**TITLE:**

The effect of goals and vision on movements: A case study of optic ataxia and limb apraxia.

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**Running head: Goals in grasping**

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**ABSTRACT**

Normally we can perform a variety of goal-directed movements effortlessly. However, damage to the parietal cortex may dramatically reduce this ability, giving rise to optic ataxia and limb apraxia. Patients with optic ataxia show clear misreaches towards targets when presented in the peripheral visual field, whereas limb apraxia refers to the inability to use common tools or to imitate simple gestures. In the present paper we describe the case of a left-brain damaged patient, who presented both symptoms. We systematically investigated both spatial and temporal parameters of his movements, when asked to reach and grasp common objects to move (Experiment 1) or to use them (Experiment 2), presented either in the central or peripheral visual field. Different movement parameters changed in relation to the goal of the task (grasp to move vs. grasp to use), reflecting a normal modulation of the movement to accomplish tasks with different goals. On the other hand, grip aperture appeared to be more affected from both task goal and viewing condition, with a specific decrement observed when CF was asked to use objects presented peripherally. On the contrary, a neat effect of the viewing condition was observed in the spatial distribution of the end-points of the movements, and of the horizontal end point in particular, which were shifted towards the fixation point when reaching towards peripheral targets. We hypothesize that optic ataxia and limb apraxia have a differential effect on the patient’s performance. The specific presence of optic ataxia would have an effect on the movement trajectory, but both symptoms might interact and influence the grasping component of the movement. As ‘cognitive side of motor control impairment’, the presence of limb apraxia may have increased the task demands in grasping to use the objects thus exacerbating optic ataxia.

**KEY WORDS:** optic ataxia, limb apraxia, grasping, reaching, movement control.

**1. INTRODUCTION**

In everyday life, we are used to perform series of fine and complex movements automatically and with high precision. Our abilities range from simple pointing movements, as to press the button of the elevator, to more complex actions involving the use of objects. Although our performance may depend on whether or not eye movements are coupled with the action (Prado, Clavagnier, Otzenberger, Scheiber, Kennedy, & Perenin, 2005), healthy adults are able to perform such movements towards the peripheral visual field with good precision. After damage to the parietal and/or premotor areas, these abilities can be compromised leading to two well-known neuropsychological symptoms: optic ataxia (OA) (Perenin & Vighetto, 1988) and limb apraxia (LA) (Kertesz & Ferro, 1984).

First described as one of the symptoms of Balint’s syndrome (Balint, 1909), OA is often observed as a consequence of a bilateral lesion in the superior parietal lobe (Milner, Dijkerman, McIntosh, Rossetti, & Pisella, 2003; Kharnath & Perenin, 2005; Pisella et al., 2000; Pisella, Michel, Gréa, Tilikete, Vighetto & Rossetti, 2004). However, it can also be observed following unilateral lesions of either the right or left hemisphere (Blangero et al., 2010; Perenin & Vighetto, 1988; Karnath, & Perenin, 2005), or involving more inferior parts of the parietal lobe (Perenin & Vighetto, 1988; Meek et al., 2013). Despite rare examples of OA involving central vision (i.e., *foveal optic ataxia*, Buxbaum & Coslett, 1997; Perenin & Vighetto,1988; Jeannerod, Decety, & Michel, 1994), OA is characterized by evident misreaches towards peripherally presented visual targets (Rossetti, Pisella, & Vighetto, 2003), with spared basic perceptual and motor abilities (Balint, 1909; McIntosh, *in press*). In some patients, OA can affect reaching movements towards targets presented in the controlesional visual field (the so-called *field effect*) and/or using the controlesional hand (the so-called *hand effect*) (Blangero, et al., 2008; Khan, Crawford, Blohm, Urquizar, Rossetti, & Pisella, 2007; Rice et al., 2008; Striemer, Locklin, Blangero, Rossetti, Pisella, & Danckert, 2009). This symptom is modality-specific and does not seem to emerge with auditory or tactile stimuli (Rossetti, Pisella & Vighetto, 2003), suggesting that OA may derive from a specific deficit in coupling vision and action.

Although alterations of the grasping component have also been noted when grasping objects placed at different distances from the body and/or hemi-spaces of action (Cavina-Pratesi, Ietswaart, Humphreys, Lestou, & Milner, 2010; Perenin & Vighetto, 1988; Jakobson Archibald, Carey, & Goodale, 1991) and in scaling the grip aperture according to the size of the object in OA (Cavina-Pratesi et al., 2010; Milner et al., 2001), most studies focused on the assessment of patients’ reaching and transport phase of the movement. This literature reports a systematic deviation of both end points and movement trajectories in reaching for peripheral targets (Blangero et al., 2010; Dijkerman, McIntosh, Anema, de Haan, Kappelle, & Milner, 2006; Jackson, Newport, Mort, & Husain, 2005; Khan, Pisella, Vighetto et al., 2005; Khan et al., 2007; Milner, Dijkerman, McIntosh, Rossetti & Pisella, 2003). Other alterations of the reaching component pertain the lack of movements’ modulation to avoid possible collisions with no-target stimuli (Schindler, Rice, McIntosh, Rossetti, Vighetto, & Milner, 2004) or the automatic correction of the reaching movements in relation to rapid changes of the target location (Blangero et al., 2008; Pisella et al., 2000), a phenomenon commonly observed in normal adults and known as automatic pilot (McIntosh, Mulroue, & Brockmole, 2010). Interestingly, despite these deficits, the performance of patients with OA seems to improve when (i) the movement onset is delayed (~5 sec) (Milner et al., 2001; Milner et al., 2003; Himmelbach & Karnath, 2005) or when (ii) the visuo-motor coordination demand is reduced like, for instance, when the target of the action is not physically present and patients are asked to pantomime the reaching and/or grasping action (Milner et al., 2003) or when on-line vision is removed (Jackson et al., 2005; Milner et al., 2003). In these conditions, participants rely on previous knowledge of the target location and proprioceptive feedbacks (see also Lingnau et al., 2012), rather than on the online integration between the vision of the target or of the hand and the actual movement. Taken together these observations led to one of the most acknowledged interpretation of OA as the impairment of online visuo-motor control (Rossetti, Pisella, & Vighetto, 2003). According to this view, the posterior parietal lobe is responsible for the conversion and integration of perception into action and for online motor control, and is involved in more automatic rather than voluntary corrections (Pisella et al., 2000; Blangero et al., 2008).

On the other hand, limb apraxia is a high-order impairment of goal-directed movements in which patients’ difficulties cannot be ascribed to simple perceptual or motor deficits (Rumiati et al., 2010). Although it is commonly observed as a consequence of damage to parietal and premotor cortices (Haaland, Harrington, Knight, 2000; Kertesz & Ferro, 1984), limb apraxia has also been associated with left-brain damage, affecting the frontal lobes (Haaland et al., 2000) or subcortical structures, such as basal ganglia or periventricular and internal capsule (Hanna-Pladdy, Heilman, & Foundas, 2001). Limb apraxia has most frequently been observed following stroke in the left hemisphere (Buxbaum, 2001; for a recent review, see Rumiati et al., 2010), but it is not limited to stroke. It can be observed in patients with different conditions including Alzheimer’s and Parkinson’s disease (Leiguarda, et al., 1997; Wheaton & Hallett, 2007).

Two main clinical forms of limb apraxia have been classically distinguished: ideational apraxia (IA) prevalently characterized as a deficit in using objects, and ideomotor apraxia (IMA) defined in terms of a deficit at imitating gestures (Liepmann, 1920; De Renzi Motti & Nichelli, 1980). Pantomiming the use of objects, such the ability to mimic the use of the object without the actual object being physically presented, or on verbal command can be pathological in either IMA or IA patients. Thus, patients with IA may show spared abilities to recognize common tools and tool-use sequence of actions (Lunardelli, Negri, Sverzut, Gigli & Rumiati, 2011; Rumiati, Zanini, Vorano, & Shallice, 2001), but are impaired in the ability to use objects (or pantomime their use), leading to sequential or conceptual errors (see Cooper, 2007; Buxbaum, 2001; Rumiati et al., 2001). In contrast, with IMA some neuropsychologists refer to patients’ difficulties in imitating visually presented meaningful and/or meaningless gestures or to reproduce them on verbal command (De Renzi et al., 1980; Liepmann, 1920; Goldenberg & Spatt, 2009; Rumiati et al., 2010; Tessari, Canessa, Ukmar, & Rumiati, 2007). Impairments can manifest in the alteration of the movements’ sequence, or of the spatial orientation of the gesture, as well as in semantic errors (Rumiati & Tessari, 2002; Tessari, Canessa, Ukmar, & Rumiati, 2007).

Interestingly, despite these gross mistakes, limb apraxia is not always associated with alterations of reaching and grasping movements (Haaland, Harrington, & Knight, 1999) neither of the kinematic parameters of the movement, such as movement duration, time to peak velocity or movement’s end point (Hermsdörfer, Mai, Spatt, Marquardt, Veltkamp, & Goldenberg, 1996; Ietswaart, Carey, Della Sala, & Dijkhuizen, 2001), suggesting a possible dissociation between kinematic and qualitative aspects of action performance . However, this evidence has not been confirmed *tout court,* and other studies showed alterations in both kinematic parameters and movement trajectory (Caselli et al., 1999; Hermsdörfer, Hentze & Goldenberg, 2006). For instance, Hermsdörfer, Randerath, Goldenberg, and Johannsen (2012) found that, compared to patients without apraxia as well as healthy controls, movement trajectory and duration were reduced in left-brain damaged patients with apraxia when they pantomimed or demonstrated the use of a spoon; however, although still present, this difference was reduced in the actual use of the object. This result emphasizes the role of the context and of the action’s mechanical constraints, which may facilitate the performance and reduce the deficits compared to the pantomime condition.

This observation is in line with the hypothesis that imitation of goal-directed actions may rely on two independent action–schemas, defining the action on or action with an object, respectively (Johnson-Frey and Grafton, 2003). Following this view, the “action on the object” schema is involved in grasping-to-move the object and would privilege the selection of a comfortable grip for a safe transport and final position of the object, whereas the “action with an object” schema would favour the selection of functional object grips aiming at a rapid object use. The first interpretation (“different constraint hypothesis”) suggests that these two schemas are independent and can be differentially impaired. By contrast, the “same constraint hypothesis” assumes that the two schemas are interdependent and thus no differential impairment can be observed (see Osiurak et al., 2008; Rosenbaum, 1992). This latter interpretation has been falsified in a study with left- and right-brain damage patients (Osiurak et al., 2008). A subset of patients was able to correctly grasp the objects but impaired in using them, thus showing that the two schemas can be selectively impaired. This evidence is in line with the interpretation that apraxia is a disorder affecting the representation of the kinematics of the action related to the object use and in the production of internal models of objects related actions (Buxbaum, Johnson-Frey, & Bartlett-Williams, 2005), rather than a general deficits of hand-object configuration.

