

## Mediate Responses as Direct Evidence for Intention: Neuropsychology of Not-To, Not-Now, and Not-There Tasks

Yves Rossetti and Laure Pisella

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*Les mouvements volontaires sont donc des réactions aussi nécessaires que les mouvements réflexes simples; seulement ces derniers sont les réactions immédiates des impressions périphériques directes, les autres sont les réactions médiates des sensations centrales indirectes, c'est à dire des images ou idées parmi lesquelles doivent nécessairement se trouver celles du mouvement même. . . .*

—Alexander Herzen, 1874, pp. 96–97

### 3.1 Introduction

Intention is a concept frequently referred to in everyday neuroscience. Because consciousness studies are mostly concerned with “consciousness of” (awareness), the aspect of intention that is usually studied is “intention to” (intentional behavior). Intention is thus most often contrasted with reflexive and automatic activities, that is, negatively defined. A well-known formulation of the dissociation between consciousness (admittedly a prerequisite for intention; see Revonsuo and Rossetti, 2000) and automatism has been provided by Penfield (1975, p. 39) in his analysis of complex behavior observed during epileptic seizures:

In an attack of automatism the patient becomes suddenly unconscious, but, since other mechanisms in the brain continue to function, he changes into an automaton. He may wander about, confused and aimless. Or he may continue to carry out whatever purpose his mind was in the act of handing on to his automatic sensory-motor mechanism when the highest brain mechanism went out of action. Or he follows a stereotyped, habitual pattern of behavior. In every case, however, the automaton can make few, if any, decisions for which there has been no precedent.

Although Penfield’s “confused” may refer to an altered conscious state and his “aimless,” “automatic,” and “stereotyped” to altered intentional control of action, he is clearly contrasting his automaton with intentional behavior, at least implicitly. Penfield (1975, p. 47) goes on to define what

the automaton cannot do: "The human automaton, which replaces the man when the highest brain mechanism is inactivated, is a thing without the capacity to make completely new decisions. . . . The automaton is incapable of thrilling to the beauty of a sunset or of experiencing contentment, happiness, love, compassion. These like all awarenesses, are functions of the mind." Penfield's automaton exhibits the "inability to make new decisions," which, among other features, is described as a mind property and implicitly contrasted with the automatic properties of brain matter. Without naming intention, Penfield (1975, p. 47) also proposes a positive definition of the automaton, which can in turn serve as a negative definition of intention: "The automaton is a thing that makes use of the reflexes and the skills, inborn and acquired, that are housed in the computer. . . . This automatic coordinator . . . is ever active within each of us. . . ."

Thus automatic behavior can be opposed to and dissociated from both consciousness (see Revonsuo et al., 2000) and intention (table 3.1). Revonsuo and colleagues (2000, p. 335), distinguish between "weak zombiehood," where a person is "not conscious but can only carry out routine action programs" and "strong zombiehood," where a person "can carry out nonroutine tasks involving new decisions and the processing of the meaning of the task and surrounding objects." Although these two types of zombiehood both refer to states where consciousness would be absent, it is questionable whether strong zombiehood could imply intention. That complex behavior may be expressed in the absence of consciousness does not imply that such behavior is intentional. Indeed, as their review of the literature shows, Revonsuo and colleagues (2000) conclude that, although weak zombiehood can be observed during epileptic seizures or sleep-related motor disorders, there is no evidence for strong zombiehood, nor is there evidence that a proper judgment could be exercised or new decisions be made during either state.

If we admit that nonautomatic behavior is by nature intentional, then intentional or voluntary actions should include most of our daily activities, such as grasping objects, moving around, or driving a car. There is no doubt that some of these activities are at least initiated intentionally and occasionally performed under voluntary control. The main purpose of intention, however, is to deal with the higher-order organization of our lives, such as long-term planning or strategies. On the other hand, the vast majority of the processes participating in simple actions are unconscious and nonintentional. When you grasp a single object in front of you, a cup, say, the

**Table 3.1**  
Main characteristics of automatisms

Automatisms	Behavior initiation	On-line control	Sensory awareness	Self-consciousness
Visuomotor reactions	No	Elementary	Dissociated or delayed	Normal
Habits	No (only subsequent)	Elementary and sequence control	Unattended	Normal
Environmental dependency syndrome	Yes	Elementary and sequence control	Full	Normal?
Sleep related motor disorders and epileptic seizures	Yes	?	None or misinterpreted	Altered
Psychoses	Yes	Distorted	Distorted	Altered

*Note:* "On-line control" may range from elementary on-line control (e.g., parietal automatic pilot; Pisella et al., 2000) to complex sequences (e.g., following an itinerary, walking to an object and throwing it, and social interaction). "Sensory awareness" refers to the ability of the subject to process relevant sensory information during the automatic behavior. "Self-consciousness" refers to reflexive consciousness. "Environmental dependency syndrome" refers to what appears to be the most complex case of automatism, where behavior can be initiated and controlled on the basis of on-line sensory inputs without obvious self-consciousness alteration.

only intentional aspect here is to trigger the action. Existence of an intention becomes more obvious if you decide to grasp the cup in an unusual way, for example, if you guide your hand throughout a complicated trajectory, if you use two middle fingers to form the grip, or grasp the cup upside down. Alternatively, it may be expressed by the selection processes that precedes the action when several potential goals are present. Along this line, you may wonder how intention might be approached under experimental laboratory conditions.

