



Short Communication

Visual inference of arm movement is constrained by motor representations

Ghislain Saunier^{a,b,*}, Aurore C. Paillard^d, Claudia D. Vargas^c, Thierry Pozzo^{d,e,f}^a Laboratório de Cognição Motora, Instituto de Ciências Biológicas, Universidade Federal do Pará, Belém, Pará, Brazil^b Laboratório de Neuroplasticidade, Universidade Federal do Pará, Belém, Pará, Brazil^c Laboratório de Neurobiologia II, Instituto de Biofísica Carlos Chagas Filho, Universidade Federal de Rio de Janeiro, Rio de Janeiro, Brazil^d INSERM U1093 Cognition Action Plasticité Sensorimotrice, Université de Bourgogne, Campus Universitaire, BP 27877, 21078 Dijon, France^e Istituto Italiano di Tecnologia, RBCS Dept., Via Morego 30, 16163 Genova, Italy^f Institut Universitaire de France, Université de Bourgogne, Campus Universitaire, BP 27877, 21078 Dijon, France

HIGHLIGHTS

- The participation of motor representations during motion inference was addressed.
- End point prediction was better for motion directed toward the midline of human body.
- The spatial prediction of end point is mapped onto implicit biomechanical knowledge.

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ABSTRACT

Several studies support the idea that motion inference is strongly motor dependent. In the present study, we address the role of biomechanical constraints in motion prediction and how this implicit knowledge can interfere in a spatial prediction task. Right-handed (RHS) and left-handed subjects (LHS) had to estimate the final position of a horizontal arm movement in which the final part of the trajectory was hidden. Our study highlighted a direction effect: end point prediction accuracy was better to infer the final position of horizontal motion directed toward the median line of human body. This finding suggests that the spatial prediction of end point is mapped onto implicit biomechanical knowledge such as joint limitation. Accordingly, motor repertoires are embodied into spatial prediction tasks.

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Efficient interaction with a moving object requires predicting its future position in space. For instance, motion reconstruction becomes challenging when a part of the motion is missing. Previous studies of our group [1–3] evidenced that ending movement estimation relies on endogenous input throughout the recall of internal models of action rather than the quantity of visual input [2]. These results support the more general idea that perception is action-dependent and that motor competencies are involved in such predictive tasks [4,5], through the recruitment of a frontoparietal action perception network [6].

The aim of this study is to better understand the neural mechanisms ensuring motion inference. Like demonstrated in previous studies [1,2], visual inference can rely on the representation of

external force constraints (i.e., effect of gravity on body limbs) to estimate the ending position of simple or complex human movement. However, the asymmetry of space perception or representation of biomechanical limitations also may influence visual inference. Indeed, it has been suggested that the encoding of spatial position of external objects in a body centered frame of reference supports the elaboration of appropriate motor reactions toward stimuli potentially interacting with the body [7,8]. Furthermore, the reaction time to a tactile stimulus administered at the hand is modulated by the direction of a concomitant audio stimulus approaching or receding from the hand [9–11].

Moreover, a pseudo-negligence of space perception is classically reported with an over-representation of the right space, independently of the subject's laterality [12]. Such asymmetry of spatial representation might interfere in the perception of the moving stimulus and additionally tune the inference process of human horizontal movement.

At last, body representation and biomechanical properties could also adjust visual inference. Indeed, a seminal study of Shiffrar

* Corresponding author at: Universidade Federal do Pará, Instituto de Ciências Biológicas, Campus Universitário do Guamá, CEP: 66075-110 Belém, Pará, Brazil. Tel.: +55 91 32018903.

E-mail address: ghislain@ufpa.br (G. Saunier).

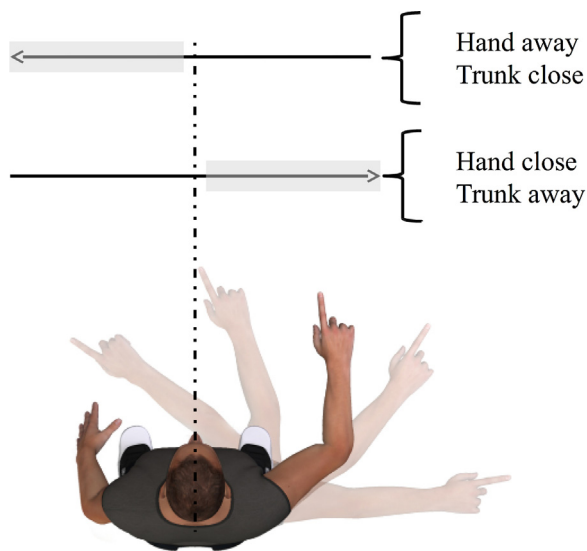


Fig. 1. Horizontal dark lines indicate the direction of the moving stimuli displayed on the screen. The gray rectangle indicates the occluded part. The right to left to right visual stimulus (upper) for a right-handed participant moves toward the trunk while it moves away from the hand. In contrast, the left to right visual stimulus (lower) for a right-handed participant moves toward the hand while it moves away from the trunk. The successive arm positions of a right-handed figure the biomechanical constraints that limits the potential arm movement toward the body midline (the vertical dark dotted line). (For interpretation of the references to spectra in this figure legend, the reader is referred to the web version of this article.)

and Freyd [13] reported that the motor system interfered with the perception of an illusive human movement induced by two successive static pictures of a human limb. The authors concluded that intrinsic knowledge about joints biomechanics and its limitations constrained the visual system.

