

Optic Ataxia: A Gateway to the Human Visual Action System

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Abstract

Stroke patients with optic ataxia have an outstanding inability to perform spatially accurate movements to visual targets located in their peripheral visual field. Neuropsychological investigations of such patients contributed essentially to the two visual stream hypothesis which presumes dissociated action- and perception-related processing of visual information in the human brain. Here we review the anatomical foundations of optic ataxia that have been elucidated in detail quite recently and allow for the identification of brain areas that are necessary for the control of hand in space. We further evaluate the behavioral findings from crucial experimental paradigms in patients with optic ataxia, in comparison to results from patients with visual form agnosia, a disorder characterized by severely impaired visual perception without deficits of action control. On this background, the actual validity of the two visual streams model is discussed facing the (I) perceptual functions of the dorsal posterior parietal cortex, (II) sustained activation of these areas supporting the retention of spatial information, and (III) the anatomical dissociation between a foveal and an extrafoveal action system.

At the beginning of the 20th century Rudolf Bálint (1909) reported a neurological case demonstrating various deficits associated with the processing of visual stimuli. One of the most prominent characteristics of the patient was his striking inability to move his right hand to visual targets. While reaching for objects in his environment, he 'misreached' them; the hand deviated grossly from the target. Bálint (1909) ruled out several perceptual deficits and primary motor deficits that could have contributed to this inability. He left us with an impressively concise characterization of the patient's behavior and pathology:

"... we tested his visual fields using a perimeter; it was found that the fields were normal both for objects and for colors. [...] Stereoscopic vision was tested in the usual way by asking the patient to say which of two objects was closer to him, which one was higher, etc.; he made hardly any errors. [...] He recognized objects or images immediately. When describing the patient's general condition I mentioned that the muscular power of the upper and lower extremities was fully retained and that, for the most part, the patient executed elementary movements correctly. [...] A substantial abnormality became visible, however, in the movements of his right hand. He himself reported that while lighting a cigarette he often lit the middle and not the end. [...] Thus when asked to grasp a presented object with his right hand, he would miss it regularly and would find it only when his hand knocked against it. [...] all the movements performed deficiently with the right hand were executed perfectly or with very little error with the left hand." (Translation by Harvey, 1995).

Rudolf Bálint deduced from his thorough observations that the pathology was caused neither by a pure motor nor by a perceptual deficit alone, but rather represents a deficient sensorimotor coordination in the visual domain. Thus, he coined the term "optic ataxia" for the observed deficit. In the following decade Gordon M. Holmes (1918) and Holmes and Horrax (1919) reported seven patients suffering from a disability to localize objects or visual stimuli in their surroundings. In addition to the symptoms described by Rudolf Bálint, six out of seven patients demonstrated a striking inability to verbally report the absolute or relative position of certain objects, a severe deficit in spatial orientation, as well as characteristic eye movement deficits (Holmes, 1918; Holmes & Horrax, 1919). Incorporating the reports of Bálint and Holmes, the Bálint-Holmes syndrome today is defined to consist of four cardinal symptoms (cf. Karnath, 2003; Rafal, 1997): (I) optic ataxia, (II) disturbed organization of eye movements, (III) impaired spatial orientation, and (IV) simultanagnosia (the inability to perceive more than one object at a time (Farah, 1990)). However, as in Bálint's groundbreaking observation, several patients have been reported in the following decades whose misreaching behavior could be clearly

dissociated from pure perceptual impairments. Garcin and colleagues (1967) were the first submitting a convincing demonstration of isolated optic ataxia excluding perceptual, oculomotor, and visual attention deficits.

The most detailed report on a group of 10 unilateral patients suffering from isolated optic ataxia was published by Perenin & Vighetto (1988). Summarizing the previous findings they concluded that the report of "most [...] bilateral syndromes are more reminiscent of the 'visual disorientation' of Holmes" (p. 644). However, like Garcin et al. (1967) they pointed out, that their own patients did not reveal impairments of primary vision or spatial perception that could lead to the dramatic visuomotor impairments. Moreover, they emphasized the value of hand-specific visuomotor discoordination in bilateral cases as it was already observed by Rudolf Bálint (1909) and others (Guard et al., 1984; Hecaen & de Ajuriaguerra, 1954). Such hand-specific deficits cannot be attributed to a general visual impairment alone. The latter would equally affect both hands. Investigating a group of patients with unilateral lesions of the posterior parietal cortex (PPC), Perenin & Vighetto (1988) extended the existing knowledge by demonstrating a striking difference in the consequences of lesions to the left or right hemisphere. Patients with lesions of the right hemisphere showed significant misreaching to targets in the left visual field with both hands while movements to right-sided targets remained largely unaffected ("field effect"). Lesions of the left hemisphere led to an additional "hand effect". The authors observed that only movements with the contralesional right hand to targets in the contralesional visual hemifield deviated grossly from the target position. In contrast, movements with the ipsilesional left hand to targets on either side and with the right hand to left-sided targets were precise. This pattern of lateralization has been supported by recent single-case studies of patients with unilateral optic ataxia (Himmelbach & Karnath, 2005; Khan et al., 2005; Revol et al., 2003).

