). The Theory of Event Coding (TEC): a framework for perception and action planning. *Behavioral Brain Science*, 24(5), 849-878.
- Iacoboni, M., Molnar-Szakacs, I., Gallese, V., Buccino, G., Mazziotta, J. C., & Rizzolatti, G. (2005). Grasping the intentions of others with one's own mirror neuron system. *PLoS Biology*, 3, e79.
- Jacobs, A., Pinto, J., & Shiffrar, M. (2004). Experience, context, and the visual perception of human movement. *Journal of Experimental Psychology Human Perception and Performance*, 30, 822-835.
- Jeannerod, M. (2001). Neural simulation of action: a unifying mechanism for motor cognition. *Neuroimage*, 14, S103-109.
- Jeannerod, M. (2006). *Motor Cognition: What Actions Tell to the Self*. Oxford: Oxford University Press.
- Kandel, S., Orliaguet, J. P., & Boë, L.J. (2000). Detecting anticipatory events in handwriting movements. *Perception*, 29, 953-964.
- Kandel, S., Orliaguet, J. P., & Viviani, P. (2000). Perceptual anticipation in handwriting: the role of implicit motor competence. *Perception & Psychophysics*, 62, 706-716.

- Knoblich, G. & Prinz, W. (2001). Recognition of self-generated actions from kinematic displays of drawing, *Journal of Experimental Psychology: Human perception and Performance*, 27, 456-465.
- Kozlowski, L., & Cutting, J. E. (1977). Recognizing the sex of a walker from dynamic point-light displays. *Perception & Psychophysics*, 21, 575-580.
- Louis-Dam, A., Kandel, S., & Orliaguet, J.-P. (2000). Anticipation motrice et anticipation perceptive. *Psychologie Française*, 45, 333-342.
- Louis-Dam, A., Orliaguet, J.-P., & Coello, Y. (1999). Perceptual anticipation in grasping movement: When does it become possible? In M. G. Grealy & J. A. Thomson (Eds.), *Studies in Perception and Action*. London: Lawrence Erlbaum Associates.
- Loula, F., Prasad, S., Harber, K., & Shiffrar, M. (2005). Recognizing people from their movement. *Journal of Experimental Psychology: Human Perception and Performance*, 31, 210-220.
- Méary, D., Chary, C., Palluel-Germain, R., & Orliaguet, J. P. (2005). Visual perception of writing and pointing movements. *Perception*, 34, 1061-1067.
- Muchisky, M. M., & Bingham, G. P. (2002). Trajectory forms as a source of information about events. *Perception & Psychophysics*, 64, 15-31.
- Nishitani N, Hari R (2000) Temporal dynamics of cortical representation for action. *Proceedings of the National Academy of Sciences-USA*, 97, 913-918.
- Orliaguet, J.-P., Kandel, S., & Boe, L. J. (1997). Visual perception of motor anticipation in cursive handwriting: influence of spatial and movement information on the prediction of forthcoming letters. *Perception*, 26, 905-912.
- Pavlova, M., & Sokolov, A. (2000). Orientation specificity in biological motion perception. *Perception and Psychophysics*, 62, 889-899.

- Pozzo, T., Papaxanthis, C., Petit, J. L., Schweighofer, N., & Stucchi, N. (2006). Kinematic features of movement tunes perception and action coupling. *Behavioral Brain Results*, 169, 75-82.
- Prasad, S., & Shiffrar, M. (2009). Viewpoint and the recognition of people from their movements. *Journal of Experimental Psychology: Human perception and performance*, 35, 39-49.
- Prinz, W. (1997). Perception and action planning. *European Journal of Cognitive Psychology*, 9, 129-154.
- Rizzolatti, G. and Craighero, L. (2004). The mirror-neuron system. *Annual Review of Neuroscience*, 27, 169–192.
- Schütz-Bosbach, S., & Prinz, W. (2007). Perceptual resonance: action-induced modulation of perception. *Trends in Cognitive Sciences*, 11, 349-355.
- Shiffrar, M., & Freyd, J. J. (1993). Timing and apparent motion path choice with human body photographs. *Psychological Science*, 4, 379-384.
- Stevens, J. A., Fonlupt, P., Shiffrar, M., & Decety, J. (2000). New aspects of motion perception: selective neural encoding of apparent human movements. *NeuroReport*, 11, 109-115.
- Thornton, I. M., Rensink, R. A., & Shiffrar, M. (2002). Active versus passive processing of biological motion. *Perception*, 31, 837-853.
- Troje, N. F., & Westhoff, C. (2006). The inversion effect in biological motion perception: evidence for a "life detector"? *Current Biology*, 16, 821-824.
- Troje, N. F., Sadr, J., Geyer, H., & Nakayama, K. (2006). Adaptation aftereffects in the perception of gender from biological motion. *Journal of Vision*, 6, 850-857.
- Troje, N. F., Westhoff, C., & Lavrov, M. (2005). Person identification from biological motion: effects of structural and kinematic cues. *Perception & Psychophysics*, 67, 667-675.

- Virji-Babul N, Moiseev A, Cheung T, Weeks D, Cheyne D, et al. (2008) Changes in mu rhythm during action observation and execution in adults with Down syndrome: implications for action representation. *Neuroscience Letters*, 436, 177-180.
- Viviani, P. (2002). Motor competence in the perception of dynamic events. In W. Prinz. & B. Hommel (eds.), *Attention and performance XIX Common mechanisms in perception and action* (pp. 406-442), Oxford, Oxford University Press.
- Viviani, P. & Stucchi, N. (1989). The effect of movement velocity on form perception: geometric illusions in dynamic displays. *Perception & Psychophysics*, 46, 266-274.

Captions

Figure 1. Upper panel: Schematic representation of the experimental apparatus. Movement sequences were shown on a vertical monitor (1024*768 pixels, sampling rate: 85hz) and the participant indicated with the computer mouse displaced on the horizontal surface the predicted end-point of the movement after the visual stimulus vanished at 60% of total movement duration. Low panel: Various kinematic profiles used (biological motion, constant, inverse and increasing velocity). “Other-generated” and two examples of “self-generated” kinematic profiles are presented. Note that 7 participants showed a higher tangential velocity when performing the action whereas 7 participants showed a lower tangential velocity when performing the action when compared to the tangential velocity “other-generated” actions.

Figure 2. Mean and standard error of spatial error in judging the end-point of the movement as a function of the kinematic characteristics, the identity of the movement and the structural information.