Can we seriously refer to intention in overtrained animals that perform a simple task such as looking and pointing at a stimulus when this task has been practiced hundreds or thousands of times daily over months and years? Are not these experimental conditions closer to pavlovian conditioning than to anything related to intention at all? Is the animal's intention to

perform the task or to get a reward? Even in the more complex case of problem solving, because the number of possible solutions is usually extremely limited with regard to the huge number of practice and reinforcement trials performed by the animal, the task of the animal may consist of recognizing a situation and a solution more through automated association processes than through intentional strategic processes. As colleagues working with monkeys often say: "This monkey is too clever to comply with the instructions and perform the task." Indeed, under such experimental conditions, the best manifestation of the animal's intention would be to *stop* performing the task. Such a conclusion is consistent with the fact that intention is most often incorrectly referred to as "preparatory activity" before an action is initiated (e.g., Boussaoud, 2001; Synder et al., 1997), whereas, in point of fact, a preparatory activity takes place even when an action is produced reflexively. As pointed out by Toni and colleagues (2001), the brain activity recorded during the delay introduced between stimulus and response does not necessarily correspond to intention-related activity.

In human studies as well, most experimental conditions designed to explore voluntary actions rely on reactions to a stimulus as a clue to intention. These reactions are most often overlearned in everyday life (e.g., pointing or grasping, key pressing) or are investigated after a learning session in the case of more complex tasks. Therefore the intention of the subject may be restricted to the will to perform the task or to comply with the instructions. Reaction time tasks by definition test the subject's ability to *react* to a stimulus rather than to intentionally respond to it. Clinical examination may provide a less constrained way to explore intentional aspects of behavior. "Intentional" is often used to describe the tremor observed during cerebellar ataxia, for example. But here it refers only to the fact that the tremor appears during the performance of an action rather than at rest, as is the case in Parkinson's disease. The best manifestation of a deficit of intention *per se* is the inability to comply with simple instructions. Such deficits are observed chiefly in patients with damage in the frontal lobes. Presented with a comb or a toothbrush and asked to ignore it, or even specifically instructed not to grasp it, a typical frontal patient will grasp and use it immediately (see Lhermitte, 1983). In the case of "anarchic hand," observed following frontocallosal lesion (Della Salla et al., 1994), the patient reports that the affected hand moves of its own accord, for example, grasping the pencil being used by the other hand. So strong is the deficit in

intentional control that patients neither criticize their reactions nor express any frustration at not succeeding in the task. This symptom has led Marchetti and Della Salla (1998) to distinguish between “anarchic hand” and “alien hand,” where the patient is aware of the inappropriate behavior of the affected hand and spontaneously complains about it. As these examples clearly illustrate, the expression of intention may be more obvious in a not-to-respond task than in a classical response task. The phrase “mediated reaction of indirect central sensations” used by Herzen in 1874 (as cited in Starobinski, 1999, pp. 139–140; see chapter epigraph) clearly means that an intermediate stage of processing has to be involved—that such a reaction must be distinguished from “immediate reactions of direct peripheral impressions.” As we will see, in complex behavior expressed during epileptic seizures or sleep-related motor disorders (see Revonsuo et al., 2000), where an altered state of consciousness is responsible for a disconnection between the inner and the outer world, the illusion of intention may reflect the subjects’ following an internal goal rather than their reacting to external stimuli.

Intention is best expressed when subjects are not forced to submit to the stimuli presented in the environment, as they are under most experimental conditions. The aim of the present chapter is to review some of the tasks used to explore intentional behavior, focusing on indirect responses rather than on the overlearned direct responses subjects perform hundreds of times daily.

### **3.2 A Clinical Aspect of Frontal Lobe Functions**

Because pathologies of intention are all expressed by negative symptoms (i.e., a deficit in intentional control) rather than by positive symptoms (what would hyper-intention stand for?), it is difficult, if not impossible, to provide a positive definition of intention. It is therefore useful to examine the functional deficits associated with intention disorders. To emphasize the point made in section 3.1, let us briefly review the example of patients with frontal damage. Patients with a disinhibition syndrome provide us with a characteristic negative image of intention. It is their lack of intentional control that releases automatism, both simple (e.g., perseveration) and even complex. Behaving in a reactive mode to the environment, typical patients grasp any object (e.g., a comb) presented to them, even when instructed not to do so, and automatically perform the action normally appropriate

for the object grasped (e.g., they comb their hair). In the case of complex actions, such as grasping a toothbrush and using it, the patients' "purposeful" behavior may well appear to be intentional. However, such automatic "utilization behavior" (Lhermitte, 1983; Lhermitte et al., 1986) in fact represents a loss of autonomy and is characteristic of the "environmental dependency syndrome" (Lhermitte, 1986) that accompanies frontal lobe lesion (Lhermitte, 1983). It is observed both for social stimuli (imitation behavior) and for physical stimuli (utilization behavior; Lhermitte et al., 1986). The ability to perform a goal-oriented action, even complex, should not therefore be considered as evidence for intention. Rather, patients behave "as though implicit in the environment was an order to respond to the situation" in which they find themselves (Lhermitte, 1986, p. 342). This environmental dependency syndrome can be observed in a home setting such as a bedroom (the patient preparing to go to bed) or in a doctor's office (the patient taking the doctor's blood pressure). A clear and simple experimental demonstration of this idea has been also provided by Riddoch and colleagues (2000), who asked patients with frontal lobe damage (with an "anarchic hand syndrome") to reach to and grasp a cup of tea presented to them. When instructed simply to grasp the cup with the hand on the side of the handle, patients performed the task accurately. But when instructed to use the given hand, patients made numerous errors, where the handle of the cup "triggered" an action from the wrong hand. Also, when patients were reaching to the target cup, their hand might be "captured in flight" by a distracter cup presented close to the hand's trajectory (Humphreys and Riddoch, 2000). Their environmental dependency is thus clearly the result of a deficit in intentional control of action. According to Heckhausen and Beckmann (1990), this dependency corresponds to the expression of habits or overlearned stimulus-response transformations. The following sections will therefore consider tasks in which independence from the experimental stimulus is expressed, that is, where an *indirect* response has to be performed.

