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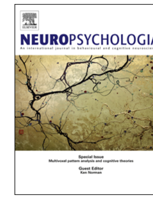

A visuomotor disorder in the absence of movement: Does Optic Ataxia generalize to learned isometric hand action?

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ABSTRACT

Visuomotor deficits in parietal patients suffering from Optic Ataxia (OA) have been so far studied during natural reaching movements. We aimed at understanding if these disorders are also present when more abstract visuomotor transformations are involved. A patient with unilateral OA was tested during both standard reaches and isometric actions, therefore in the absence of hand displacement. Isometric action was affected similarly to standard reaches, with endpoint errors to visual targets that were found in both central and peripheral vision. The dissociation of perceptual and motor components of errors highlighted the existence of field, hand and hemispace effects, which depended on the type of error investigated. A generalization of the reaching disorder to learned isometric conditions would suggest that lesions of posterior parietal cortex (PPC) affect sensory-motor transformations not only for standard reaches, but also when visual signals need to be aligned with information from hand force receptors, therefore regardless of the specific remapping required to generate the directional motor output. The isometric impairment emerged with high and similar severity regardless of whether targets were in central or peripheral vision. Since under all isometric conditions gaze and hand position were decoupled, the spatial correspondence between the hand and the gaze seems to play a critical role in this syndrome. This indicates that regardless of the action to be performed and the specific remapping required, there exists in PPC an abstract representation of the directional motor output, where the computation of eye–hand alignment by parietal neurons plays a crucial role.

1. Introduction

Modern views on sensorimotor transformation hold that reach plans are represented simultaneously in different reference frames, as to allow optimal remapping and task-dependent reweighting of sensory signals (Battaglia-Mayer, Caminiti, Lacquaniti, & Zago, 2003; Caminiti et al., 2010; McGuire & Sabes, 2009). Under this assumption, lesions of the cortical areas involved in such transformations, such as PPC, should result in similar reach defects regardless of the specific remapping required. Parietal patients with Optic Ataxia (OA) make inaccurate reaches mostly to peripheral visual targets (Bálint, 1909; Ratcliff & Davies-Jones, 1972; for different aspects of OA see Buiatti, Skrap, and Shallice (2013), Buxbaum and Coslett (1997, 1998), Gaveau et al. (2008), Gréa et al. (2002), Jackson, Newport, Mort, and Husain (2005), Karnath and Perenin (2005), Khan et al. (2005), and Perenin and Vighetto (1988)). We tested a patient with OA and a group of healthy controls while they performed a learned isometric hand task where they moved a visual cursor toward targets presented on a screen by controlling the force applied on an isometric joystick. During natural reaches, visual information on target location and proprioceptive signals about hand position should be aligned, as to generate an arm displacement vector appropriate to bring the hand on the target. Under isometric conditions such computation first requires remapping the position of the hand into that of the cursor, which implies a learning process, and then transforming this information into a force of appropriate direction and amplitude on the joystick, as to correctly bring the cursor on the final target. This necessitates the association between the force applied and the displacement of the visual cursor. Furthermore, under isometric conditions, cursor and target positions are derived from the available visual feedback and continuously adjusted and integrated with the hand force output. In other words, during natural reaching vision and kinesthetic information are combined, while under the isometric condition remapped target location and hand force signals have to be aligned.

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We found that the patient showed defects regardless of whether he performed under isometric conditions or made natural reaches, thus generalizing to learned isometric conditions the defects observed for natural movement. Furthermore, in the isometric task the patient displayed errors of similar severity when generating force ramps to displace a cursor toward targets in both central and peripheral vision. This impairment was statistically comparable in magnitude to the errors performed during natural reaching toward exatrafoveal targets. Therefore, rather than target eccentricity, the spatial correspondence between gaze direction and hand position on the target, never present under isometric task condition, seems to play a critical role in OA during normal reaching.