In search of the typical lesion location provoking this visuomotor disturbance, modern imaging techniques such as computerized tomography (CT) and magnetic resonance imaging (MRI) have been used. Single case studies of patients with optic ataxia have shown lesions typically including the superior parietal lobule (SPL) (Auerbach & Alexander, 1981; Buxbaum & Coslett, 1998; Ferro, 1984). However, lesions of individual patients rarely are restricted to a well specified anatomical site but include various regions related and not related to the disorder. Thus, only the anatomical evaluation of a larger group can reveal the crucial lesion site. Such an analysis first has been carried out by Perenin & Vighetto (1988). The anatomical evaluation of their 10 patients with unilateral left- or right-sided lesions revealed an overlap of lesion location that was symmetrical in both hemispheres. It included the intraparietal sulcus (IPS) and either the upper part of the inferior parietal lobule (IPL) or – more often – the medial or the ventral part of the SPL. Still, the paper-and-pencil techniques available at those times

held some uncertainties and, in addition, did not allow for a direct visual comparison between the pattern of lesion location in patients with vs. without optic ataxia. The necessity of such contrasts for valid anatomical conclusions in modern imaging studies was demonstrated by Rorden & Karnath (2004). A recent study therefore re-investigated the typical lesion location in a group of 16 unilateral stroke patients with optic ataxia, collected over a time period of 15 years, and compared them with 36 stroke patients without that disorder using digitized brain templates and standardized rendering algorithms for 3D visualization of the subtraction analysis (Karnath & Perenin, 2005). The authors found no evidence for the previous assumption that the disruption of visually guided reaching in humans is associated with a lesion centering on the SPL on the convexity. In both left and right hemispheres, they rather found optic ataxia associated with a lesion overlap that affected the lateral cortical convexity at the parieto-occipital junction (POJ), i.e. the junction between the IPL and superior occipital cortex in both hemispheres including – in the left hemisphere even more posteriorly – also the junction between the superior occipital cortex and the SPL (Fig. 1). Via the underlying parietal white matter the lesion overlap extended in both hemispheres to the medial cortical aspect where it affected the precuneus close to the parieto-occipital sulcus (Fig. 1).

----- Figure 1 about here -----

Converging evidence is reported from an intriguing event-related fMRI study conducted with healthy subjects (Prado et al., 2005). The authors measured the brain activity when participants reached either towards a target represented on the fovea or towards an extrafoveal target. The analysis of the correlated BOLD effects revealed increased signals bilaterally at the POJ depending on the retinal position of the visible target (Fig. 2). Their results fit surprisingly well with the above mentioned finding of a reaching deficit for targets in the peripheral visual field typically following a damage to precisely this region (Karnath & Perenin, 2005). A third piece of evidence has been presented by van Donkelaar and Adams (2005) who applied TMS at the PPC while the subjects were pointing to peripheral targets. Without any interference, normal subjects tend to overshoot eccentric targets in their peripheral visual field (Bock, 1986; Bock, 1993). The application of interfering TMS pulses led to a bias of pointing movements of the contralateral arm towards the position of visual fixation (van Donkelaar & Adams, 2005). This effect obviously mimics the pathological movement bias in patients with optic ataxia (Carey, Coleman, & Della, 1997; Jackson, Newport, Mort, & Husain, 2005; Milner, Dijkerman, McIntosh, Rossetti, & Pisella, 2003; Milner, Paulignan, Dijkerman, Michel, & Jeannerod, 1999; Ratcliff & Davies-Jones, 1972). Altogether, these investigations – using three different methods of functional mapping (stroke lesions, fMRI, TMS) – support the

assumption of a circumscribed region in the posterior parieto-occipital cortex specifically dedicated to the visual control of hand movements to extrafoveal targets, while movements to foveated targets seem to recruit a (cortical) network not including this area.

----- Figure 2 about here -----

The Two Visual Stream Hypothesis

The numerous reports about patients with visuomotor disorders have contributed substantially to the currently dominant idea of a dichotomous organization of the visual system. Based on a body of already existing evidence from behavioral and anatomical studies in animals and on their own experiments in monkeys, Ungerleider and Mishkin (1982) suggested the existence of a ventral occipito-temporal "what" pathway and of a dorsal occipito-parietal "where" pathway. They decomposed the visual system into a spatial processing system on the one hand and an identification system on the other hand. However, the aforementioned observations of neurological patients suffering from optic ataxia falsified their conclusions. These observations represent behavioral dissociations *within* the supposed "where" processing and could not be fitted easily to the original suggestions of Ungerleider and Mishkin (1982). Therefore, Milner and Goodale (1995) modified the model. Referring to the same anatomical structures, they suggested a dissociation between action- and perception-related visual processing. Such a differentiation seemingly fits to the observations in patients suffering from optic ataxia but also to the behavior of patients with damage to the ventral occipito-temporal pathway. As we said before, some of these patients demonstrated both motor as well as perceptual deficits with respect to spatial characteristics (Holmes, 1918; Holmes & Horrax, 1919). Such a general disorder of spatial information processing would be in agreement with the suggested distinction proposed by Ungerleider and Mishkin (1982). But decisively, several patients revealed exclusive spatial disorders of only goal-directed movements while their perceptual estimation of absolute and relative spatial distances was accurate (Garcin, Rondot, & de Recondo, 1967; Perenin & Vighetto, 1988). Furthermore, these findings of action-specific impairments in patients with uni- or bilateral lesions of the POJ were complemented by patients with the reverse dissociation of disorders, namely intact spatial action processing with concomitant severe impairments of spatial perception when lesions were located more ventrally in the occipito-temporal cortex. Damage to occipito-temporal areas of the human brain typically leads to apperceptive visual agnosia (e.g.: Farah, 1990). A well known patient suffering from such disorder, D.F., demonstrated well preserved reaching and grasping behavior

while she revealed a striking disability to report the identity, size, and/or orientation of different objects (Goodale, Milner, Jakobson, & Carey, 1991; Milner et al., 1991). For instance, she was able to smoothly move her hand through an oblong slot. In contrast, the adjustment of a second slot with respect to the first (a perceptual task) was imprecise. The opposite pattern is observed in patients with optic ataxia. While the same motor task cannot be executed adequately, they can easily match different line orientations (Perenin & Vighetto, 1988).