### 3.3 Stop Tasks

A deficit in inhibitory control just as exhibited by patients with frontal lobe lesion represents a pathology of intention, so subservience to external stimulus exhibited by normal subjects in most experimental conditions represents an attenuated equivalent of the frontal patient's "utilization behav-

ior," hence a nonintentional behavior. Thus the "stop task" paradigm is the most obvious paradigm to consider when the issue of intention is raised.

### **Blocking the Initiation of Action**

When Slater-Hammel (1960) asked normal subjects presented with a dot running around a circle to respond synchronously to a particular dot position on the circle, they were able to easily anticipate the course of the dot so as to lift their finger with the appropriate timing. This result suggests that the motor response had to be triggered by the central command before the dot actually reached the crucial position. When, however, the dot stopped for a time before reaching this position, subjects could inhibit their response only if the delay between the dot immobilization and the expected time to reach the position was longer than about 200 ms. This result suggests that, once a simple movement has been triggered, even if not overtly initiated, the intention to stop it cannot block its expression.

In the "stop signal" paradigm developed by Logan and coworkers (see Logan, 1981), participants in a typical experiment perform a speeded reaction time task (e.g., visual discrimination) and are occasionally presented with a stop signal (e.g., a tone) that instruct them to withhold their response. The stop signal paradigm has been applied to both hand and eye responses (most often, withholding key presses and countermanding saccades). The stop signal is usually triggered at different delays after presentation of the stimulus. Depending on the length of the delay, subjects are more or less successful in withholding their response. One of the most notable findings with this paradigm is that the stop signal reaction time (SSRT), that is, the latency for interrupting a response, is usually shorter than the classical reaction time. Ranging around 200 ms, SSRTs tend to be shorter for the eye than for the hand (usually shorter than 200 ms; e.g., De Jong et al., 1995; Logan and Irwin, 2000), and shorter in monkey than in human subjects (Hanes and Shall, 1995). As might be expected, the modality in which the stop signal is provided also modulates the latency for interrupting a response (Cabel et al., 2000). The difference found between the response reaction time and the stop signal reaction time suggests that different mechanisms are at work in stop signal tasks, as does differential modification of the two responses by experimental manipulation (e.g., Logan and Irwin, 2000). Consistently, reaction times to go and stop signals follow different time courses over the life span (Williams et al., 1999) and inhibitory control of behavior is impaired by a moderate dose of alcohol that does not affect

response reaction time (Mulvihill et al., 1997). Let us now consider how these two responses are produced.

As the delay of the stop signal increases, humans and monkeys increasingly fail to withhold the response. The hypothesis is that the generation of the response is determined by a race between a go and a stop process (e.g., De Jong et al., 1995; Hanes and Shall, 1995). This race model predicts and describes the probability of inhibition as a function of stop signal delay and response reaction time, although comparison of various versions of the stop signal paradigm suggests that several stop signal processing mechanisms may be involved. When the stop signal required subjects to inhibit any response (stop-all) or only one response (selective stop), inhibition was found to be effected by a peripheral mechanism (De Jong et al., 1995). Moreover, analysis of agonist-antagonist electromyographic (EMG) activity during fast elbow extension movements showed that the EMG response to response inhibition may correspond to an adapted reflex activity (Kudo and Ohtsuki, 1998). By contrast, when subjects had to produce a fixed alternative response to the stop signal (stop-change), the lateralized readiness potential suggested that a selective, central inhibition mechanism was involved (De Jong et al., 1995). For eye movement, there is good evidence that the monkey frontal eye field (FEF) is critically involved in the inhibition of saccades (Hanes et al., 1998).

The brain areas chiefly involved in stop tasks are found in the frontal cortex. Recent brain imaging studies have shown that the inferior frontal cortex plays an important role in the inhibition of inappropriate responses: They consistently report that the inferior frontal cortex is activated together with either the left prefrontal cortex (Collette et al., 2001); the premotor cortex, right anterior cingulate, and inferior parietal lobule (Menon et al., 2001; Rubia et al., 2001); or the bilateral dorsolateral prefrontal cortex (Rubia et al., 2001).

### **Blocking the Execution of Action**

Because the stop signal paradigm, as generally applied, requires that subjects inhibit initiation of their main response, no response is produced during critical trials. Another experimental approach, motor psychophysics, analyzes movement kinematics in various conditions (e.g., Prablanc, 1979), focusing instead on fast reactions to a stimulus change. Its findings are worth comparing with those of stop signal studies. Motor psychophysics studies