2. Methods

2.1. Medical case report

In patient FDL (19 year-old male, right-handed) the MRI (volumetric T1 inversion recovery sequence analysis on a 3T scanner) revealed a large unilateral lesion that on the histology resulted to be a high-grade glioma centered on the right superior parietal lobule (SPL, BA 5 and 7; Fig. 1), affecting both banks of the IPS, and extending to the precuneus (BA 7 and 31), anterior to the parieto-occipital fissure, and involving the dorsomedial superior longitudinal fasciculus (SLF) just posterior to the superior aspect of the corona radiata (Wakana, Jiang, Nagae-Poetscher, van Zijl, & Mori, 2004). The white matter involvement of the SPL and precuneus included subcortical, subgyral, gyral and lobar sectors (Yasargil, 1984). MRI scans taken 28 days after surgery, therefore seven days after the time of FDL testing, showed that on the cortical surface the surgical field involved the superior parietal lobule (Brodmann areas 5 and 7) just posteriorly to the post-central sulcus. The white matter interested by the surgical cavity was that of the SPL and partially by that of the inferior parietal lobule and the precuneus, reaching the periventricular area behind the superior portion of the atrium of the right lateral ventricle. Overall, surgery resulted in a removal of large part of the right superior parietal lobule, as it can be seen from the brain sections encompassing the entire volume of the lesion (Fig. 1). Long association fiber involvement was studied with a 32-direction fiber tract analysis at 3.0 T MRI. Before surgery, the patient was treated with bethametason and mannitol for 7 days, as to reduce the cortical edema. This therapy was continued, although at decreasing doses, for 7 days after surgery. At the clinical tests, 1 day before and 7 and 14 days after surgery, an original light tactile deficit to the left hand, present about one month before hospitalization, had resumed and FDL showed normal object shape, orientation, and two-points discrimination, and was normal in the graphestesia test in both the right and left hand. Limb proprioception, as shown by the ability to verbally describe with closed eyes the position imposed to both right and left arms/hands and to reproduce with the left arm/hand a posture imposed to the right one, was intact. Muscle tone and reflex activity were as in healthy controls. Visual perimetry showed the absence of visual field defects. Standard clinical tests did not reveal any primary sensory or motor impairment. Standard neuropsychological tests were used to exclude hemispatial neglect, and gaze apraxia. Patient FDL was tested 21 days after surgery and revealed signs of a manifest Optic Ataxia (OA), which was assessed in a quantitative fashion through a natural reaction-time reaching task (Fig. 2A, left). Details about patient's behavior in this task will be given in Section 3. Briefly, FDL performed large reach errors with the left hand to peripheral targets presented both in the left and right visual fields, and with the right hand mainly in the left visual field. The left and right hand force output profiles (Fig. 2B) tested through an isometric task (Fig. 2A, right) were affected only in the ataxic field and were not statistically different from controls for the remaining target directions, as revealed by the quantitative analysis of the endpoint errors (see Section 3).

2.2. Controls

As controls we tested 8 age-matched right-handed subjects with normal or corrected-to-normal vision and free of any debilitating condition of the CNS. As patient FDL, all control subjects were novel to the task prior the experimental session and therefore were not overtrained during the data collection sessions. They gave informed consent to participate in the experiment. The Ethical committee of the University of Rome SAPIENZA approved all experimental procedures.

2.3. Apparatus and tasks

2.3.1. Natural arm reaching task

Patient FDL and control subjects were first tested in a natural reaction-time reaching task, that was used as a control task aimed at evaluating in a quantitative fashion the patient's reaching behavior. Subjects were required to perform arm movements from a central position toward both foveated and extrafoveal targets presented on a touch-screen at the vertex of an imaginary hexagon (Fig. 2A, left).