Although OA and limb apraxia have close origins in parietal lobe damage, leading to different alterations of goal directed movements, researchers have neglected to directly compare them in neuropsychological patients. In contrast, research on perception and action has classically focused on debating the differences between OA and visual form agnosia (Daprati & Sirigu, 2006; McIntosh & Schenk, 2009; Hesse, Ball & Schenk, 2012), an impairment in the recognition of visually presented objects that cannot be accounted for an impairment in vision (Humphreys & Riddoch, 1987). Regardless of the absence of conscious recognition of objects, patients with visual form agnosia show preserved abilities in reaching and grasping objects of different sizes and weight presented at different locations in space (Carey, Dijkerman & Milner, 1998; Goodale, Milner, Jakobson & Carey , 1991; Goodale & Weestwood, 2004; McIntosh, Dijkerman, Mon-Williams, & Milner , 2004; Milner et al., 1991, Ball et al., 2012), thus representing an ideal candidate for a double dissociation with OA. In this view, the observations of patients with OA without visual form agnosia, and of patients showing the opposite pattern led to suggest the existence of two visual system pathways (Goodale & Milner, 1992; Goodale & Westwood, 2004): the *vision for action* (*how*) pathway, responsible for visually guided movements and relying on the fast update of eye and limb information, and the *vision for recognition* (*what*) pathway, responsible for object recognition. Brain correlates of these two pathways have been identified in the dorsal stream (how), which connect early visual areas of the occipital lobes to the parietal cortex, and in the ventral stream (what), connecting the same visual areas to the temporal lobe (Milner & Goodale, 1992). More recently, this model has been revised (Himmelbach & Karnath, 2005; Milner & Goodale, 2008) to acknowledge a more complex organization of the dorsal stream and positing its further distinction into a dorso-dorsal and a dorso-ventral pathway (Pisella, Binkofski, Lasek, Toni, & Rossetti, 2006; Rizzolatti & Matelli, 2003; Binkofski & Buxbaum, 2013), with the former being dedicated to immediate motor control, and the latter being involved more complex gestures. In line with this view, it has been demonstrated that regions along the dorso-dorsal pathway are sensitive to reach direction, whereas regions along the dorso-ventral pathway are sensitive both to reach direction and grip type (Fabbri, Strnad, Caramazza, & Lingnau, 2014). While damage to the dorso-dorsal would give rise to OA, damage to the dorso-ventral pathway would give rise to limb apraxia.

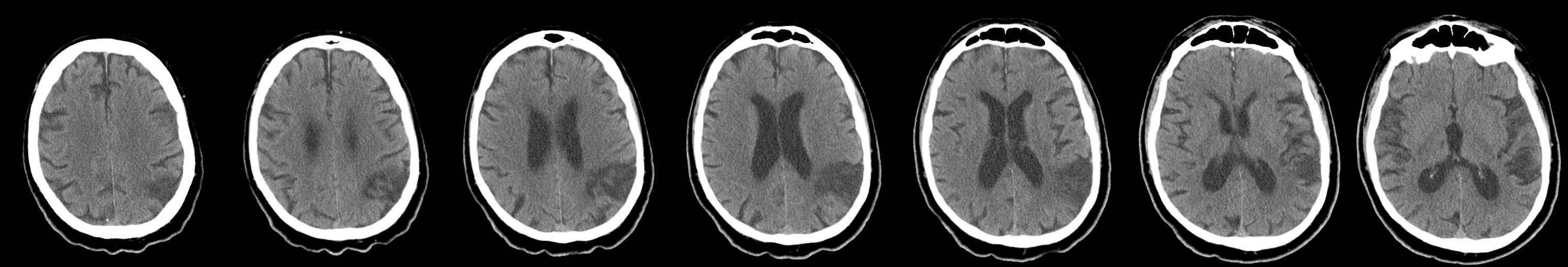
The present study describes the case of a patient CF who suffered from an ischemic attack that damaged the left parietal lobe causing OA in conjunction with both ideomotor and ideational apraxic symptoms. Thanks to the presence of both OA and limb apraxia, previously described in association only in one study (Perenin & Vighetto, 1988), we were able to measure how reaching and grasping performance changes when these two different syndromes are present in conjunction. This was achieved by manipulating key aspects of the tasks that are well known to have a differential impact on optic ataxia and limb apraxia. Specifically, CF was asked to reach for and grasp common objects presented either in central or peripheral view, with the purpose of moving them to a different location (Experiment 1) or to use them (Experiment2). Given the presence of optic ataxia, we expected that specific alteration of the kinematic parameters would emerge in the peripheral viewing condition, irrespective of the task’s goal. On the other hand, the presence of limb apraxia, and ideational apraxia in particular, even without a direct influence on the kinematic parameters, may have increased the difficulty of the task, when CF was required to use the object. Therefore, we expected that alteration of spatial and kinematic parameters of the movements would be more evident when CF was required to grasp to use the object (Experiment 2) and when this action was performed towards the peripheral visual field in particular. Specifically, in line with the previous literature on OA (Milner et al, 2003) we expected the end-point of the movement to deviate towards the fixation point in the peripheral viewing condition and that this tendency would be enhanced in the grasp to use condition due to the additional load of this task for our patient due to the presence of apraxia. In relation to the task, we expected a modulation of the performance by the goal of the task (Osiurak et al., 2010) and possibly a modification of the grasping parameters in the grasp to use task as a consequence of apraxia (Randerath, Goldenberg, Spijkers, & Hermsdörfer, 2010).

**2. Materials and method**

***2.1. Case report***

CF is a 80 years old man, right handed (with 13 years of education) suffering from an ischemic stroke, affecting the left temporo-occipital and inferior parietal cortices (Figure 1). In the acute phase, a brief neuropsychological examination revealed the presence of Broca’s aphasia, ideomotor apraxia and optic ataxia. Neurological assessment did not revealed motor or visual field deficits which could account for the presence of these symptoms. About one month after the ischemic accident, the patient underwent a complete neuropsychological assessment and was asked to perform two experimental tasks specifically investigating OA and limb apraxia. The experiments were presented during different testing sessions. CF performed Experiment 1 first and Experiment2 after one week.

**Figure 1**: CT scan of CF depicting his left hemisphere damage, involving inferior parietal lobe and both superior and middle occipital and temporal structures. The lesion involves also supra-marginal, angular and inferior parietal gyri. The CT was taken in the same month as the testing sessions.



***2.2. Neuropsychological Assessment***

During the assessment, CF was collaborative, focused and motivated, showing appropriate behavior during the whole testing session during which language, attention, executive functions, visuospatial and motor functions were screened.

CF was well-oriented in space and time, and he did not show evident somatosensory or visual deficits. Spontaneous speech was fluent and well-articulated, although still disprosodic and characterized by sporadic phonemic paraphasias, and conduite d'approche, such as the progressive self-healing and approximation to a desired word. Language assessment, which was carried out with the Aachener Aphasie Test (AAT, Luzzatti et al., 1995), confirmed the presence of a mild Broca’s aphasia. Comprehension of complex instructions (9/50 errors on the Token test) and simple words and phrases, presented in both verbal and written modality (115/120 on AAT comprehension subtest) was spared. Whereas the performance on the denomination subtest of AAT was within the normal range (109/120), phonemic paraphasias and *conduite d'approche* were observed in the retrieval of compound nouns. Repetition of words and sentences was also mildly impaired (score of 134/150). As far as reading and writing skills, reading performance was only slightly compromised (score of 27/30) and characterized by errors similar to those observed in oral language (with conduits and phonological errors emerging only when asked to read morphologically complex words or brief sentences); in contrast, writing was moderately impaired, especially writing to dictation (score of 6/30) in which perseverations, omissions and substations of letters were mostly present.

Short and long-term memory were preserved: both verbal and spatial span resulted within normal range (5/8 on the Digit Span, Orsini, Grossi, Capitani, Laiacona, Papagno, & Vallar, 1987, and 5/8 on the Corsi Test, Spinnler & Tognoni, 1987), as well as verbal memory (score of 8/80 for immediate and of 9/16 for deferred of word lists (Mauri et al., 1997).

Non-verbal intelligence and reasoning skills as measured with Progressive Raven Matrices (26/36) (Carlesimo et al., 1995) were within the normal range, as well as abstract thinking at the Weigl’s Sorting Test (12/15, Spinnler e Tognoni, 1987). As far as attentional functions were concerned, simple visual search was intact (Trail Making Test- A performed on 54 sec, Giovagnoli, Del Pesce, Mascheroni, Simoncelli, Laiacona, & Capitani, 1996) in contrast, great difficulties emerged in shifting attention between two tasks at the Trail Making Test- B (Giovagnoli et al., 1996), to the point that CF was stopped before completing the task.

CF was tested for limb apraxia and OA. Performance on these tasks was recorded and rated offline by three independent judges. Importantly, CF was found to be apraxic both when asked to use objects (7/14, De Renzi et al., 1968) and to imitate meaningful (23/36) and meaningless gestures (16/36, Tessari et al., 2011). When using objects and tools, CF was allowed to use his dominant hand or both hands when the tool required it during the assessment of tool use. During gesture imitation he was asked to use only his ipsilesional hand. The presence of optic ataxia was inferred during the assessment of ideational apraxia, since CF showed evident misreaches to the target: for example, he committed spatial errors in orienting the key to fit in the padlock. Therefore, OA was assessed clinically by asking the patient to reach with each hand for a target (pen) presented peripherally to the right or left hemi-space (Borchers, Müller, Synofzik, & Himmelbach, 2013; Perenin & Vighetto, 1988; McIntosh, *in press*), as shown in Figure2. Reaching errors emerged with both hands, but were slightly more pronounced performing the action with the controlesional hand (5/6 number of misreaches towards both hemi-spaces) than with the ipsilesional hand (2/6 number of misreaches towards both hemi-spaces). OA was further assessed by asking the patient to point with the index finger at a red button placed on the table while fixing the examiner’s nose. The red dot was placed at different locations on a grid: overall, a comparable number of evident misreaches were observed with the right (15/27) and left (18/27) hand. In relation to the specific hemi-space, CF misreached targets presented on his left side 11 out of 18 trials (5 with the right and 6 with the left-hand), 9 out of 18 trials in the centre (3 with the right and 6 with the left hand) and 13 out of 18 trials in performing the movement towards the right side (7 with the right and 6 with the left hand). When asked to perform the same task looking at the coins, CF was able to reach them accurately, with no errors with either hand. It was noted that CF’s strategy to perform the task and to reduce errors was to use both thumb and index fingers and then grasp the object rather than simply point at it. Furthermore, since during the apraxia assessment CF experienced difficulties in grasping and orienting the key correctly to fit it in the lock, we specifically tested CF’s ability to orient his right hand in central vision according to the orientation of the hole of a disk. CF showed an excellent performance on this task: he was able to orient his right hand as required by the disk hole, which had different orientations from the table (30°, 60°, 90°, 120° and 150°).