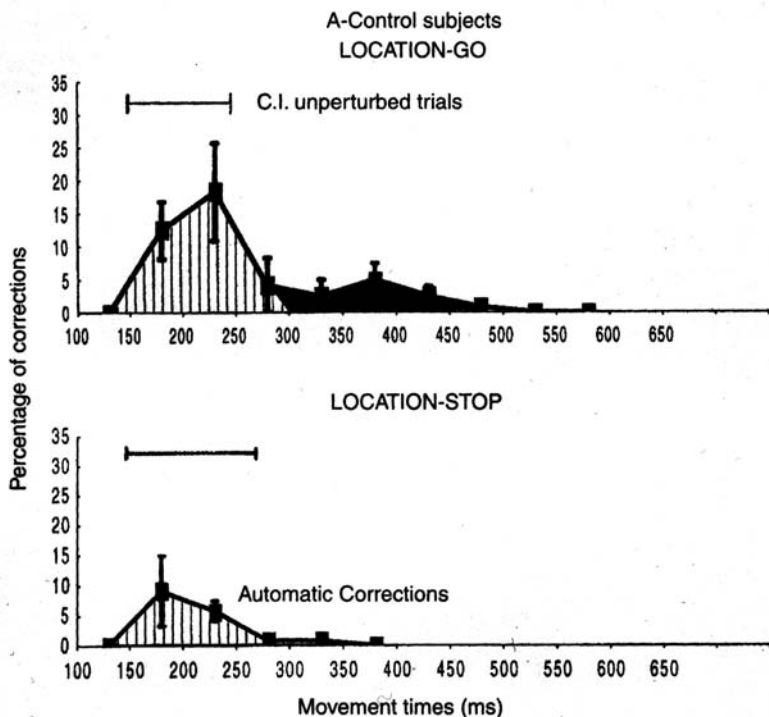
of the control of simple goal-directed actions have shown that movements, even of short duration, can be corrected on-line (see Rossetti et al., 2000; Pisella and Rossetti, 2000; Rossetti and Pisella, 2002). For instance, fast modifications of motor components were observed during grasping movements in response to changes in object orientation or location (Desmurget et al., 1995, 1996; Gréa et al., 2000, forthcoming). Similarly, after a fast pointing movement has been programmed and initiated toward a visual target, it can be corrected without a significant increase in movement time (Pélisson et al., 1986; Goodale et al., 1986), that is, without reprogramming a new motor output. Interestingly, the latency for updating an ongoing movement is usually found to be around 100 ms, which is much faster than the reaction time observed with the stop signal paradigm. In addition, such on-line corrections can be observed whether or not the target displacement is consciously perceived (Pélisson et al., 1986; Prablanc and Martin, 1992). If the corrective system can bypass the conscious decision level, to what extent can such an automatic system resist intentional control? Could corrective movements be considered the equivalent, in normal subjects, of unwilled movements toward objects (e.g., anarchic hand syndrome; Della Sala et al., 1994) in frontal patients? What explains the apparent slow stop signal reactions with regard to these fast movement corrections? The stop signal and the motor psychophysics approaches have not been combined to answer these questions until recently. We have conducted a series of experiments in which subjects had to point at a visual target (Pisella et al., 1998, 1999, 2000). During the pointing movement execution, the visual target could be altered on a fraction of trials. This target change could be used as a go signal to perform an in-flight correction to a new target location or as a stop signal to interrupt the ongoing movement. Therefore the two types of response had to interfere with an already ongoing pointing action. In contrast to previous researchers, we investigated whether the hand would perform a correction or be interrupted, rather than whether a movement would be initiated. Accordingly, our stop signal did not appear before movement initiation but was triggered by the movement onset. Two types of perturbations were designed to test whether automatic corrective processes can be triggered in response to a chromatic change as well as to a target jump; they were also used as stop signals to create a conflict between the automatic correction system and voluntary motor control.

In a “location-stop” pointing experiment, subjects were first presented with one green target and asked to point at it at specified rates. This target remained stationary on 80% of the trials and unexpectedly jumped to the right or left at movement onset on the remaining 20%. Subjects were asked to systematically interrupt their ongoing movement to touch the target when it jumped. The direction of the target jump was thus irrelevant for this task. Strict compliance with the “Stop” instruction would imply that subjects would either succeed in stopping their movement or fail to interrupt their action and therefore touch the primary position of the target (Pisella et al., 2000). In striking contrast to this prediction, however, a significant percentage of corrective movements were performed in the direction of the target jump despite the “Stop” instruction. Because these corrections were produced spontaneously by naive subjects and against their own intention to stop their movement in accordance with the instruction, they must be considered automatic. After touching the displaced target, subjects were fully aware of their mistakes and spontaneously expressed a strong frustration.

We explored whether the ongoing hand movement was corrected or interrupted with respect to movement times. Sampled movement times ranged from about 100 ms to 450 ms with a Gaussian distribution, corresponding to movement speeds because the distance between targets and starting point was constant in the experiment. In figures 3.1A–C, fast automatic movement corrections with respect to stimulus and instruction are shown in green, and slow intentional movement corrections in red. Four conditions combined two types of instruction—correction (go) or interruption (stop). In the two location conditions (left column), subjects were instructed to point, under different time constraints, to one target first presented on the tactile screen (see Pisella et al., 2000). At movement onset, a target jump could be triggered unexpectedly, in response to which subjects were instructed either to correct (location-go condition) or to stop (location-stop condition) their ongoing pointing movement to the target. In the two color conditions (right column), subjects were first presented with one green and one red target on the tactile screen and instructed to point to the green target. At movement onset, the two targets could exchange colors unexpectedly (see Pisella et al., 2000), in response to which subjects were instructed either to correct (color-go condition) or to stop (color-stop condition) their ongoing pointing movement to the green tar-

get. For each condition, the horizontal bars indicate 95% confidence intervals of movement time computed for all unperturbed trials. Figure 3.1a shows the number of corrected movements made by three control subjects with respect to movement duration. Because they occurred in a restricted temporal window, escaping the slower processes of voluntary interruption, the involuntary corrections resulted from a failure to inhibit an automatic process of on-line visuomotor guidance. This "automatic pilot" (see also Place, 2000), which was systematically activated during movement execution, led subjects to produce disallowed corrective movements over a narrow range of movement times, between about 150 ms and 300 ms. Over a range of about 200–240 ms, the same rate of correction was found in this (location-stop) condition and in a control (location-go) condition where subjects had to correct the action in response to the target jump. Only movements slower than 300 ms could be fully controlled by voluntary processes. In contrast to this normal pattern, patient I.G. with a bilateral lesion of the posterior parietal cortex showed a lack of on-line automatic corrective processes, whereas intentional motor processes were preserved (figure 3.1b; Pisella et al., 2000, experiment 3). From this finding, we concluded that fast movements are controlled by a (posterior) parietal "automatic pilot" (PAP) located in the dorsal stream, whereas slow movements are controlled by intentional motor processes that remain largely independent of the posterior parietal cortex. Thus the notion of automatic pilot extended that of "hand sight" (Rossetti et al., 2000) in the sense that it refers not only to unconscious visual processing by the action system, but also to an autonomous use of visual information, which bypasses and even counteracts intention. Following Lhermitte's hypothesis (Lhermitte et al., 1986), the automatic activity observed in this experimental situation seems to result from the "release of parietal lobe activities."