The very same dissociation between both groups of patients - optic ataxia vs. visual form agnosia patients - holds for grasping movements. Whereas a patient with optic ataxia could easily estimate the size of different objects, her grip size was just weakly correlated with the objects' size during actual grasping movements (Jeannerod, Decety, & Michel, 1994). The contrary behavior was found in a patient with visual form agnosia. She revealed a weak correlation between the actual target size and her estimation of it, while she adjusted her grip size during actual grasping movements adequately to the different objects (Goodale et al., 1991). Just recently, it has been shown that the spared visuomotor abilities of this patient are mediated (amongst other structures) by parietal areas, i.e. by areas believed to be part of the dorsal stream (Culham et al., 2003; James, Culham, Humphrey, Milner, & Goodale, 2003). A small number of further patients has subsequently been reported with varying degrees of behavioral impairments and dissociations (e.g.: Ferreira, Ceccaldi, Giusiano, & Poncet, 1998; Hildebrandt, Schutze, Ebke, & Spang, 2004; Le et al., 2002; Marotta, Behrmann, & Goodale, 1997).

Grasping Visual Illusions: Complementary Evidence for Two Visual Streams?

Further evidence for a dissociated processing of visual information derives from healthy human subjects. Several studies revealed a significant impact of visual illusions on perceptual estimates of size and/or location while grasping and pointing movements were unaffected (Aglioti, Desouza, & Goodale, 1995; Bridgeman, Gemmer, Forsman, & Huemer, 2000; Danckert, Sharif, Haffenden, Schiff, & Goodale, 2002; Haffenden, Schiff, & Goodale, 2001; Meegan et al., 2004). However, despite numerous findings in favor of such a dissociation, subsequent studies revealed a more inconsistent view. Some authors did not find a comparable dissociation or found at least a somewhat smaller but nevertheless significant effect on actions (Daprati & Gentilucci, 1997; Elliott & Lee, 1995; Franz, 2003; Franz, Bülthoff, & Fahle, 2003; Franz, Gegenfurtner, Bulthoff, & Fahle, 2000; Gentilucci, Chieffi, Deprati, Saetti, & Toni, 1996; Pavani, Boscagli, Benvenuti, Rabuffetti, & Farne, 1999). Interestingly, the measure typically used to demonstrate effects on grasping movements in these studies has been the maximum grip aperture

(MGA). Undoubtedly, the MGA appears to be a straightforward measure of grasping performance. However, in search of potential effects of illusions (i.e. perceptual context cues) on reaching and grasping, other parameters of grasping might be taken into account such as velocity and force. Some authors indeed revealed effects of visual illusions on these kinematic parameters (Brenner & Smeets, 1996; Jackson & Shaw, 2000; van Donkelaar, 1999). Actually, the discussion is quite controversial. Evidence in favor of as well as against an influence of visual illusions on grasping has been reported (for review: Bruno, 2001; Carey, 2001; Franz, 2001; Goodale & Westwood, 2004; Milner & Dyde, 2003; Plodowski & Jackson, 2001).

One of the most valuable contributions to the debate proposes the use of different spatial attributes of a certain object during estimation and grasping tasks. Following this line of evidence, estimation relies more on size and extend information, whereas grasping is guided by discrete target positions for each finger at the respective object. It seems as if visual illusions typically exert a different influence on these different spatial attributes. Thus, the observed behavioral dissociations would not represent a divergence between perception and action but between different spatial properties used for the execution of the respective tasks (Smeets, Brenner, de Grave, & Cuijpers, 2002). Milner and Dyde (2003) on the other hand have suggested a differentiation between illusions which affect different levels of visual processing. They found a differential impact of the rod-and-frame illusion and the simultaneous-tilt illusions (Dyde & Milner, 2002). Whereas the first is assumed to be based on contextual information, the latter might be due to local interactions within the visual field mediated by inhibitory connections in V1 (Milner & Dyde, 2003). Just recently, the work of Bruce Bridgeman and Paul Dassonville added further controversial evidence to this field of research. They explored the impact of the Roelofs effect on goal-directed hand movements and perceptual estimations of stimulus positions (Bridgeman et al., 2000; Bridgeman, Peery, & Anand, 1997; Dassonville & Bala, 2004; Dassonville, Bridgeman, Kaur, Thiem, & Sampanes, 2004). The observed dissociation of the Roelofs effect on pointing and estimation has previously been assumed to be in line with the two visual streams theory (Bridgeman et al., 1997). But in their most recent work both authors interpret their findings in a very different way. The dissociation between action and perception found for this illusory change of target position might be indirectly mediated by an underlying common process involved in action control and perception. From their latest results they conclude that a shift of the subjective body midline within one and the same egocentric spatial frame induced by the Roelofs effect exerts a different impact on the accuracy of perceptual estimations and immediate goal-directed movements (Dassonville & Bala, 2004; Dassonville et al., 2004). However, while their data suggest a simple common mechanisms to explain different outcomes for motor control and perception, it does not rule out dual visual processing per se. If we assume, in agreement with Milner and Goodale (1995), that the proposed

midline shift is mediated by and affecting only the ventral (cognitive or perceptual) visual stream, the results of the Dassonville and Bridgeman groups fit nicely to the two visual streams theory. Furthermore, up to now it remains unclear whether their results can be generalized to other visual illusions as well.