In order to test these hypotheses, a computerized behavioral task was implemented to measure the capacity of left-handed (LHS) and right-handed subjects (RHS) to infer the occluded part (last 40% of the total trajectory) of horizontal human movement displayed in the frontal plane (see Fig. 1). Subjects were asked to estimate the final position of inward or outward moving stimuli (respectively toward the median line of human body but away from the dominant hand and vice versa).

Sixteen healthy subjects, eight right-handed (RHS) (3 women, 20.42 ± 1.07 years) and eight left-handed subjects (LHS) (2 women, 21.62 ± 3.46 years), were selected. They were classified according to the Edinburgh handedness inventory [14]. All participants provided informed written consent and had normal or corrected to normal visual acuity (self-report). This study was conducted in accordance with the Declaration of Helsinki (1964).

The present protocol replicated the methodology fully described in Pozzo et al. [1] and Saunier et al. [2]. The display consisted in a white dot (3 pixels in diameter) depicting the trajectory of the index marker recorded in 3D at a frequency of 100 Hz (Elite System, BTS Bioengineering, Italy) during a straight pluri-articular arm movement performed in the horizontal plane (for further details on recording session, see [1]). The first 60% of the dot motion was displayed, which corresponded to the beginning of the deceleration phase for the index tangential velocity profile.

The dot's movement was displayed either from left to right (L) or from right to left direction (R) in a 17" color flat screen connected to a PC (resolution of 1024×768 pixels, where the pixel is a rectangle of 0.33 mm in length by 0.35 mm in height; refresh rate of 75 Hz). Three visual stimuli corresponded to the kinematics of horizontal finger movements, with three different time to peak velocity (TPV = 42.2%; 45.8% and 50% of the total motion duration).

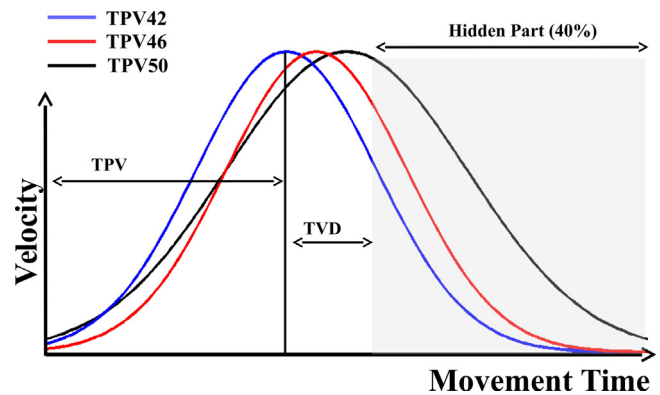


Fig. 2. Velocity profiles of the moving stimulus representing a straight pluri-articular arm movement performed in the horizontal plane. Three velocity profiles were displayed with time to peak velocity (TPV) differing (TPV50, black curve, TPV equals 50% of movement time; TPV46, red curve, TPV equals 46% of movement time; TPV42, blue curve, TPV equals 42% of movement time). The first 60% of the total arm pointing movement was displayed. Occluded part of the motion is indicated by a gray rectangle. Abbreviations for the three displays: TPV, time to peak velocity; TVD, time of the visible deceleration phase. (For interpretation of the references to spectra in this figure legend, the reader is referred to the web version of this article.)

Accordingly, the quantity of visual input available and thus potentially used to reconstruct the lacking part of the trajectory was manipulated. The visible time of deceleration phase was greater for TPV42 versus TPV46 and for TPV46 versus TPV50 (Fig. 2). If the motion reconstruction mainly relies on visual input, one can expect a greater or lower accuracy of ending position estimation for a longer or shorter visible deceleration phase (TPV42 and TPV50 respectively). The stimulus conditions (i.e., L vs. R and the 3 TPV) were randomized. The path length along the trajectories was 171 mm (14° of visual angle). Total movement duration was 1.10 s with a mean velocity of 155 mm/s (12.7° /s) and a maximum velocity of 276 mm/s (22.6° /s).

Participants sat at a comfortable viewing distance (about 70 cm) in front of a screen in a darkened room and were informed about the movement's nature displayed on the screen. When a hair cross (10×10 pixels) appeared at the center of the screen, the subject should fixate at the cross. The participant initiated the movement using the space bar of the keyboard with the non-dominant hand so that the cross disappeared and the dot started to move. Then the subject replaced the hand in a similar but opposite side of the dominant hand. A random blank interval between 0.2 and 1 s followed the disappearance. Subjects were required to fixate the center of the screen until the appearance of the stimulus presentation and the initiation of the dot's trajectory. They were then asked to evaluate where the motion would have stopped if it was completely displayed (only the first 60% of the whole movement was visible). Participants responded with the dominant hand by displacing the crosshair cursor with the mouse on the final estimated position and validated it by a left-click. The computer automatically recorded the response. Each experimental session consisted in 72 trials (2 directions \times 3 velocity profiles \times 12 repetitions). In order to verify the subject's visuo-motor ability to point with the cursor toward the stimulus, an additional control task consisted in estimating the disappearance position when 99% of the motion length was displayed. This control session consisted in 24 trials (12 repetitions per direction).

The experimental design was based on our previous observations showing a systematic overshoot of the end point estimation [9,11]. Thus, if the implicit knowledge of biomechanical restrictions interferes with the end point estimation, then a lesser overshoot and a better estimation precision is expected in RHS for a stimulus moving toward the trunk that limits the arm's inward movement

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