Thus the automatic behavior shown here by normals may be related to the dysfunction of executive skills in patients with a frontal lobe lesion. Indeed, that normal subjects make disallowed corrections even when target jumps signal them to stop their movements is reminiscent of the weakness of intentional control over ongoing activity described in frontal patients, in which "the ongoing activity exerts a more powerful influence than the encoded intention-action" (Cockburn, 1995, p. 95). The parietal automatic pilot observed in normal subjects may thus be one possible substrate of the environment dependency syndrome. Accordingly, frontal patients



**Figure 3.1**

(A) Parietal automatic pilot. Three control subjects performed corrections instead of stopping their ongoing movement in response to target jump in the location-stop condition. These corrections were performed with movement times comparable to unperturbed trials (horizontal bar) and against the subjects' intention to stop the movement. We identified them as fast automatic corrections (in green). In the location-go condition, when subjects were explicitly instructed to correct their movement, we observed an additional pool of corrections performed with a substantial increase of movement duration as compared to unperturbed trials (horizontal bar). We identified them as slow intentional corrections (in red). In response to the color change (right column), only slow intentional corrections were performed. The automatic pilot guiding the fast automatic corrections could not be triggered by this "ventral" feature.

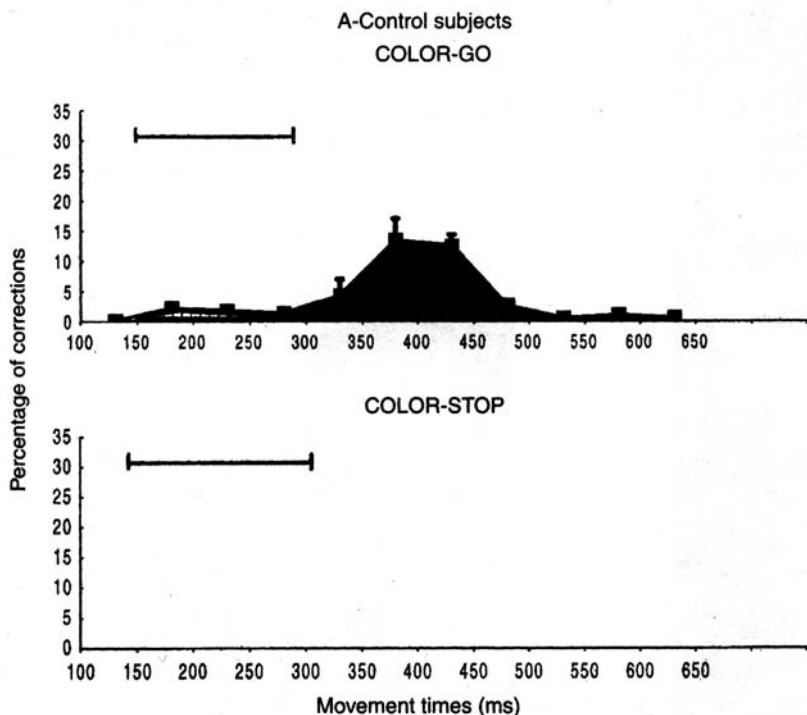
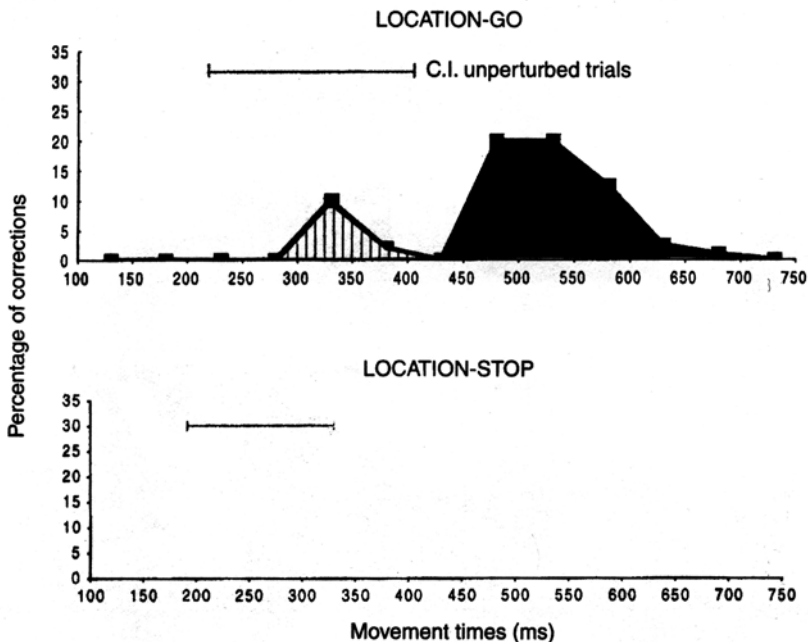


Figure 3.1 (continued)

tested on the same tasks should exhibit a complete loss of intentional inhibition of their automatic corrections. In support of this hypothesis, a recent experiment showed that patient G.C. with a unilateral lesion of the dorso-lateral convexity of the frontal lobe performed 100% corrections, when the target jump was associated with a stop instruction (location-stop condition; figure 3.1c), even though she was able to orally repeat the instruction throughout the experiment (see Pisella et al., 2000). However, the frustration expressed by our normal subjects over corrections despite themselves stands in contrast with the usual lack of concern displayed by frontal patients or even with the patients' report that "they had to do it" (e.g., Lhermitte, 1986). This main difference may involve a time factor. On the one hand, the impairment in frontal patients has been described for the execution of the serial tasks lasting several seconds (e.g., Lhermitte, 1986; Cockburn, 1995). On the other, the normal subjects' automatic corrections for simple aiming movements fall only within a narrow time window, representing