Interestingly, it is also unclear how the performance of patients suffering from optic ataxia or visual form agnosia is affected by visual illusions. As far as we know, illusions such as e.g. the Müller-Lyer or the Ebbinghaus illusion have not been investigated in patients with these disorders. A recent study reported that patients with visual agnosia were not prone to a size-weight illusion (larger objects are felt to be lighter in comparison to smaller objects of the same physical weight). When executing the same task without visual information, i.e. when retrieving the size of the objects from kinesthetic input only, the patients showed the same illusion effect than controls (Dijkerman, Lê, Démonet, & Milner, 2004). However, although this experiment revealed a clear dissociation between visual and kinesthetic processing, it is unclear whether these patients would incorporate the illusory visual information into motor behavior or not.

Delayed Movements: Timing Makes the Difference

Several studies disclosed a behavioral dissociation between movements to visible targets and movements to remembered positions in neurological patients. Goodale and co-workers (1994) observed that a patient with visual agnosia was unable to adjust grip aperture properly when the target object was removed before movement onset. In striking contrast, patients with optic ataxia improve their performance considerably after a delay of a few seconds following the presentation of a target while their immediate action to visible targets is severely distorted (Himmelbach & Karnath, 2005; Milner et al., 2001; Milner et al., 2003; Milner et al., 1999; Revol et al., 2003). Thus, it has been assumed that the dorsal visual pathway - which is intact in patients with visual form agnosia - is dedicated to a fast processing of visual information. On the other hand, an intact ventral pathway - found in patients with optic ataxia - seems to be devoted to a longer lasting processing of visual information and its output does not seem to be immediately available for movement control. These conclusions are supported by the increased effects of visual illusions on actions after interfering time delays between stimulus presentation and movement onset in healthy subjects (Bridgeman et al., 2000; Bridgeman et al., 1997; Elliott & Lee, 1995; Gentilucci, Benuzzi, Bertolani, & Gangitano, 2001; Gentilucci et al., 1996; Hu & Goodale, 2000; Meegan et al., 2004; Rival, Olivier, Ceyte, & Ferrel, 2003). It has been questioned whether this increase relies on the elapsed time after the target presentation or simply on the disappearance of the visual stimulus before the execution of a movement. The latter presumption has been favored

by Westwood and Goodale (2003) who reported significant illusory effect on the peak grip aperture if the target was occluded right after the start signal for movement onset. They found no additional effects of a prolonged delay between the occlusion of the objects and the start signal. This finding led the authors to assume a sudden switch between dorsal and ventral control of visuomotor performance. They concluded that the ventral visual system provides the decisive spatial information which is necessary to control hand movements as soon as no immediate visual information about target size and position is available (Goodale, Westwood, & Milner, 2004).

However, other behavioral experiments in healthy subjects yielded different results. The impact of a visual illusion on pointing accuracy increased significantly with longer time delays (Bridgeman et al., 2000; Meegan et al., 2004). So, even if there would be a dramatic shift between "two distinct modes of control" (Goodale et al., 2004) - in anatomical terms: between the dorsal and the ventral pathway - there still seems to be an additional progressive change depending on the time delay between target presentation and movement onset. Such progressive improvement of pointing accuracy has also been found in two patients with optic ataxia (Himmelbach & Karnath, 2005). Both patients demonstrated a gradual decrease of absolute pointing errors over a range of delay times from 0 to 10 seconds preceding movement onset (Fig. 3). In agreement with the dependence of the effect of visual illusions on the interfering time delay in healthy subjects (Bridgeman et al., 2000; Meegan et al., 2004), this gradual decrease in optic ataxia patients argues against a sudden shift between anatomically separated systems. Rather, it points to either a gradually decreasing dorsal processing of visual information in gradually delayed movements or to a gradually increasing contribution from alternative systems (which might be, e.g., the occipito-temporal stream). This concept of a gradual change - instead of a sudden switch - in the functional anatomy of movement-related information processing, is corroborated by the observation of a reverse behavioral pattern in healthy subjects, i.e. a gradual decrease of movement accuracy depending on the length of a pre-response delay (Bradshaw & Watt, 2002).

----- Figure 3 about here -----

Neuroimaging studies in healthy human subjects has suggested that areas of the dorsal posterior parietal cortex are critically involved in delayed movement tasks (Connolly, Andersen, & Goodale, 2003; Culham, 2004; Lacquaniti et al., 1997) and in visuo-spatial memory-tasks (for review: Owen, 2004). Most interestingly, sustained activity of the medial superior parietal cortex has been demonstrated during a delay of 9 seconds between target presentation and movement execution using an event-related