**Figure 2:** Examples of CF’s performance on the OA clinical assessment using his right (top panels) or left (bottom panels) hand. One examiner was sitting in front of CF and the patient was asked to look at his nose while reaching for a pen presented on his right (left panels) or left hemifield (right panels).

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***2.3. Experimental tasks***

CF performed two experiments with a similar set-up, but with a different final goal: in Experiment 1, CF was asked to reach and grasp common objects with the goal to move them to a different location. In Experiment 2, CF was required to perform the same action (to reach and to grasp common objects) but the purpose was different as CF was also requested to mimic the use of the object. In the clinical assessment, CF misreached using both hands, but more often using the controlesional hand, suggesting a possible hand effect. Therefore, he was asked to perform the experiments using only his right hand. Prior to starting the experiment, we ensured that CF was able to recognize the objects and to mimic their use and to distinguish the objects and their orientation (upward or downward with respect to patients’ body) in the peripheral viewing condition, showing only mild difficulties in distinguishing between small fork and brush.

*2.3.1 Experimental Setup*

As depicted in Figure 3, CF was sitting on a chair in front of a table with a black wooden board (80 x 65 cm) placed on the top. A red fixation light-emitting-diode (LED) (10 mm) was built in the board at a distance of 35 cm from the starting point (SP, a green disk of 10 mm diameter placed at the centre of a black circular area of 100 mm diameter). This area represented the end point of the action in which CF was asked to move (Experiment 1) or to use (Experiment 2) the objects. These were presented at two possible positions: either at the right or left side of the fixation LED (4° distance) at a reaching distance of about 40 cm from the starting point. Two padded supports were employed to facilitate the grasping action, one for small and one for big objects. CF’s movements were recorded with a MiniBIRD electromagnetic tracker (model 500; accuracy: 1.8mm in position, 0.5° in orientation) (Ascension Technology Corporation, Burlington, VT, USA) operating at 100 Hz. Markers (5mm) were attached on the nails of the index finger and the thumb of the right hand using straps made of Velcro™, carefully positioned to avoid loss of sensibility on the fingertips and to allow as easy as possible grip of the objects. For practical reasons only two markers were used, but in order to reduce the possible confounding of the grasping movements on the velocity profile, temporal parameters were extracted from the thumb marker, reasoned to be a more stable finger during the movement. A web camera was placed on the top of the MiniBird to monitor online CF’s eye movements.

*2.3.2 Experimental 1: Grasp to move*

CF was asked to reach and to grasp three common objects (brush, tweezers and fork) of two different sizes (small: brush 9 cm x ~ 0.5 cm, tweezers 8 cm x ~1 cm , fork 8 cm x ~0.3 cm; or large: brush 24 cm x ~ 2 cm, tongs 22.5 cm x ~2.77 cm, fork 23.5 cm x ~2.8 cm) (see Figure 3). Objects were presented one at a time, in upward (with the object’s handle facing the patient’s body) or downward (with the object’s handle facing away from the patient’s body) orientation, either at the right or left side of the fixation LED. CF was instructed to move the objects to the SP area. This action was performed in two different conditions: keeping the gaze fixed at the central LED (peripheral viewing condition) or moving the gaze towards the objects to be grasped (central viewing condition).

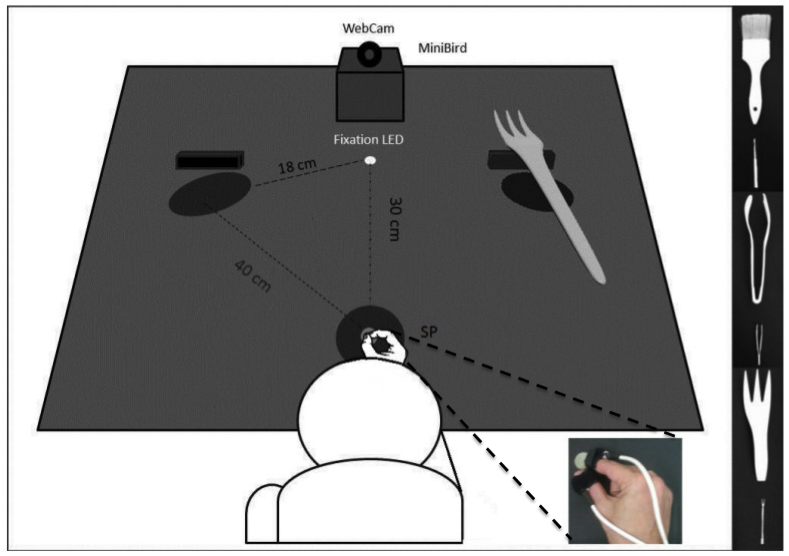
At the beginning of each trial, CF had his eyes closed and his right hand resting on the table. CF’s index and thumb fingers were placed at the SP, pointing at the fixation LED. After a recorded voice saying “Open your eyes” was played, CF opened his eyes and was instructed to look at the fixation LED for two seconds. Then, CF was presented with an auditory tone (250 ms; 1000 Hz) as go signal to initiate the movement. In the central viewing condition the fixation LED turned off when the auditory tone was presented and CF was asked to move his eyes towards the object. In the peripheral viewing condition, the LED remained illuminated for the entire duration of the trial. At the end of each trial, CF was asked to close his eyes again and to place his hand back at the SP location. Once the examiner had changed the arrangement of the object on the table, a new trial started.

CF performed four blocks of 24 trials each (96 in total): two blocks in the peripheral and two in the central viewing condition. The viewing condition was manipulated according to an ABBA schedule with peripheral viewing condition first. Within each block, CF was presented with three sets of eight trials, one for each type of object (brush, tweezers and fork). For each object, the other factors (size, orientation, and location) were presented in randomized sequences and the order of these subsets was randomized between blocks. CF‘s eye movements were checked online with the aid of the webcam and trials on which CF did not follow the instructions correctly (to keep fixation at the LED or to look at the object) were repeated at the end of the block.

*2.3.3 Experiment 2. Grasp to use common objects*

Experiment 2 was similar to Experiment 1, with the only difference being the goal of the task: CF was asked to reach and to grasp a common object (brush, tweezers and fork) presented on the right or left side of the LED, to bring it towards the SP area and to mimic the use of the object within this area. The experimental design was the same as in Experiment 1, and CF performed four blocks of 24 trials, with the viewing condition (peripheral and central) manipulated between blocks with an ABBA schedule, with the central viewing condition first, and the other factors (size, orientation and location of the objects) presented in random sequences for each object type.

**Figure 3.** Experimental set up (left panel)and objects(right panel).



**2.2.4. Data Reduction and Analysis**

The initial reaching and grasping movement, common to both experiments, was analyzed using customised software written in LabVIEW™ (National Instruments). The coordinates of the two sensors were filtered with a high-pass second-order Butterworth filter, with a frequency cut-off of 10 Hz. Movement on- and offset was determined by comparison of markers’ speed against a threshold of 50 mm/sec, and subsequent analysis was restricted to the parsed movements. We did not take into consideration the secondary movement, which varied across experimental tasks (to move or to use the object at SP location), but we analyzed the first reaching and grasping movement, which was consistent across tasks.

We extracted the following dependent variables. The temporal parameters were: (1) Movement time (MT), i.e. the duration from on- to offset of the movement (in ms); and (2) peak velocity (PV), defined as the maximum velocity of the marker attached to the thumb (mm/s) (3) Time to peak velocity (TPV), i.e. the time interval between movement onset and the time point of peak velocity (in ms). The grasping parameters were: (4) Maximum Grip Aperture (MGA), that is the maximum spatial distance (in mm) between the two sensors during the grasping movement; and (5) Time to maximum grip aperture (TMGA), that is the time interval between movement onset and maximum grip aperture. (in ms)

Furthermore, we also extracted spatial parameters of the reaching movements such as (6) horizontal and vertical end points (x, y) of the movements. These spatial parameters were obtained by averaging the sample coordinates of the two markers for each trial. The horizontal end-point was calculated in term of distance from the centre of the table, so that larger positive values indicated a larger distance from the centre of the table.

As there was a good number of trials per condition (*n*= 12) with only two missing trials altogether (one for use and one for move), CF’s performance was analyzed with an Univariate ANOVA with task goal (Experiment 1- grasp to move and Experiment 2- grasp to use), viewing condition (peripheral and central), side (left and right), size (small and large) and orientation (handle of the object towards or away participants’ body) of the objects for each dependent variable. Interactions were explored with pairwise comparisons with Bonferroni correction.

Furthermore, a subset of trials in which CF was presented with the fork was extracted and compared with the performance of six normal controls (3 women; mean age 61.8, *SD* = 5.7) that underwent for practical reasons both experiments using only the small and large fork. All participants were right handed and performed the experiments using their dominant hand. This data set was analyzed using the Bayesian method (BTD and BSDT\_Cov\_Raw) of Crawford, Garthwaite, and Ryan (2011), which allows testing for deficits and dissociations taking into account the effect of a covariate. Using this method, we were able to control for the effect of age and to obtain an index of the estimate of the effect size of the difference between the patient’s score and controls (Zccc). In order to compromise between the need of an adequate numbers of comparisons and of informative results for the purpose of the present study, we took into consideration only the key manipulation for OA and limb apraxia, such as the task goal and viewing conditions, and the other factors were collapsed together.

**3. Results**

**3.1 CF performance**

**3.1.1 The effect of the task goal**

As shown in Table 1, which summarizes main effects and interactions of the ANOVA, a significant main effect of the task was observed on the temporal parameters of the movement, such as MT, and PV, suggesting that the overall execution of the movement was faster when CF was asked to grasp to move (MT *M*=1088.2 ms; PV *M*=660 mm/s) than to grasp to use (MT M=1217.4 ms; PV *M*=616 mm/s) the objects.