B-Patient I.G. (bilateral lesion of the posterior parietal cortex)



**Figure 3.1** (continued)

(B) Parietal automatic pilot. Patient I.G., with a bilateral lesion of the posterior parietal cortex (PPC), showed a specific impairment for producing the fast automatic corrections. In the go conditions, she performed only slow intentional corrections in response to both the target jump and the color change. In the stop conditions, she could always follow the instruction of interrupting the ongoing movement. This lack of fast automatic corrections cannot be explained by a general slowing of visual or motor processing (see Pisella et al., 2000). We concluded that the PPC is necessary for the processes of the automatic pilot.

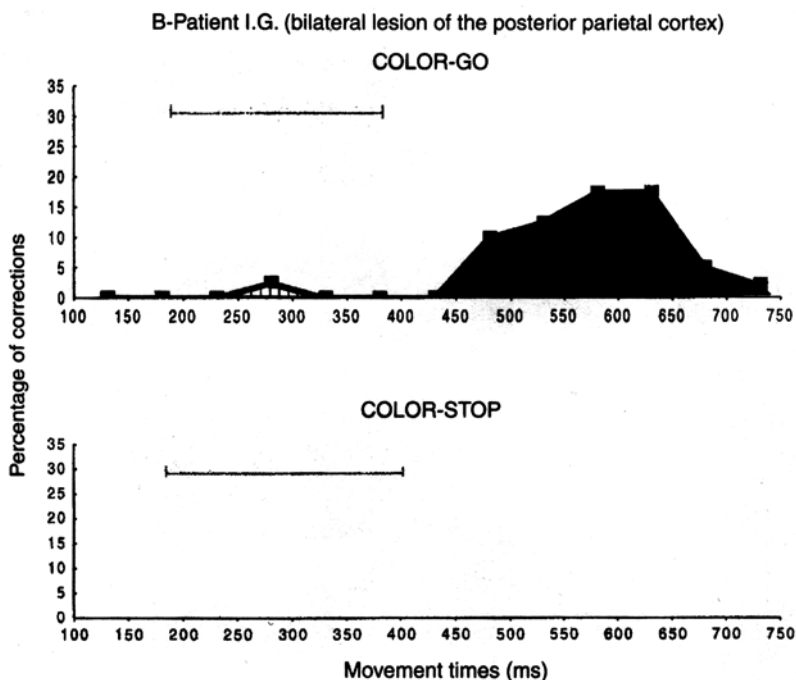
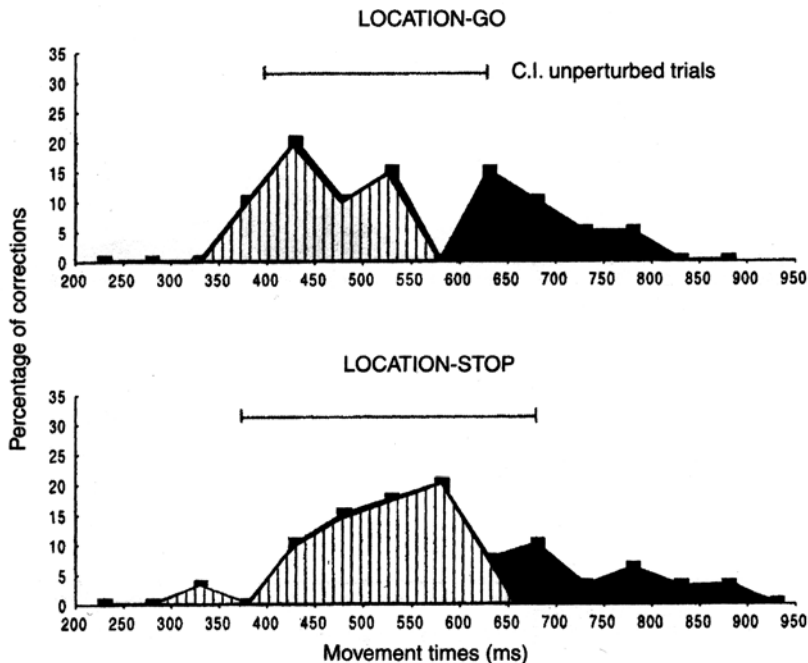


Figure 3.1 (continued)

only a temporary lack of voluntary control. It may be hypothesized that normal subjects behave in the same way as frontal patients because the speed constraints of our paradigm do not give the frontal lobe enough time to inhibit automatic corrective processes.

It is clear that intention can be overtly expressed in tasks where a reaction to a stimulus has to be repressed. It is interesting to note that most of the simple direct tasks performed in experimental conditions would be performed at least as well by frontal patients as by normals. Although not to respond to a stimulus may appear simpler than actually responding to it, this is obviously not the case in frontal and normal subjects, especially under time constraints, when the control of an ongoing action is concerned. On the other hand, it would be misleading to assume that intention can be expressed specifically through the inhibition of action, as has been claimed (e.g., Libet, 1993). The following sections present a variety of tasks involving not only the repression of the most direct response to a stimulus but the more complex use of the stimulus in a process evocative of intentional response organization.