fMRI paradigm (Connolly et al., 2003). The authors convincingly distinguished between non-spatial preparation of a movement - induced by a cue lacking spatial information - and the retention of previously provided spatial information. Thus, it seems as if the prolonged superior parietal activation represents either the retention of a specific target position or hand trajectory. These findings clearly endorse a critical involvement of the dorsal stream in the maintenance of spatial information which, in some cases, is dedicated to the execution of goal-directed movements later on. Correspondingly, single-cell recordings in monkeys revealed maintenance-related activity of neurons in dorsal posterior parietal areas in visuo-spatial memory tasks employing eye movements (Chafee & Goldman-Rakic, 1998; Gnadt & Andersen, 1988; Snyder, Batista, & Andersen, 1997) and, more specifically, in delayed hand movement tasks (Murata, Gallese, Kaseda, & Sakata, 1996; Quintana & Fuster, 1999; Snyder et al., 1997). Quite recently, Tsutsui and co-workers (2003) demonstrated successfully sustained activity of IPS neurons correlated with the retention of surface orientation over a period of 2.3 seconds. Altogether, these data suggest a possible involvement of dorsal stream areas in the retention of spatial information in general and of visuospatial information dedicated to the guidance of hand movements in particular.

Such correlative data gathered in neuroimaging investigations of healthy humans and single cell recordings in monkeys are corroborated by brain interference methods. Inducing a transient inactivation of the posterior parietal cortex (PPC) in rhesus monkeys interfered with the retention of spatial information - the required response direction - only. In contrast, inactivation of the prefrontal cortex in the same experiment interfered with delayed performance after the presentation of spatial and non-spatial cues (Quintana & Fuster, 1993). A recent transcranial magnetic stimulation (TMS) study in healthy human subjects using a memory guided pointing task complements these findings (Smyrnis, Theleritis, Evdokimidis, Muri, & Karandreas, 2003). The application of a single TMS pulse over the PPC as early as 300 ms after target presentation had a significant effect on the accuracy of hand movements executed 3000 ms after target offset. Similar findings for memory guided saccades further support the assumption of a crucial involvement of the SPL and IPS in memory guided actions (Muri et al., 2000; Muri, Vermersch, Rivaud, Gaymard, & Pierrot-Deseilligny, 1996; Oyachi & Ohtsuka, 1995). Altogether, these findings indicate a crucial involvement of the superior PPC in the early spatial encoding of either a target position or a movement trajectory which is required to be executed later on.

Interacting Streams

Although Milner and Goodale (1995) already explicitly stated the necessity of functional interactions between the two visual streams, the vast majority of subsequent contributions to the field emphasized the apparent distinction between different ways of visual processing. In fact, the experiments on delayed movement execution reviewed in the preceding chapter support a close interaction of processing systems instead of functionally distinct pathways. A further argument against separate processing systems with respect to different time constants of information processing - i.e. immediate vs. delayed onset of movements - is provided by the recent report of a patient with visual agnosia (S.B.) showing accurate delayed grasping movements (Dijkerman et al., 2004). Although there are substantial differences between this and the previously examined case D.F., this observation obviously questions those conclusions which essentially were based on the behavior of only one patient with visual agnosia (patient D.F.; Milner & Goodale, 1995).

The handling of everyday objects instead of geometric, meaningless items by patients suffering from visual form agnosia and patients with optic ataxia provides us with further evidence for the (necessary) interaction between object recognition and action control. The well known patient D.F. seems to be unable to grasp everyday objects appropriately according to their typical use (Carey, Harvey, & Milner, 1996). While she grasped these objects skilfully to pick them up, she did not appear to take account of the way these objects were supposed to be used afterwards as healthy subjects would do (e.g. grasping a hammer at its head instead of grasping it at its handle). Moreover, in this series of experiments, a general difficulty in grasping complex objects was observed in D.F. Grasping rectangular objects as well as irregularly shaped objects did not pose a problem to her as long as they provided a clear main axis which she could aim for. But if the objects lacked such an outstanding principal axis, she showed a considerable number of trials with inadequate grip posture (Carey et al., 1996). These specific impairments of grasping everyday objects according to their specific use and of grasping irregular objects with multiple spatial axes might be due to a general lack of allocentric analysis or encoding of complex object properties for appropriate visuomotor guidance (Dijkerman, Milner, & Carey, 1998; McIntosh, Dijkerman, Mon-Williams, & Milner, 2004). Interestingly, the reverse behavioral dissociation was observed in a patient with optic ataxia. While being unable to adjust her grip size to cylinders of various diameters, her behavior improved considerably if she was asked to grasp familiar cylinder-shaped objects (Jeannerod et al., 1994). Obviously, tasks which require a high-level object recognition and/or an allocentric encoding of object features pose a problem to a subject with a damaged ventral system while it seems to open alternative routes of information processing for a patient with a damaged dorsal system. However, such conclusions

should be drawn with great caution since these results have been shown in only one patient with visual form agnosia (patient D.F.; Carey et al., 1996; Dijkerman et al., 1998; McIntosh et al., 2004) and in only one patient with optic ataxia patient (patient A.T.; Jeannerod et al., 1994).

The need for an interaction between the dissociated ways of processing is apparent and, as stated before, has been already considered in the original concept of the two visual streams. It has been suggested that the ventral stream acts as an identifier which 'flags' certain goals or objects for upcoming actions (Goodale & Milner, 2004; Milner & Goodale, 1995). The incorporation of such information could be performed via the inferior parietal lobule and superior temporal areas that receive projections from the occipito-parietal as well as from the occipito-temporal pathways. Alternatively, back-projections to early visual areas could label certain objects or features which then form the basis for information processing leading to the execution of appropriate actions. Such back-propagation has been shown in a combined electrophysiological and functional magnetic resonance study of visual spatial attention (Noesselt et al., 2002). As Milner and Goodale (1995) suggested, mechanisms of selective attention might be the mediating process between anatomically dissociated streams of processing.