In relation to the spatial parameters, the main effect of the task was significant only for the vertical end-point of the movement, which was shifted more towards the body when the final goal was to use (*M*=171.5 mm) the object rather than to move (*M*=179.2 mm) it at a different location. This effect was further modulated by the viewing condition and the hemi space of the action. Overall, CF’s end-movement was closer to the body when performing the action towards the right then left side (*p*<0.01 for all the comparisons). This bias of the end-point toward CF’s body was more prominent when the secondary action required the use of the object rather than the simple transport, when performed peripherally towards the left hemi-space (to move *M*=185.3 mm; to use *M*=173.2 mm), *F*(1,158)= 7.1, *p*=0.008, η2=0.04, and in central viewing towards the right side (to move *M*=179.4 mm; to use *M*=166.4 mm), *F*(1,158)= 8.4, *p*=0.001, η2=0.05. Finally, the end point of the movement was closer to CF’s body in peripheral than central viewing, in the grasp to use task when the action was performed towards the left side, *F*(1,158)= 10.1, *p*=0.002, η2=0.06, and in grasp to move task when the action was performed towards both left, *F*(1,158)= 5.5, *p*=0.02, η2=0.03, and right side, *F*(1,158)= 27.5, *p*<0.001, η2=0.014.

Table 1: Summary of main effect and interaction of Univariate ANOVA.

In the following table, we refer to the goal of the task (to move, to use), the viewing condition (peripheral, central), the side (left, right hemi-spaces of the action), the size (small, large size of the objects) and orientation (upward, downward orientation).

|  |  |  |  |
| --- | --- | --- | --- |
| Main Effect | Interactions | Variable | ANOVA statistics |
| The task goal |  | MT | *F*(1,158)=15.01, *p=*0.001, *η2*=0.08 |
|  |  | PV | *F*(1,158)=6.9, *p=*0.009, η2=0.04 |
|  |  | Vertical end-point | *F*(1,158)=10.22,  *p=*0.002, η2=0.06 |
|  | *Task\*Side\*Viewing* | Vertical end-point | F(1,158)=5.44, p=0.02, η2=0.03 |
| Viewing |  | PV | *F*(1,158)=6.1, *p*=0.014, η2=0.037 |
|  |  | MGA | *F*(1,158)=26.9, *p<*0.001, η2=0.14 |
|  |  | Vertical end point | *F*(1,158)=38.05, *p*<0.001, η2=0.19 |
|  |  | Horizontal end-point | *F*(1,158)=39.6, *p*<0.001, η2=0.20 |
|  | *Viewing \*Side\*Size* | MT | *F*(1,158)=6.4, *p*=0.012, η2=0.039 |
|  | *Viewing\*Task* | MGA | *F*(1,158)=21.2, *p<*0.001, η2=0.11 |
|  | *Viewing \*Side\*Size* | Vertical end-point | *F*(1,158)=4.1, *p*=0.04, η2=0.03 |
| Side |  | MT | *F*(1,158)=23.1, *p<*0.001, η2=0.12 |
|  |  | PV | *F*(1,158)=43.9, *p<*0.001, η2=0.21 |
|  |  | **TPV** | *F*(1,158)=5.7, *p=*0.017, η2=0.03 |
|  |  | TMGA | *F*(1,158)=16.8, *p<*0.001, η2=0.09 |
|  | *Side\*task* | TMGA | *F*(1,158)=4.6, *p=*0.03, η2=0.02 |
|  |  | Horizontal end point | *F*(1,158)=67.4, *p<*0.001, η2=0.29 |
|  |  | Vertical end-point | *F*(1,158)=80.22, *p<*0.001, η2=0.33 |
| Size |  | MGA | *F*(1,158)=91.4, *p*<0.001, η2=0.36 |
|  | *Viewing \*Size* | MGA | *F*(1,158)=14.06, *p<*0.001, η2=0.08 |
|  | *Viewing \* Side\* Size* | MGA | *F*(1,158)=5.5, *p=*0.02, η2=0.03 |
| Orientation |  | TPV | *F*(1,158)=4.04, *p=*0.046, η2=0.02. |
|  |  | Vertical end-point | *F*(1,158)=24.3, *p=*0.001, η2=0.13 |
| Size |  | Horizontal end-point | *F*(1,158)=6.3, *p=*0.013, η2=0.03, |
|  | *Orientation\*Size* | TPV | *F*(1,158)=4.08, *p=*0.03, η2=0.03 |
|  |  | Vertical end-point | *F*(1,158)=35.2, *p<*0.001, η2=0.18 |
|  |  | Horizontal end-point | *F* (1,158)= 4.7, *p=*0.03, η2=0.03 |
|  | *Size\*Side* | Vertical end-point | *F*(1,158)=6.4, *p=*0.01, η2=0.04 |

**3.1.2. The viewing condition**

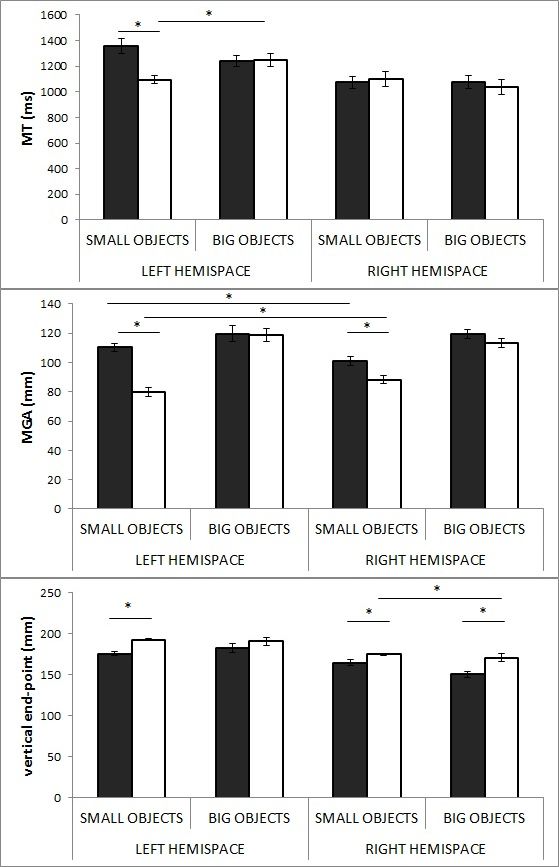
CF was slower in performing the reaching movements in peripheral (MT *M*=1188.3 ms; PV *M*=615 mm/s) than in central (MT *M*=1117.3 ms; PV *M*=660 mm/s) viewing condition. However, the main effect of viewing condition did not reach the significant level for MT, *F*(1,158)=3.3, *p*=0.069, η2=0.021, as it did for PV.

Furthermore, the three-way interaction between viewing condition, side and size of the objects was significant for MT. As shown in Figure 4, for each viewing condition, CF took more time to perform the movement towards the left than right hemi-space (*p*<0.05 in all the comparisons) with the exception of similar MT in reaching the small objects presented in central view. Considering each object size and hemi space independently, the only modulation of CF performance was observed in the increase of MT reach small objects in the peripheral compared to central viewing presented in the left hemi-space, *F* (1, 158)= 14.9,p<0.001, η2=0.08. Finally a modulation of CF’s MT in relation to the size of the object was observed only when the objects were presented in central viewing condition in the left hemi-space, *F*(1,158)=5.2, *p*=0.023, η2=0.032

The grasping aperture was also highly affected by the viewing condition, as the MGA was larger in the peripheral (*M*=112.7 mm) than central (*M*=99.3 mm) view. This effect was further modulated by the goal of the task as shown by the significant interaction between experimental task and viewing condition. CF showed a larger MGA when required to use (*M*=116.6 mm) rather than to move (*M*=108.7 mm) the objects in the peripheral viewing condition, *F*(1,158)= 5.7, *p*=0.018, η2=0.03, whereas the opposite pattern was observed in central viewing, *F*(1,158)= 17.05, *p*<0.001, η2=0.09 (grasp to use *M*=91.3 mm: grasp to move *M*=107.1 mm). Interestingly, only when asked to grasp to use the objects, CF showed a larger MGA in peripheral than central viewing, *F*(1,158)= 47.8, *p*<0.001, η2=0.23

In term of spatial movement parameters, end point was shifted more towards the fixation LED and towards the CF’s body in peripheral (horizontal end-point *M*=195.6 mm; vertical end-point *M*=168.5 mm) than in central (horizontal end-point *M*=207.3; vertical end-point *M*=182.3 mm) viewing condition (see also Figure 4). This observation was confirmed by a significant main effect of viewing condition, horizontal and vertical, end-points. For this last variable, the three-way interaction viewing condition by hemi-space and size of the objects was also significant.

**Figure 4:** Mean CF’s performance for MT (top row), MGA (central row) and vertical end-point (central row) in peripheral (black filling) and central (white filling) viewing conditions in relation to the hemi-space of the action and the size of the objects. The horizontal lines represent the comparisons which reached significance (*p*<0.05).

****

**3.1.3. The movement hemi-space**

For both temporal and spatial parameters, CF’s performance changed in relation to the spatial hemi-space of the action. For the temporal parameters, a significant main effect of the hemi-space was obtained for MT, PV, and TPV. CF showed longer MT and TPV towards the left (MT: *M=* 1233.5, *SD*=240.6; TPV: *M=* 403.3, *SD*=163.02) than right (MT: *M=* 1072.1 ms, *SD=*261.9; TPV *M=* 343.7 ms, *SD*=164.6) hemi-space whereas, PV was higher for movements performed towards the right (*M=* 695.03 mm/s, *SD*=151.3) in comparison to the left hemi-space (*M=* 581.1 mm/s, *SD*=81.7). .

The hemi-space of the action did not influence the grasping parameters per se, but the interaction hemi-space by task was significant for TMGA. This interaction was driven by (i) the difference between tasks in the performance towards the right side, *F*(1,158)=4.01, *p=*0.04, η2=0.205, being longer in grasping to use (*M=* 775.4 mm, *SD*=243.4) than in grasping to move task (*M=* 686.8 mm, *SD*=180.8), and by (ii) the difference in the TMGA between hemi-spaces in the grasp to move task, *F*(1,158)=19.8, *p<*0.001, η2=0.11. In this task, CF took more time to reach the MGA when the objects were presented on the left (*M=* 884.7 mm, *SD*=168.5) than right (*M=* 686.8 mm, *SD*=180.8) location.