C- Patient G.C. (unilateral lesion of the dorsal frontal cortex)



**Figure 3.1** (*continued*)

(C) Parietal automatic pilot. The pointing performance of patient G.C., with a unilateral lesion of the dorsal prefrontal cortex, reveals a lack of inhibition of both fast automatic corrections (as in control subjects) and slow intentional corrections (contrary to control subjects), although she was able to orally repeat the instruction throughout the experiment. The lack of concern displayed by patient G.C. stands in contrast with the frustration expressed by the control subjects over the corrections that escaped them. This main difference may be linked to a time factor. The control subjects' automatic guidance was released only for simple aiming movements falling within a narrow time window. Their automatic corrections resulted from only a temporary lack of voluntary control.



## C- Patient G.C. (unilateral lesion of the dorsal frontal cortex)

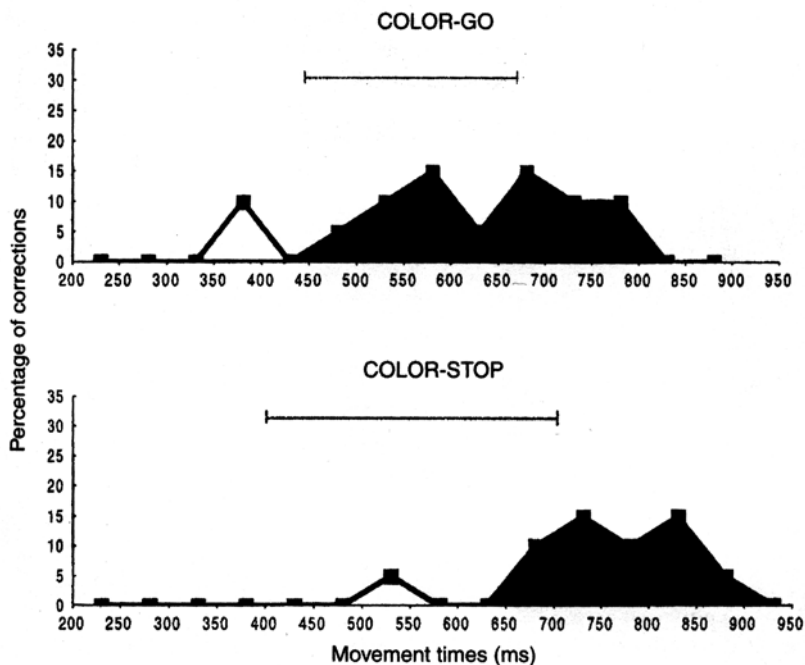
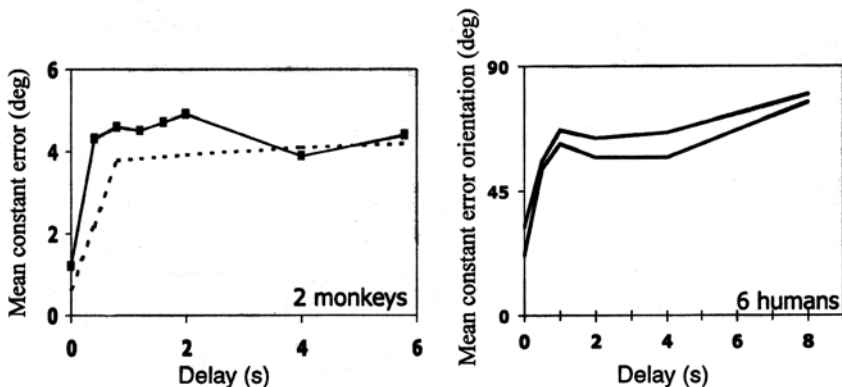


Figure 3.1 (continued)

## 3.4 Delayed Tasks

To achieve a distant goal, self-control is a necessary aspect of intelligent behavior. Delaying an action is obviously a difficult task to perform for a patient with frontal lobe damage. As we have seen, one of the aspects of the environmental dependency syndrome is the deficit in inhibiting immediate responses. When patients with a prefrontal lesion are compared to patients with a posterior lesion or to healthy controls, they exhibit a profound deficit in delayed response tasks (Verin et al., 1993). If immediate and delayed responses can be dissociated in these patients, then different functional organization may be responsible for the two types of response.

Differences between immediate and delayed responses have been reported for both eye and hand movements. There is a general decrease in performance when the delay introduced between stimulus and response increases, chiefly manifested as an increase in response variability. The interesting aspect of these results is that the time course of the change does not



**Figure 3.2**

(A) Effect of delay on distribution of errors. Constant errors are plotted as a function of the delays; plotted points are the errors averaged across all target locations. When delay intervals between the target extinction and the go signal were increased, similar effects on accuracy and precision were observed in two studies of ocular (left) and manual (right) motor responses. The left panel, which depicts constant saccadic errors in two monkeys, shows a sharp increase between 0 s and 1 s and stabilization at longer delays (White et al., 1994). The right panel, which depicts constant pointing errors toward visual targets in human subjects, also shows a sharp increase between 0 s and 1 s, followed by a plateau at longer delays. (Adapted with permission from Rossetti et al., 1994.)

follow a smooth curve. For example, it was shown that the amount of error observed for delayed saccade in monkeys increased sharply when the delay increased from 0 ms to 400 ms and then reached a nearly horizontal plateau (figure 3.2A). In the same way, immediate and delayed grasping movements performed by human subjects exhibit different kinematic patterns, irrespective of the duration of delay (2 s or 30 s) introduced between stimulus and response (figure 3.2B, Goodale et al., 1994; see also Hu et al., 1999). In particular, delayed movements exhibit an altered opening and closure of the finger grip and a reduced maximal grip size as compared to normal movements. Strikingly, pantomimed movements performed beside the object are similar to movements delayed by 2 s or 30 s.