The ill-defined term 'flagging' might be synonymous with the known encoding of the behavioral relevance or saliency of objects and features (Assad, 2003). In a recently reported experiment Toth and Assad (2002) demonstrated the unexpected coding of color by neurons in the lateral intraparietal area (LIP) following associative training. Two identical saccade targets on the right and left side were presented simultaneously. The investigated monkeys had to execute a saccade either to the left or to the right target based on information provided by a visual cue which had been presented before the saccade targets. The direction of the required saccade was either indicated by the position or by the color of the cue. During a delay following cue presentation neurons within LIP revealed changes of the spike rate in correlation with the presented color. Remarkably, they did so only if color was the informative dimension during the respective trial, i.e. such encoding of color was only observed if this attribute of the cue was of behavioral relevance. This neuronal behavior fits to the requirements of "a local selective transfer of information between brain areas" (Assad, 2003) which seems to be close to the 'flagging' concept of Milner and Goodale (1995).

Perspectives

The existing literature on visuomotor control processes seems to clearly indicate that immediate, goal-directed visuomotor responses to point-like targets or towards objects which provide an unambiguous request for action (e.g. catching a falling cup)

essentially rely on the so-called dorsal stream of visual processing. This kind of action is largely independent of detailed analyses of non-spatial aspects of the target object. However, although typically taken together as "the dorsal stream", there is nothing like a monolithic action system comprising the numerous functionally different areas of the PPC. For example, most of the visuomotor studies in patients with optic ataxia dealt with deficits of movements to peripheral visual targets only. An anatomical differentiation between a foveal and an extrafoveal action system has been explicitly considered quite recently (Milner et al., 2003). Most recent experimental findings suggest that this behavioral distinction of visuomotor processing is indeed reflected at the cortical level (Karnath & Perenin, 2005; Prado et al., 2005; van Donkelaar & Adams, 2005). Moreover, the dorsal parietal areas apparently do not simply represent exclusively an "action system". The clear dissociation between a "where" and a "what" stream as suggested by Ungerleider and Mishkin (1982) was falsified after the demonstration of the remarkable behavioral dissociations between action and perception in patients with optic ataxia and visual form agnosia. However, numerous reports starting with Holmes and Horrax (Holmes, 1918; Holmes & Horrax, 1919) up to recent investigations such as the one by Phan and colleagues (2000) demonstrated perceptual deficits in patients with exclusive posterior parietal brain damage. Further, some of the areas in the dorsal PPC involved in the perception of spatial relations, also are involved in memorizing spatial information.

We already emphasized the importance of functional interactions between the dorsal and ventral streams. Largely in agreement with the Milner and Goodale (1995) model, it is possible that, beyond immediate action control, the abovementioned PPC functions in spatial cognition are not mediated by the dorsal stream per se, but by systems that depend on ventral stream inputs. This hypothesis remains to be substantiated by according experiments in healthy humans and brain damaged patients. Alternatively, it could become necessary to revise the "perception vs. action model" in the version outlined by Milner and Goodale (1995) by incorporating (I) perceptual functions of the dorsal PPC, (II) sustained activation of these areas supporting the retention of spatial information, and (III) the anatomical dissociation between a foveal and an extrafoveal action system.

Further, we should be aware that much of our current knowledge about the anatomo-functional relationship in visuomotor control processes derives from few patients with (often non-acute) brain damage. Beyond the legitimate enthusiasm to observe and conclude from the behavior of stroke patients suffering from specific visuomotor disturbances after stroke, we must keep in mind that not all of this behavior necessarily reflects a pure consequence of a disturbed brain system. The reason is that many of the patients studied in the experiments reviewed above already suffered from chronic impairments at the time of the respective examination. Thus, (partly) conscious

strategies might have been adopted by these patients to execute certain perceptual and visuomotor tasks. For example, Goodale and Milner (2004) anecdotally reported such strategies adopted by their patient D.F. to accomplish perceptual tasks. During a line copying task she apparently used a motor imagery strategy, tracing the line in her mind only (Dijkerman & Milner, 1997). Likewise, optic ataxia patients with chronic brain lesions might make use of spared abilities to guide their movements under conditions which provide them with enough time. Milner and co-workers (2001) revealed a significant improvement of such a chronic patient's performance if the object to be grasped was shown to her in advance. Under this 'preview' condition, her movements seemed to rely partly on memorized spatial information instead of the actually available sight of the object. In contrast, healthy subjects simply ignored previewed object information (Milner et al., 2001). Thus, it is evident that some of these strategies have been deliberately adopted by the patients while other strategies might unfold unconsciously. These observations clearly show that contextual information and high level representations of action (including explicit knowledge of preserved abilities) are involved in action control.

Marc Jeannerod and Pierre Jacob recently broadened our view on the dualism of visual action-control and of visual perception emphasizing the involvement of such high level representations of action (Jeannerod & Jacob, 2005). They pointed out that quite simple visuomotor transformations involved in reaching and grasping movements to point-like targets or geometric objects require no or only little conceptual information concerning the goals, the environmental conditions, and the consequences of these actions. However, a comprehensive theory of action control needs to incorporate such high-level information into visuomotor representations as it crucially affects the actually required kinematics of an intended or demanded action. Future studies in patients with optic ataxia should focus on such contextual influence. Moreover, past contributions to the field focused almost exclusively on the antagonism between the behavioral consequences of optic ataxia and visual form agnosia. Investigating these patients' reactions to manipulations of contextual information and comparing them with the behavioral changes observed in patients with other higher order motor deficits (apraxia) and recognition impairments (associative and apperceptive agnosia) might reveal the anatomical substrates which are necessary to incorporate semantic information in action control. We think that uncovering these integration processes would constitute the next step on our way of understanding action control in a natural environment.