Finally, CF’s performance changed in relation to both end points, as shown by a significant main effect of the hemi-space of action for both horizontal and vertical end-points. The horizontal end-points were shifted more towards the centre when performing the movements towards the left (*M=* 193 mm, *SD*=13.5) then right (*M=* 208.8 mm, *SD*=13.7) hemi-space. The vertical end-points of the movement was placed more towards the CF’s body in the right (*M=* 165.5 mm, *SD*=20.3) than left (*M=* 185.5 mm, *SD*=19.8) hemi-space.

**3.1.4 The grasping component**

Overall, CF’s modulated his grasp aperture according to the object size, as shown by a significant main effect of the size for MGA. This was larger for big rather than small objects. However, while a similar grip was observed between conditions when grasping for big objects (peripheral MGA *M*= 119.5 mm; central viewing MGA *M*= 117.8 mm), a larger MGA emerged in reaching for small objects in the peripheral (*M*= 105.7 mm), rather than central viewing (*M*= 83.8 mm). This evidence was confirmed by the significant interaction viewing condition by size of the objects. In both viewing conditions, CF showed a larger MGA in grasping big rather than small objects (*p*<0.001 in both comparisons), but the MGA was larger in peripheral than central viewing only for small objects, *F*(1,158)=40.4, *p<*0.001, η2=0.20. Finally the three-way interaction viewing condition by size and side of the objects, was also significant for MGA (see Figure 4), and showed a trend towards significance for TMGA, *F*(1,158)=3.73, *p=*0.055, η2=0.023. In grasping small objects, CF showed a larger MGA in peripheral than central viewing in both left, *F*(1,158)=40.4, *p<*0.001, η2=0.20, and right hemi-space, *F*(1,158)=6.9, *p=*0.009, η2=0.042, whereas similar performance was observed in grasping big objects (*n.s.* for both comparisons). Comparing the two hemi spaces, CF showed a larger MGA in left than right space when grasping small objects presented peripherally, *F*(1,158)=3.9, *p=*0.04, η2=0.02whereas the opposite pattern was observed in central viewing, but it did not reached significance level, *F*(1,158)=2.8, *p=*0.09, η2=0.01.

**3.1.5 The orientation and size of the objects**

CF showed a longer TPV when reaching for objects presented with the handle towards (*M=* 398.4 ms, *SD*=196.7) rather than away (*M=* 349.2 ms, *SD*=125.7) from CF’s body. This evidence was corroborated statistically with a significant main effect of the orientation for TPV. This effect was further modulated by the size of the objects, as shown by a significant interaction orientation by size of the object. While CF showed a similar performance in grasping big objects, TPV was longer for small objects with the handle facing CF rather than away, *F*(1,158)=8.9, *p=*0.003, η2=0.05.

The vertical and horizontal end-points were differentially influenced by the orientation and size of the object. The vertical end point changed in relation to the objects’ orientation, being longer with the handle facing CF’s body (*M=* 181.1 mm, *SD*=20.6) than when placed away (*M=* 169.8 mm, *SD*=22.9). On the other hand, the horizontal end point was affected by the size, being shifted more towards the center for small (*M=* 199 mm, *SD*=14.8) than big (*M=* 203.6 mm, *SD*=15.9) objects. Finally, the interaction between size of the objects and orientation and size of the objects and action hemi-space were significant for both vertical and horizontal endpoints.

***3.2. Comparison CF and Controls***

As shown in Table 2, CF’s performance differed from controls in both spatial and temporal parameters (see also Figure 2) in both experiments. In particular, CF was slower than controls in performing the action in the peripheral view condition in both goal-directed actions (grasp to move: MT zccc= 8.6, *p* = .01; TPV zccc= 6.2, *p* = .035; to grasp to use: MT zccc= 7.4, *p* = .02; TPV zccc= 6.2, *p* = .03). On the contrary, CF performs as well as controls in central viewing (grasp to move: MT zccc= 4.3, n.s.; TPV zccc= 4.3, n.s., grasp to use: MT zccc= 1.6, n.s.; TPV zccc= 3.8, n.s.).

Similarly, CF’s MGA was similar to controls in the grasp to move task, but he showed a larger MGA in the peripheral viewing condition when asked to use of the objects (zccc= 6.7, *p* = .028), whereas in central viewing this comparison did not reach significance (zccc= 5.07, *p* = .06).

In relation to the spatial distribution of the movement, CF’s horizontal end-points were shifted more towards the central LED compared to controls in the peripheral viewing conditions (for grasp to move: zccc-11.1, *p* = .005; and for grasp to use: zccc-8.8, *p* = .02), as well as in central viewing when he was asked to use the object (zccc= 9.7, *p* = .008). In relation to the vertical-end point, CF undershot of the movement compared to controls in peripheral viewing condition only when asked to use the objects (zccc= -22.7, *p* < .001). A similar tendency seemed to emerge also when using object presented centrally but it did not reach significance (zccc= -5.3, *p* =.055).

Finally, while a larger difference in CF’s performance between viewing conditions was observed in the grasp to use task in terms of MT (zDCCC= -12.2, *p* = .02), no differences were observed between the two tasks considering the viewing conditions separately in any of our variables.

In relation to the spatial aspect of the reaching movements, CF’s horizontal end-point was shifted towards the centre of the table in peripheral viewing (zccc= -11.1, *p* < .001), but not in central viewing, when correcting for multiple comparisons (zccc= -4.5, *p* = .04).

**Table 2:** Average performance of CF and controls**.**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Experiment 1 GRASP TO MOVE** | | | | |
| Viewing |  | Peripheral |  | Central |
|  | CF | Controls | CF | Controls |
| MT (ms) | **1206.9\*** | 912.5 (67.1) | 1122.5 | 867.3 (69.9) |
| PV (mm/s) | 631.4 | 721.9 (85.8) | 652.8 | 759.1 (76.9) |
| TPV (ms) | 383.7\* | 304.1 (58.6) | 361.1 | 296.5 (33.07) |
| MGA (mm) | 105.4 | 84.1 (7.8) | 109.3 | 78.4 (6.2) |
| TMGA (ms) | 871.8\* | 668.1 (70.3) | 830.6 | 659.2 (61.6) |
| Vertical End Point (mm) | 166.07 | 191.4 (7.5) | 183.6 | 187.4 (4.08) |
| Horizontal End Point (mm) | **199.4\*** | 209.4 (4.7) | 203.2 | 208.3 (1.8) |
| Experiment 1 GRASP TO USE | | | | |
| Viewing |  | Peripheral |  | Central |
|  | CF | Controls | CF | Controls |
| MT (ms) | **1380.6\*** | 912.2 (61.6) | 1125.6 | 838.6 (117.2) |
| PV (mm/s) | 552.5 | 748.9 (66.7) | 672.1 | 818.08 (85.8) |
| TPV (ms) | 444.3\* | 275.7 (32.2) | 397.5 | 252.6 (42.6) |
| MGA (mm) | **120.6\*** | 82.08 (5.7) | 97.7 | 76.2 (4.2) |
| TMGA (ms) | 888.7 | 669.2 (58.6) | 786.2 | 615.1 (80.6) |
| Vertical End Point (mm) | **165.9 \*** | 188.7 (4.3) | 170.6 | 183.7 (5.6) |
| Horizontal End Point (mm) | **196.6 \*** | 211.8 (3.3) | **202.5\*** | 208.5 (0.98) |

Asterisk indicates *p* < 0.05; results which survived multiple comparisons correction are highlighted in bold.

**4. DISCUSSION**

The present study aimed at exploring the possible changes of both spatial and temporal aspects of reaching and grasping movements in a left-brain damaged patient with both optic ataxia and limb apraxia. To do so, we manipulated key factors that are sensitive to optic ataxia, such as viewing condition (peripheral vs. central), and limb apraxia, such as the goal of the task (to move or to use common tools) and the characteristics of the objects (their size). These manipulations were expected to increase the understanding as to the possible differential contributions of the two syndromes in the reaching and grasping components of the movements. In particular we endorse the view of Goldenberg (2013) on apraxia as high order motor deficit, in which basic kinematic alterations are not the direct outcome of apraxia. However, we reasoned that apraxia may play a role in affecting the kinematic parameters more indirectly by making the grasp to use task (Experiment 2) more complex for this patient. OA alteration thus might be enhanced in particular when the task is to grasp to use an object in the peripheral field. In the following we will discuss each of the findings in turn. The first few sections will be dedicated in discussing CF performance specifically and in the last section discuss CF’s performance in relation to controls, with the focus on the key manipulation: task goal and viewing condition.

**4.1. The task goal and the viewing condition**

CF performance changed in relation to the goal of the task with the increase of the temporal (MT and PV) and spatial (vertical endpoint) parameters of the reaching movements when the secondary action required a more fine and purpose action (grasp to use of the objects). The modulation of the reaching parameters with the goal of the task is also observed in healthy young and elderly and reflects the normal adaptation of the motor system to the requirement of the task (Cicerale, Ambron, Lingnau, & Rumiati, 2014). In line with this interpretation, CF and controls showed a similar performance in relation to the task goal. Taken together this evidence supports of the view that apraxia is a high order motor deficit, whose effect may not be reflected necessarily in changes of the kinematic parameters (Goldenberg, 2013).

However, the presence of apraxia seemed to have an indirectly effect on CF’s performance enhancing of OA deficits. This was evident when looking at the grasping parameters. While CF showed a similar MGA between viewing conditions when the goal of the task was to move the objects, differences between central and peripheral viewing conditions appeared when CF was asked to grasp the objects in order to use them. In this task, CF showed a larger MGA in the peripheral viewing compared with the central viewing, which can be considered as evidence of a worsening of the grasping component (Carnahan, Vandervoort, & Swanson, 1998). This evidence could be ascribed to the presence of apraxia, as previous studies reported an alteration of grasping in patients with left-brain damage and apraxia (Osiurak et al., 2008; Randerath et al., 2010). In particular, Randerath et al. (2010) showed that some patients with apraxia may select inappropriate grip types (i.e., incongruent with the function of the object) compared to controls, but this selection does not necessarily lead to the erroneous use of the objects. The present results take this observation further and suggest that apraxia could also be reflected in more subtle alterations of the grasping component.

Interestingly, while in peripheral viewing a trend towards significance appeared in MGA, with the grip being slightly larger in the grasp to use than grasp to move experiment, the opposite pattern emerged in the central viewing condition. We have no principled account for this effect but a possible speculation is that being aware of his difficulties in using the objects, CF may have paid more attention and effort in the grasping component under central viewing condition.