2.3.2. Isometric reaching task

In this task, subjects (FDL and controls) were seated in front of a vertical wide screen on which visual stimuli were presented. Subjects were required to control the movement of a visual cursor toward the targets by controlling an isometric joystick with one hand, as to exert forces in the x–y direction on a horizontal plane (Fig. 2A, right). They were required first to keep the cursor within a central target for a variable control time (CT, 400–600 ms), at the end of which one of four peripheral targets was presented at the vertex of an imaginary square (distance from the center=20° of visual angle). Subjects had to move the cursor from the central to the peripheral target by applying a monotonically increasing isometric force ramp to the joystick in the appropriate direction, being the (x,y) coordinates of the cursor linearly related to F_x and F_y components of the applied force, i.e. $\vec{P}=k\vec{F}$ where $\vec{P}$ is the position of the cursor with respect to the central position and $\vec{F}$ the force applied by the subject. The cursor had to be maintained on the final target for a fixed target-hold time (500 ms). Upper limits for reaction time (RT) and dynamic force time (DFT; corresponding to the cursor movement-time) were 2000 ms and 2500 ms, respectively. Targets (two on the left and two on the right side with respect to the body midline) were presented in both central and peripheral vision in a pseudo-random sequence, until, for each direction, a minimum of 8 replications of each trial were collected. While six targets were presented in the natural reach task, only four were used in the isometric condition, as to minimize the patient's fatigue in a task that required a very fine control of force. Both natural reaching and isometric task were executed with the right and the left hand by all subjects, with the head positioned on a chin rest in front of the screen. Eye movements were monitored through an infrared eye tracker (Arrington Research, Scottsdale AZ, USA) and sampled at 220 Hz. The isometric joystick (ATI Industrial Automation, Apex NC) measured the force applied by the hand in two dimensions, with a sampling frequency of 1000 Hz. For each subject, data collection started after a short training lasting about 20 min, to familiarize with the task and with the control of the isometric manipulandum. At the end of this phase, both the patient and the controls declared to feel confident with the experimental apparatus.

2.4. Data processing and statistical analysis

2.4.1. Reaction-time and dynamic force-time

In the isometric task, the RT was defined as the time elapsing from target presentation to onset of the hand force pulse, as judged from the velocity of the cursor. Therefore, the onset of force production was considered as the first data point for which the cursor velocity exceeded the threshold v_T=9.3°/s for at least 150 ms. The value of v_T was computed as the mean plus two standard deviations of the cursor velocity for all available values (obtained from the patient and controls) during a period of 200 ms centered on the target onset. The dynamic force-time (DFT), defined as the time elapsing from the onset of the hand force pulse (cursor's movement onset) to the instant of the cursor movement endpoint (see below), reflected the time of variation in force production, in the absence of any hand/arm displacement.

2.4.2. Cursor movement endpoint

The final position reached by the cursor on the target was defined as the farthest position from the center of the workspace reached by the cursor during each trial.

2.4.3. Movement accuracy

The movement accuracy was assessed by studying the constant, variable and absolute errors of the movement endpoint, as well as the spatial dispersion of the cursor trajectory. The constant error, representing the systematic deviation of the mean endpoint from the target, was computed as the distance between the average endpoint and the relative target location. The variable error describes the variability of the endpoint positions around their mean, and was estimated as the area of the 95% confidence ellipse (McIntyre, Stratta, & Lacquaniti, 1997) calculated on all endpoints for a given target. The orientation and area of the ellipses were given by the eigenvectors of the variance and covariance matrix derived from the variability of the endpoints (Press, Teukolsky, Vetterling, & Flannery, 1992). The orientation of the ellipses was aligned to the predominantly affected direction of movement, without imposing any a priori assumption about the coordinate system in which the target position is encoded. The absolute error, computed as the average of all distances between each endpoint and the target location, represents a combination of constant and variable errors. To compute the spatial dispersion in any given direction, we divided the cursor trajectories in 20 equally spaced points and for each point the 95% confidence ellipse was calculated. Finally, we defined the index of spatial dispersion as the mean area of all ellipses, for each target.