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Acknowledgements

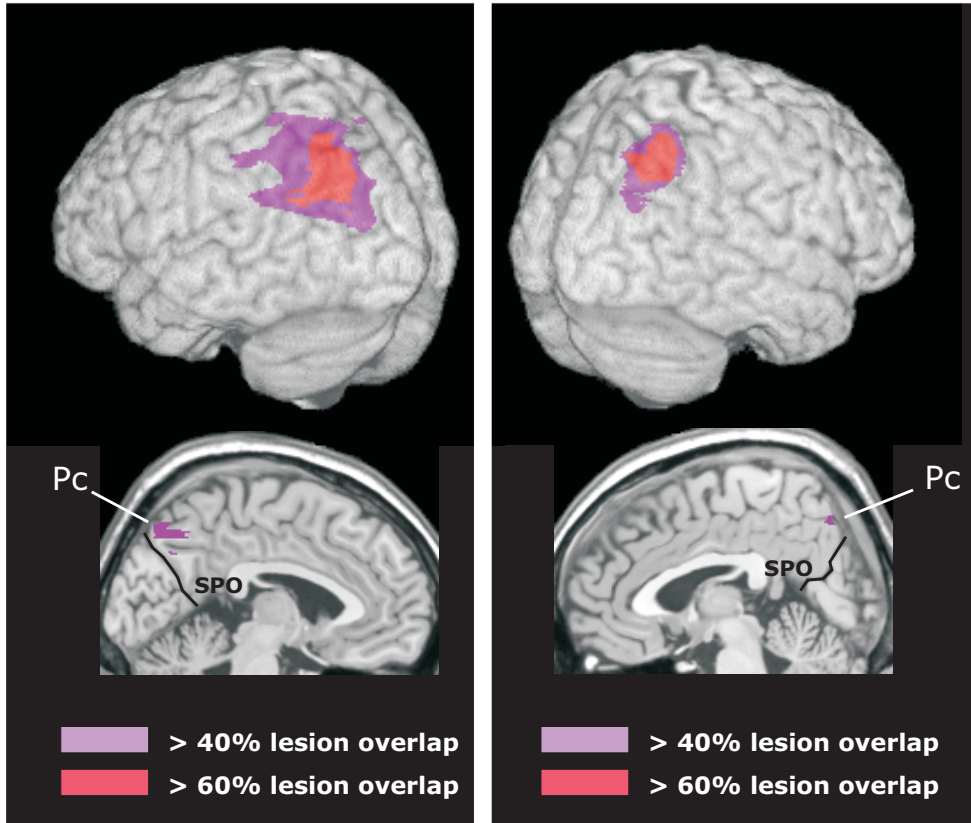
The work was supported by a grant from the Deutsche Forschungsgemeinschaft (SFB 550-A4). We are grateful to A. David Milner for stimulating discussion of a previous version of the manuscript.

Figure Captions

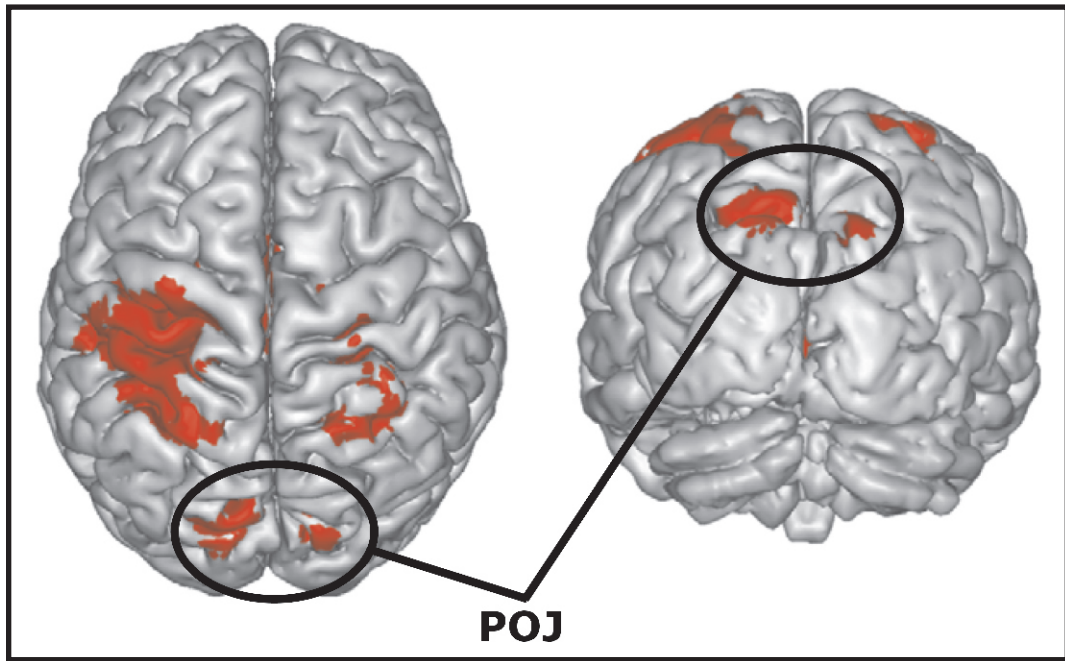
Fig. 1: Lateral and medial surface views of the center of lesion overlap in patients with unilateral optic ataxia. The percentage of lesion overlap in these patients has been calculated after the subtraction of control subjects with unilateral lesions but without optic ataxia. POS: parieto-occipital sulcus; Pc: Precuneus. (adapted from Karnath & Perenin, 2005).