The effect of the viewing condition was particularly evident and independent from the goal of the task, when considering the spatial aspects of the reaching movements. In either experiments, the horizontal end point was shifted towards the centre of the table in the peripheral viewing and veered towards the fixation LED. A similar displacement of the movement trajectory towards the fixation has been previously observed in patients with OA (Blangero et al., 2010; Milner, et al., 2003; Jackson et al., 2005), implying a possible difficulty in dissociating between eyes and limbs. In particular, Milner et al. (2003) described a similar directional bias towards fixation in two patients with OA when asked to perform an immediate reaching. The authors interpreted this effect in relation to the *magnetic misreaching* described a few years earlier by Carey, Coleman, & Della Sala(1997) in a patient suffering from progressive bilateral parietal lobe degeneration. Movement trajectory of Carley’s et al’s patient seems to be captured from the focus of fixation to such extent that he was unable to perform an action at the different location from the focus of fixation. Milner et al. (2003) suggested that optic ataxia and magnetic misreaching may represent different degrees of a unique primitive motor response in which vision and action are tightly coupled. In their argument, midbrain areas, and the superior colliculus, in particular, would be responsible for this primitive coupling, which in normal adults would be inhibited when required by the task, thanks to the parietal visuomotor system. Following this interpretation, parietal damage would decrease this inhibitory control causing the emergence of this primitive form of movement biases. This interpretation could also account for the movement bias observed in CF. However, as reasoned above, given CF’s apraxic difficulties; we expected the bias to be larger in the grasp-to use than in the grasp-to move experiment. Contrary to our expectation, the bias was not modulated by the goal of the task. This result suggests that the goal of the task may not have a specific detrimental effect on the movement trajectory promoting an increase of the movement bias towards fixation. This evidence further suggests that the attraction of the movement trajectory towards fixation may be a more primitive motor behavior associated to optic ataxia and not to limb apraxia.

**4.2. The hemi-space of action**

Since CF’s brain lesion affected the left hemisphere, we expected that the movements performed in the controlesional space would be specifically affected (i.e., a possible field effect). However, the results did not seem to support our predictions. The temporal parameters of the movements were faster when the patient was asked to reach objects placed in the right than the left side of the space. A similar advantage for the right hemi-space was observed also in the grasping component. Although we observed a similar pattern characterized by an increase of the MGA when grasping small objects presented in peripheral rather than in central view, this difference was more evident in the left hemi-space. In addition to this, the end point of the movement were similarly affected by the action hemi-space and the above mention tendencies of the endpoints to be shifted towards CF’s body midline was more pronounced when the action was directed to the left hemi-space. These results can be explained by taking into account the observed advantage of each hand in performing movements towards its own space (see Fisk & Goodale, 1985). Since CF was right-handed and performed both experiments using his dominant hand, we speculate that the observed effects are related to the ipsilateral preference, which was maintained despite the presence of OA. In addition to the ipsilateral preference explanation, this last effect could be also due to the mechanical constraints of the movement characterizing our task. For instance, since the SP was aligned with CF’s body midline and movements were performed with the right hand, a larger bias towards the right side might have been favored.

**4.3. The grasping component**

As to the grasping component, CF showed a similar performance across viewing conditions for big objects, whereas a detrimental effect of the peripheral viewing condition was observed solely when he grasped small objects. Notably, CF’s MGA was larger when grasping small objects, approaching the average MGA of big objects. This finding suggests that, in order to overcome the difficulty of the task, which was exacerbated when grasping small objects in the peripheral viewing condition, CF developed a strategy consisting in opening his hand widely. This larger grip aimed at increasing the probability of grasping the objects to reduce the error and compensating for possible alterations of the transport component of the reaching movement (Cavina-Pratesi et al., 2010; Wing, Turton, & Fraser, 1986).

This grip scaling alteration in OA has been previously described in a patient with OA (Cavina-Pratesi et al., 2010), when grasping rectangular blocks presented peripherally. The present result extends this original observation with meaningful objects to common tools, but it also goes beyond by emphasizing the importance of the task goal for our patient. For instance, when looking at the difference between CF and controls, a detrimental effect of peripheral vision on the grasping component emerged only in the grasp to use task. The presence of limb apraxia might have increased the cognitive load of the grasp to-use-task, thus bringing to light an alteration of the grasping component in the peripheral viewing condition.

**4.4. Differences between CF and controls.**

Compared with control groups, CF showed a general impairment in movement execution, which involved the reaching movements towards objects, presented peripherally and may reflect the presence of optic ataxia (Pisella et al., 2000). On the other hand, as far as the grip aperture was concerned, a specific difference between the control group and CF emerged as possibly being due to the concurrency of both OA and limb apraxia symptoms. Indeed CF showed a larger MGA than controls only when asked to reach and grasp the objects presented peripherally with the purpose of using them. Modifications of the grasping component have been observed before in apraxia patients when required to use the objects (Randerath, Goldenberg, & Hermsdörfer, 2009) or in patient with optic ataxia when grasping blocks presented peripherally (Cavina-Pratesi et al., 2010). As previously argued, the grasp to use task may have being more demanding for CF due to the presence of apraxia, and ideational apraxia in particular, by enhancing the alteration of temporal and grasping parameter in performing movements towards objects presented peripherally. Consistently with this interpretation, CF took more time to reach the maximum grip aperture in both experiments in the peripheral viewing condition.

Slightly less consistent results were obtained with respect to the spatial distribution of the movement. CF tended to perform the movement more towards fixation point than controls in both tasks when reaching towards the peripheral visual field. The horizontal end point was placed more towards the fixation point in in CF than in controls regardless of the task’s goal. This finding is consistent with the interpretation of OA as a possible default attraction towards fixation (see Milner et al., 2003). However, the presence of apraxia may have additionally contribute to CF performance, which also varied from controls in the spatial distribution of the horizontal end point in central viewing.

Finally, compared with controls, CF undershoot the movements in Experiment 2 in peripheral than central viewing, thus reinforcing the view that the presence of apraxia in association with OA may have enhanced a specific alteration in peripheral viewing when CF was asked to use the objects.

**4.5. Brain structures underpinning optic ataxia and limb apraxia in CF**

CF’s brain lesion does not involve the areas that are classically affected in OA, such as superior parietal (Buxbaum & Coslett, 1997; Jeannerod, 1988; Caminiti et al., 1996; Milner and et al., 2003; Battaglia-Mayer & Caminiti, 2002), intraparietal sulcus (Cavina-Pratesi, 2010; Perenin & Vighetto, 1988; Milner & Goodale, 1995) or parieto-occipital junction (POJ), (Perenin & Vighetto, 1988; McIntosh, in press), but involved the inferior portion of the parietal lobe and the angular gyrus. Lesions to this area, sparing the superior parietal lobe, have been previously noted in patients with concomitant OA and limb apraxia (Perenin & Vighetto, 1988).

CF’s brain lesions covered areas recently found to be associated with different forms of limb apraxia (Mengotti, Corradi-Dell'Acqua, Negri, Ukmar, Pesavento, & Rumiati, 2013): the superior temporal areas and left supramarginal gyrus were found to be lesion in patients with ideational apraxia and in patients with a selective deficit in imitation of meaningful gestures. In addition, CF’s lesion implicated also areas like the angular gyrus whose lesion was found to be responsible for a selective deficit in imitation of meaningless gestures (Mengotti et al., 2013) and postulated to be the brain correlates of the direct route, based on direct assess to visual information. Therefore, CF’s brain lesion is in line with the observed impairment in both meaningless and meaningful gestures. CF’s brain lesions, corroborated with his performance in neuropsychological tasks, support the connection between these brain areas, and both the semantic and direct route of action (Mengotti et al., 2010; Tessari et al., 2007).

Most importantly, CF’s lesion involved areas typically associated with an impairment in pantomiming the use of tools and in using them, like supramarginal gyrus (Rumiati et al., 2004; Mengotti et al., 2013) and angular gyrus (Randerath et al., 2010). Specifically, Randerath et al. (2010) found that damage to this latter area was related to an impairment of the grasping component during tool use demonstration and proposed a differential role of inferior parietal and frontal areas in tool use actions. Following their view, the supramarginal gyrus is responsible for combining visual information and semantic knowledge related to tool-use into an action plan. Instead, the inferior frontal gyrus and the angular gyrus would modulate the selection of the appropriate grasp to respond to the contingent situation. The latter two areas thus would be specifically involved in the selection of a functional grasp, in which hand configuration of the grasping action is congruent with object function, when the task requires the use of the tool. This brain-network could account for the present data and support our interpretation of CF’s alteration of the grasping component in the grasping-to use task as reflecting of the presence of apraxia.

It is worth mentioning that while limb apraxia and, in particular, ideational apraxia, may have a strong impact on patient’s daily life since it alters the ability to perform everyday actions (Rumiati, Zanini, Vorano, & Shallice, 2001), OA can be easily compensated (McIntosh, in press). Therefore, if not directly evaluated, OA might elude the neuropsychological assessment, in particular in the case of patients with a damage that does not involve brain areas classically associated with OA, such as the superior parietal lobe, but more inferior regions. In the case of CF, since his grasping difficulties were spotted during the initial clinical assessment, he was admitted to a more extended examination. This underlines the importance of assessing OA in the clinical routine and of developing a more specific assessment of this neuropsychological syndrome. It is also important to explore the possible presence of different forms of OA affecting different reference frames (eye, head and body frame of reference) (Dijkerman et al., 2006; Jax, Buxbaum, Lie, & Coslett, 2009; Khan et al., 2007), but also of possible dissociations in performance between different reaching tasks, such as pointing towards stable or moved targets for instance in order to further explore deficits in online control of action (Buiatti, Skrap, & Shallice, 2013).

**4.6. Conclusions**

The present study showed that the presence of both optic ataxia and limb apraxia modified spatial and temporal parameters of grasping and reaching movements in CF. While the alteration of the spatial parameters of the action as a function of the viewing condition may be considered as the effect of OA, the alteration of temporal parameters of the action and, in particular, the grasping component may have been enhanced by the presence of limb apraxia. Furthermore, we argued that the two deficits may have interacted to a certain degree: the presence of limb apraxia may have posed a greater processing demand for the grasp to use task, thus exacerbating OA alterations in reaching and grasping towards the peripheral visual field.

Although single case studies are of common use in the optic ataxia literature due to the sporadic nature of this symptom, the present work explores the combination of OA with apraxia. We would like to point out that a comparison of our patient’s performance with a patient with solely OA would have been ideal, and the lack of a direct comparison with data from such a patient limits the interpretation of our results. However, the value of the present work lies in the first experimental exploration of the relationship between optic ataxia and apraxia, thus opening the way to future investigations on this topic.

**REFERENCES**

Balint, R. (1909). Seelenlähmung des “Schauens” optische Ataxie räumliche Störung der Aufmerksamkeit. *Monatsschr. Psychiatr. Neurol*. 25, 5–81.

Bartolo, A., Cubelli, R., Sala, S. D., Drei, S., & Marchetti, C. (2001). Double dissociation between meaningful and meaningless gesture reproduction in apraxia. *Cortex, 37(5),* 696-699.

Battaglia-Mayer, A., & Caminiti, R. (2002). Optic ataxia as a result of the breakdown of the global tuning fields of parietal neurones. *Brain, 125,* 225-37.

Binkofski, F., & Buxbaum ,L.J. (2003). Two action systems in the human brain. *Brain and Language, 127,* 222-9.

Blangero, A., Ota, H., Rossetti, Y., Fujii, T., Ohtake, H., Tabuchi, M., Vighetto, A., Yamadori, A., Vindras, P., & Pisella, L. (2010). Systematic retinotopic reaching error vectors in unilateral optic ataxia. *Cortex, 46,* 77-93.

Blangero, A., Gaveau, V., Luauté, J., Rode, G., Salemme, R., Guinard, M., Boisson, D., Rossetti, Y., & Pisella, L. (2008). A hand and a field effect in on-line motor control in unilateral optic ataxia. *Cortex, 44,* 560-8.

Blangero, A., Ota, H., Delporte, L., Revol, P., Vindras, P., Rode, G., Boisson, D., Vighetto, A., Rossetti, Y., & Pisella, L. (2007). Optic ataxia is not only 'optic': impaired spatial integration of proprioceptive information. *Neuroimage, 36 ,*T61-8.

Borchers, S., Müller, L., Synofzik, M., & Himmelbach, M. (2013). Guidelines and quality measures for the diagnosis of optic ataxia. *Frontiers in Human Neuroscience, 7:* 324.

Buiatti, T., Skrap, M., & Shallice, T. (2013). Reaching a moveable visual target: dissociations in brain tumour patients. *Brain and Cognition, 82,* 6-17.

Buxbaum, L.J. (2001). Ideomotor apraxia: a call to action. *Neurocase*, 7, 445-58.

Buxbaum L.J., & Coslett, H.B. (1997). Subtypes of optic ataxia: Reframing the disconnection account. *Neurocase: The Neural Basis of Cognition, 3,*159-166.

Buxbaum, L. J., Johnson-Frey, S. H., & Bartlett-Williams, M. (2005). Deficient internal models for planning hand-object interactions in apraxia. *Neuropsychologia, 43,* 917-929.

Caminiti, R., Chafee, M.V., Battaglia-Mayer, A., Averbeck, B.B., Crowe, D.A., & Georgopoulos, A.P. (2010). Understanding the parietal lobe syndrome from a neurophysiological and evolutionary perspective. *European Journal of Neuroscience, 31,* 2320-40.

Carey, D.P., Dijkerman, H.C., & Milner, A.D. (1998). *Perception and action in depth. Consciousness and Cognition, 7,* 438-53.

Carey, D.P., Coleman, R.J., Della Sala, S. (1997). Magnetic misreaching. *Cortex, 33,* 639-52.

Carlesimo, G.A., Caltagirone, C., Gainotti, G., Fadda, L., Gallassi, R., Lorusso, S., y Parnetti, L. (1996). The Mental Deterioration Battery: Normative data, diagnostic reliability and qualitative analyses of cognitive impairment. *European Neurology, 36,* 378–384.

Carmeli, E., Patish, H., & Coleman, R. (2003). The aging hand. *Journal of Gerontol Series A Biological Sciencea and Medical Sciences, 58,* 146-52.

Caselli, R.J., Stelmach, G.E., Caviness, J.N., Timmann, D., Royer, T., Boeve, B.F., & Parisi, J.E. (1999). A kinematic study of progressive apraxia with and without dementia. *Movement Disorder, 14,* 276-87.

Cavina-Pratesi, C., Ietswaart, M., Humphreys, G.W., Lestou, V., & Milner, A.D. (2010). Impaired grasping in a patient with optic ataxia: primary visuomotor deficit or secondary consequence of misreaching? *Neuropsychologia, 48,* 226-34.

Cicerale, A., Ambron, E., Lingnau, A., & Rumiati, RI (2014). A kinematic analysis of age-related changes in grasping to use and grasping to move common objects*. Acta Psychologica,* 151C:134-142.

Cooper, R.P. (2007). Tool use and related errors in ideational apraxia: the quantitative simulation of patient error profiles. *Cortex, 43(3),* 319-37.

Crawford, J.R., Garthwaite, P.H., & Ryan, K. (2011). Comparing a single case to a control sample: testing for neuropsychological deficits and dissociations in the presence of covariates. *Cortex, 47,*1166-78.

Cubelli, R., Marchetti, C., Boscolo, G., & Della Sala, S. (2000). Cognition in action: Testing a model of limb apraxia. *Brain and cognition, 44(2),* 144-165.

De Renzi, E., Pieczuro, A., Vignolo, L.A.(1968). Ideational apraxia: A quantitative study. *Neuropsychologia, 6 ,* 41–52.

De Renzi, E. (1985). Methods of limb apraxia examination and their bearing on the interpretation of the disorder. *Advances in Psychology, 23,* 45–64.

De Renzi, E., & Lucchelli, F.(1988). Ideational apraxia. *Brain, 111,* 1173-85.

De Renzi, E., Motti, F., & Nichelli, P. (1980). Imitating gestures: A quantitative approach to ideomotor apraxia. *Archives of Neurology, 37(1),* 6-0.

Daprati, E., & Sirigu, A. (2006). How we interact with objects: learning from brain lesions. *Trends Cognitive Sciences, 10,* 265-70.

Dijkerman, H.C., McIntosh, R.D., Anema, H.A., de Haan, E.H., Kappelle, L,J., Milner, A.D. (2006). Reaching errors in optic ataxia are linked to eye position rather than head or body position. *Neuropsychologia, 44,* 2766-73.

Donkervoort, M., Dekker, J., van den Ende, E., Stehmann-Saris, J.C., Deelman, B.G. (2000) Prevalence of apraxia among patients with a first left hemisphere stroke in rehabilitation centres and nursing homes. *Clinical Rehabilitation, 14,* 130–6.

Fabbri, S., Strnad, L., Caramazza, A., & Lingnau, A. (in press). Overlapping representations for grip type and reach direction. *NeuroImage.*

Fisk, J. D., & Goodale, M. A. (1985). The organization of eye and limb movements during unrestricted reaching to targets in contralateral and ipsilateral visual space. *Experimental Brain Research, 60(1),* 159-178.

Giovagnoli, A.R., Del Pesce, S., Mascheroni, M., Simoncelli, M., Laiacona, M., & Capitani, E. (1996). Trail making test: Normative values from 287 normal adult controls. *The Italian Journal of Neurological Sciences,* 17, 305–309.

Goldenberg, G., & Spatt, J. (2009). The neural basis of tool use. *Brain, 132,* 1645-1655.

Goldenberg (2013). Apraxia the cognitive side of motor control. Oxfor. UK. Oxford University press.

Goldenberg, G., & Hagmann, S. (1997). The meaning of meaningless gestures: A study of visuo-imitative apraxia. *Neuropsychologia, 35(3),* 333-341.

Goodale, M. A., & Milner, A. D. (1992). Separate visual pathways for perception and action. *Trends in neurosciences, 15(1),* 20-25.

Goodale, M.A., Milner, A.D., Jakobson, L.S., & Carey, D.P. (1991). A neurological dissociation between perceiving objects and grasping them. *Nature, 10,* 154-6.

Goodale,M.A., & Westwood, D.A. (2004). An evolving view of duplex vision: separate but interacting cortical pathways for perception and action. *Current Opinion in Neurobiology, 14,* 203-11.

Haaland, K. Y., Harrington, D. L., & Knight, R. T. (1999). Spatial deficits in ideomotor limb apraxia: A kinematic analysis of aiming movements. *Brain, 122,* 1169–1182.

Haaland, K.Y., Harrington, D.L., Knight, R.T. (2000). Neural representations of skilled movement*. Brain, 123,* 2306–13.

Hermsdörfer,J., Hentze, S., & Goldenberg, G. (2006). Spatial and kinematic features of apraxic movement depend on the mode of execution. *Neuropsychologia, 44,* 1642-52.

Hermsdörfer, J., Li, Y., Randerath, J., Goldenberg, G., & Johannsen, L. (2012). Tool use without a tool: kinematic characteristics of pantomiming as compared to actual use and the effect of brain damage. *Experimental Brain Research, 218,* 201-14.

Hanna-Pladdy, B., Heilman, K.M., & Foundas, A.L. (2001). Cortical and subcortical contributions to ideomotor apraxia: analysis of task demands and error types. *Brain, 124,* 2513-27.

Hesse, C., Ball, K., & Schenk, T. (2012). Visuomotor performance based on peripheral vision is impaired in the visual form agnostic patient DF. *Neuropsychologia, 50(1),* 90-97.

Himmelbach, M., & Karnath, H. O. (2005). Dorsal and ventral stream interaction: contributions from optic ataxia*. Journal of Cognitive Neuroscience, 17(4),* 632-640.

Humphreys, G.W., & Riddoch, M.J. (1987). The fractionation of visual agnosia. In Visual Object Processing*. A Cognitive Neuropsychological Approach,* Erlbaum, Hove pp. 281–306 Ch. 10

Ietswaart, M., Carey, D.P., Della Sala, S., & Dijkhuizen, R.S. (2001). Memory-driven movements in limb apraxia: is there evidence for impaired communication between the dorsal and the ventral streams? *Neuropsychologia, 39,* 950-61.

Jackson, S.R., Newport, R., Mort, D., & Husain, M. (2005). Where the eye looks, the hand follows; limb-dependent magnetic misreaching in optic ataxia. *Current Biology, 15,* 42-6.

Jakobson, L.S., Archibald, Y.M., Carey, D.P., & Goodale, M.A. (1991). A kinematic analysis of reaching and grasping movements in a patient recovering from optic ataxia. *Neuropsychologia, 29,* 803-9.