Fig. 2: Significant fMRI activations at the bilateral parieto-occipital junction (POJ) due to the execution of pointing movements to targets in the visual periphery. (adapted from Prado et al., 2005 p.852 with permission from Elsevier).

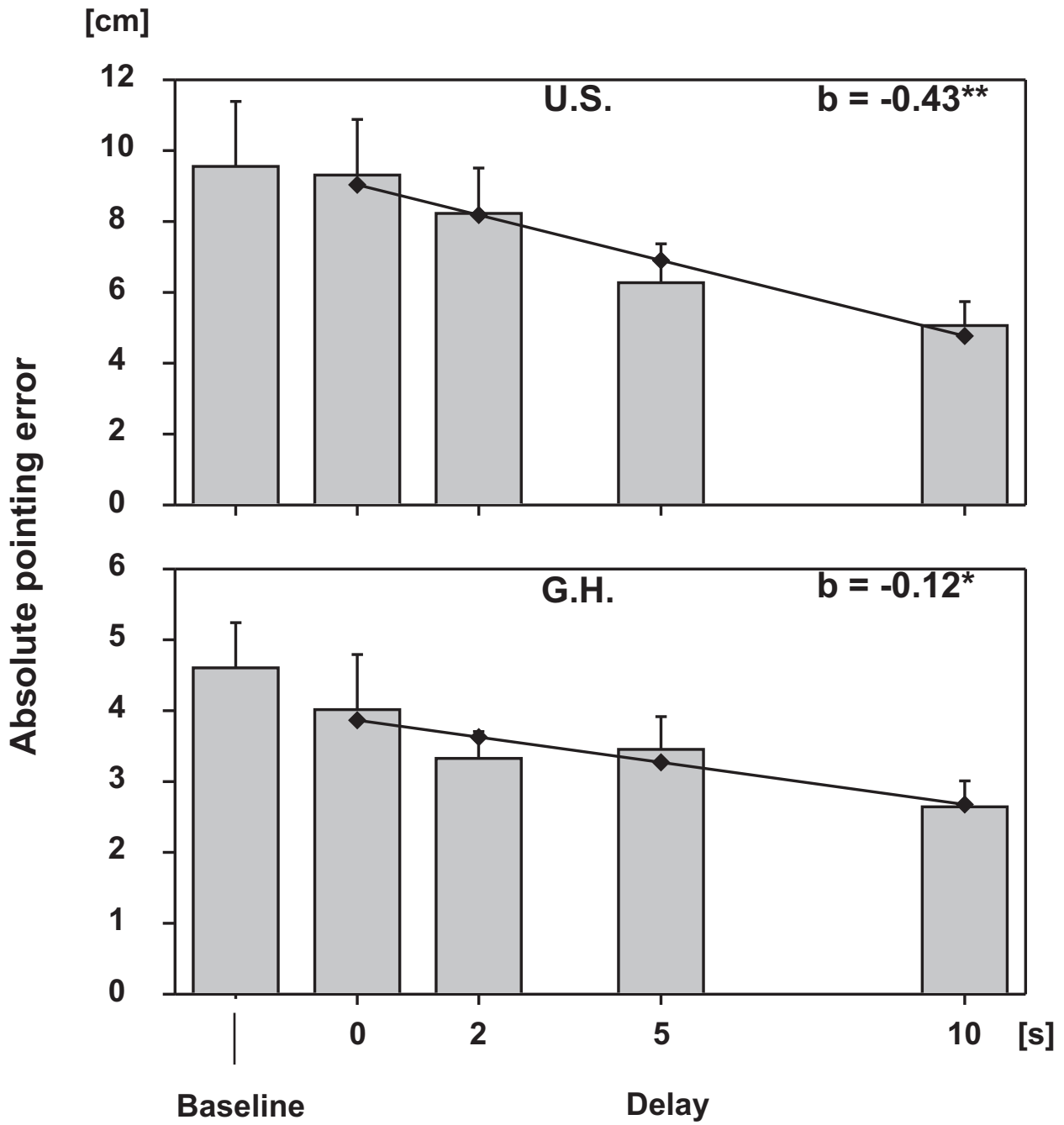
Fig. 3: Absolute pointing errors of gradually delayed movements in two patients with optic ataxia. Movements have been performed either to a visible target (baseline) or to remembered target position after a gradually increasing delay of 0 to 10 seconds. Linear regressions over delay time have been calculated revealing negative regression coefficients (b) significantly smaller than zero (* $p < 0.05$ one-tailed, ** $p < 0.01$ one-tailed). Results show that the pointing error of optic ataxia patients decreases with an increase of the period between target offset and movement onset. (adapted from Himmelbach & Karnath, 2005).



Himmelbach & Karnath Fig. 1



Himmelbach & Karnath Fig. 2



Himmelbach & Karnath Fig. 3