Jax, S.A., Buxbaum, L.J., Lie, E., & Coslett, H.B. (2009). More than (where the target) meets the eyes: disrupted visuomotor transformations in optic ataxia. *Neuropsychologia, 47,* 230-8.

Jeannerod, M. (1988). *The neural and behavioural organization of goal-directed movements.* Clarendon Press/Oxford University Press.

Jeannerod, M., Decety, J., & Michel, F. (1994). Impairment of grasping movements following a bilateral posterior parietal lesion. *Neuropsychologia, 32,* 369-80.

Johnson-Frey, S. H., & S. T. Grafton (2003). "From “Acting On” to “Acting With”: The functional anatomy of action representation." *Space coding and action production* 127-139.

Khan, A.Z., Crawford, J.D., Blohm, G., Urquizar, C., Rossetti, Y., & Pisella, L. (2007). Influence of initial hand and target position on reach errors in optic ataxic and normal subjects. *Journal of Vision, 7,* 8.1-16.

Karnath, H.O., & Perenin, M.T.(2005) Cortical control of visually guided reaching: evidence from patients with optic ataxia. *Cerebral Cortex, 15,*1561-9.

Kertesz, A., & Ferro, J.M. (1984). Lesion size and location in ideomotor apraxia. *Brain, 107,* 921–33.

Khan, A.Z., Pisella, L., Vighetto, A., Cotton, F., Luauté, J., Boisson, D., Salemme, R., Crawford, J.D., & Rossetti, Y. (2005). Optic ataxia errors depend on remapped, not viewed, target location. *Nature Neuroscience, 8,* 418-20.

Hermsdörfer, J., Mai, N., Spatt, J., Marquardt, C., Veltkamp, R., Goldenberg, G. (1996). Kinematic analysis of movement imitation in apraxia. *Brain, 119,* 1575-86.

Leiguarda, R.C., Pramstaller, P.P., Merello, M., Starkstein, S., Lees, A.J., & Marsden, C.D. (1997). Apraxia in Parkinson's disease, progressive supranuclear palsy, multiple system atrophy and neuroleptic-induced parkinsonism. *Brain, 120,* 75–90.

Lingnau, A., Strnad, L., He, C., Fabbri, S., Han, Z., Bi, Y., & Caramazza, A. (2014). Cross-modal plasticity preserves functional specialization in posterior parietal cortex. *Cerebral Cortex, 24 (2),* 541-549.

Liepmann H. (1920). Apraxie [Apraxia]. *Ergebnisse der gesamten Medizin*; *1,*  516-543.

Lunardelli, A., Negri, G.A.L, Sverzut, A., Gigli, G., & Rumiati, R.I. (2011). «I know what it is, but can't use it!» A case of Ideational Apraxia. *Giornale italiano di psicologia; 38,* 605-627.

Mauri, M., Carlesino, G. A., Graceffa, A. M. S., Loasses, A., Lorusso, S., Sinforiani, E., ... & Caltagirone, C. (1997). Standardizzazione di due nuovi test di memoria: apprendimento di liste di parole correlate e non correlate semanticamente. *Archivio di Psicologia Neurologia e Psichiatria, 58,* 621-645.

Meek, B.P., Shelton, P., & Marotta, J.J.( 2013). Posterior cortical atrophy: visuomotor deficits in reaching and grasping. Frontiers in Human Neuroscience, 21;7:294.

Mengotti, P., Corradi-Dell'Acqua, C., Negri, G.A., Ukmar, M., Pesavento, V., & Rumiati, R.I. (2013). Selective imitation impairments differentially interact with language processing. *Brain,136,* 2602-18.

McIntosh, R.D. (in press). *Optic ataxia*. In EB Goldstein (Ed). The Sage Encyclopedia of Perception.

McIntosh, R.D., Dijkerman, H.C., Mon-Williams, M., & Milner, A.D. (2004). Grasping what is graspable: evidence from visual form agnosia. *Cortex, 40,* 695-702.

McIntosh, R.D., & Schenk, T. (2009). Two visual streams for perception and action: current trends. *Neuropsychologia, 47,* 1391-6.

McIntosh, R.D., Mulroue, A., & Brockmole, J.R. (2010). How automatic is the hand's automatic pilot? Evidence from dual-task studies. *Experimental Brain Research, 206,* 257-69.

Milner, A.D., Dijkerman, H.C., McIntosh, R.D., Rossetti, Y., Pisella, L. (2003). Delayed reaching and grasping in patients with optic ataxia. *Progresses in Brain Research, 142,* 225-42.

Milner, A.D., Dijkerman, H.C., Pisella, L., McIntosh, R.D., Tilikete, C., Vighetto, A., & Rossetti, Y. (2001). Grasping the past. delay can improve visuomotor performance. *Current Biology, 11,* 1896-901.

Milner, A. D., & Goodale, M. A. (1995). *The visual brain in action.* Oxford: Oxford Press.

Milner, A. D., & Goodale, M. A. (2008). Two visual systems re-viewed. *Neuropsychologia, 46(3),* 774-785.

Milner, A.D., Perrett, D.I., Johnston, R.S., Benson, P.J., Jordan, T.R., Heeley, D.W., Bettucci, D., Mortara, F., Mutani, R., Terazzi, E., et al. (1991). Perception and action in 'visual form agnosia'. *Brain, 114,* 405-28.

Orsini, A., Grossi, D., Capitani, E., Laiacona, M., Papagno, C., & Vallar, G. (1987). Verbal and spatial immediate memory span: normative data from 1355 adults and 1112 children. *The Italian Journal of Neurological Sciences, 8(6),* 537-548.

Osiurak, F., Aubin, G., Allain, P., Jarry, C., Etcharry-Bouyx, F., Richard, I. , Le Galle, D. (2008). Different constraints on grip selection in brain-damaged patients: Object use versus object transport. *Neuropsychologia, 46,* 2431-2434.

Perenin, M.T., & Vighetto, A. (1988). Optic ataxia: a specific disruption in visuomotor mechanisms. I. Different aspects of the deficit in reaching for objects*. Brain, 111*,643-74.

Pisella, L., Binkofski, F., Lasek, K., Toni, I., & Rossetti, Y. (2006). No double-dissociation between optic ataxia and visual agnosia: Multiple sub-streams for multiple visuo-manual integrations. *Neuropsychologia, 44(13),* 2734-2748.

Pisella, L., Gréa, H., Tilikete, C., Vighetto, A., Desmurget, M., Rode, G., Boisson, D., & Rossetti Y. (2000). An 'automatic pilot' for the hand in human posterior parietal cortex: toward reinterpreting optic ataxia. *Nature Neuroscience, 3,* 729-36.

Pisella, L., Michel, C., Grea, H., Tilikete, C., Vighetto, A., & Rossetti, Y. (2004). Preserved prism adaptation in bilateral optic ataxia: strategic versus adaptive reaction to prisms. *Experimental Brain Research, 156(4),* 399-408.

Prado, J., Clavagnier, S., Otzenberger, H., Scheiber, C., Kennedy, H., & Perenin, M.T. (2005). Two cortical systems for reaching in central and peripheral vision. *Neuron, 48,* 849-58.

Randerath, J.Li. Y., Goldenberg, G., & Hermsdörfer, J. (2009). Grasping tools: effects of task and apraxia. *Neuropsychologia, 47,* 497-505.

Randerath, J., Goldenberg, G., Spijkers, W., Li, Y., & Hermsdörfer, J. (2010). Different left brain regions are essential for grasping a tool compared with its subsequent use. *Neuroimage, 53,* 171-180.

Rice, N.J, Edwards MG, Schindler I, Punt TD, McIntosh RD, Humphreys GW, Lestou V, Milner AD (2008). Delay abolishes the obstacle avoidance deficit in unilateral optic ataxia. *Neuropsychologia, 46,* 1549-57.

Rosenbaum, D.A., Vaughan, J., Barnes, H.J., & Jorgensen, M.J. (1992). Time course of movement planning: Selection of handgrips for object manipulation. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 18,* 1058–1073.

Rossetti, Y., Pisella, L., & Vighetto, A. (2003). Optic ataxia revisited: visually guided action versus immediate visuomotor control. *Experimetal Brain Research, 153,* 171-9.

Rothi, L.J.G., Ochipa, C., & Kenneth M. (1991) A cognitive neuropsychological model of limb praxis a cognitive neuropsychological model of limb praxis. *Cognitive Neuropsychology, 8,* 443-458.

Rumiati, R.I. (2005). Right, left or both? Brain hemispheres and apraxia of naturalistic actions. *Trends in Cognitive Sciences, 9,* 167-9.

Rumiati, R.I., Weiss, P.H., Shallice, T., Ottoboni, G., Noth, J., Zilles, K., & Fink, G.R. (2004). Neural basis of pantomiming the use of visually presented objects. *Neuroimage, 21,* 1224-31.

Rumiati, R.I., Papeo, L., Corradi-Dell'Acqua C. (2010). Higher-level motor processes. *Annals of New York Academy of Sciences, 1191,* 219-41.

Rumiati, R.I., & Tessari, A. (2002). Imitation of novel and well-known actions: the role of short-term memory. *Experimetal Brain Research, 142*, 425-33.

Rumiati, R. I., Zanini, S., Vorano, L., & Shallice, T. (2001). A form of ideational apraxia as a delective deficit of contention scheduling. *Cognitive Neuropsychology, 18(7),* 617-642.

Schindler, I., Rice, N.J., McIntosh, R.D., Rossetti, Y., Vighetto, A., & Milner, A.D. (2004). Automatic avoidance of obstacles is a dorsal stream function: evidence from optic ataxia. *Nature Neuroscience, 7,* 779-84.

Spinnler, H., & Tognoni, G. (1987). *Standardizzazione e taratura italiana di test neuropsicologici.* Masson Italia Periodici.

Striemer, C., Locklin, J., Blangero, A., Rossetti, Y., Pisella, L., & Danckert, J. Attention for action? Examining the link between attention and visuomotor control deficits in a patient with optic ataxia. *Neuropsychologia, 47,* 1491-9.

Tessari, A., Canessa, N., Ukmar, M., & Rumiati RI. (2007) Neuropsychological evidence for a strategic control of multiple routes in imitation. *Brain, 130,* 1111-26.

Wheaton, L.A., Hallett, M. (2007). Ideomotor apraxia: a review. *Journal of Neurological Sciences, 15,* 260, 1-10.

Wing, A.M., Turton, A., & Fraser, C. (1986). Grasp size and accuracy of approach in reaching*. Journal of Motor Behaviour, 18,* 245-60.

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