Beyond these structural changes, it is interesting to explore the nature of the representation subserving immediate versus delayed actions. Using a simple experimental design, Rossetti and colleagues (see Rossetti and Pisella, 2002) had normal subjects point with various delays to visual targets flashed on a monitor. Nine target locations were used, and organized along an arc centered on the starting position (see Rossetti, 1998). Several accu-

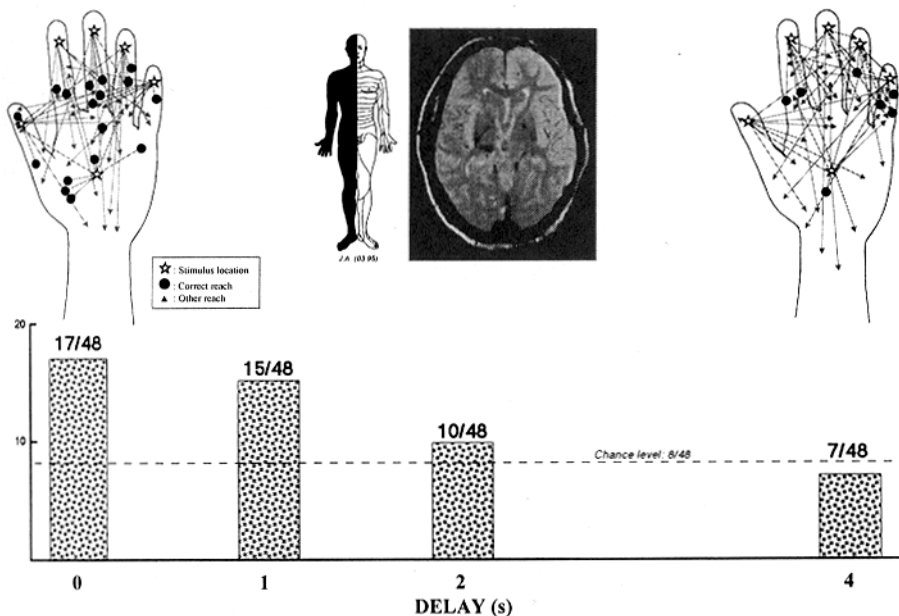
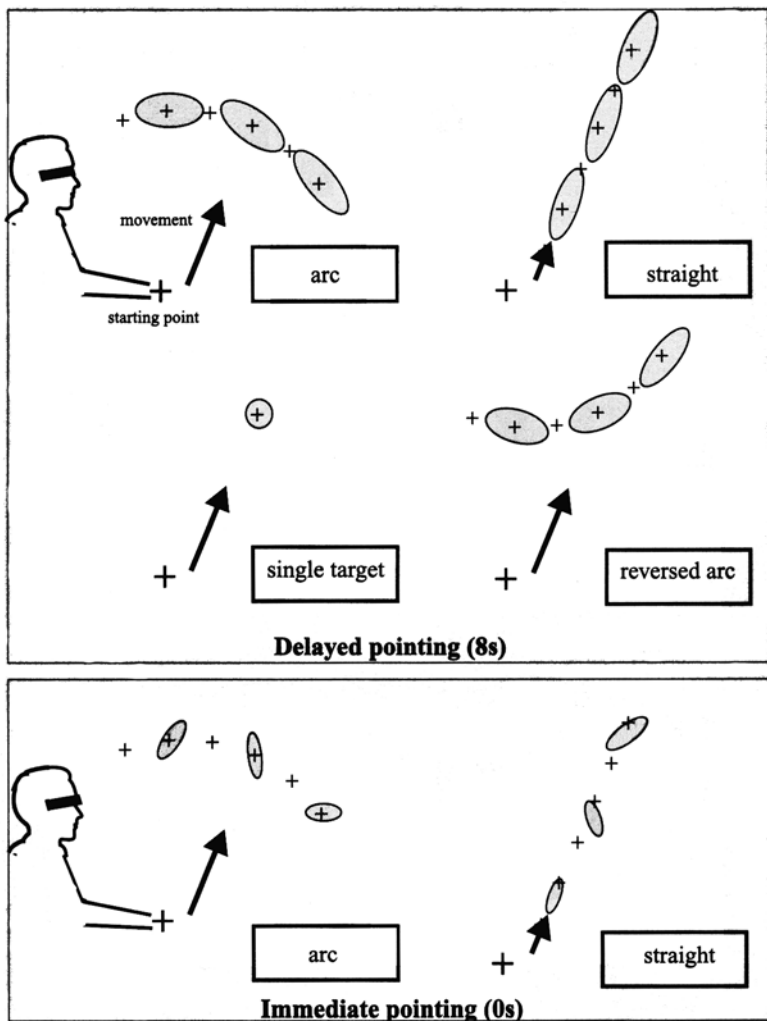


Figure 3.2 (continued)

(B) Effect of delayed tasks on action-numbsense. Patient J.A., with a thalamic lesion (areas VL and VPL) producing complete insensitivity of the right half of his body, was tested for tactile stimuli delivered to the hand. Four different sessions tested the effect of four delays introduced between the stimulus delivery and the go signal: 0 s, 1 s, 2 s, and 4 s. In each session, 48 stimuli were randomly delivered to six possible locations (stars). The number of correct responses (black dots) decreased abruptly from an above-chance (immediate and 1 s) to a near-chance level (2 s and 4 s). This result suggests that the residual somatosensory information used to direct J.A.'s response was available only for a brief period (about 1 s). (Reprinted with permission from Rossetti, 1998.)

racy parameters were investigated (see Rossetti and Pisella, 2002). First, the global variability, as assessed by the surface of the confidence ellipse fitting the movement endpoints, was found to increase continuously with the delay. Second, the orientation of the main axis of the confidence ellipses was found to follow a two-slope function: It tended to be aligned with movement direction in the absence of delay and then rapidly increased for 500 ms delay (see Rossetti and Pisella, 2002, figure 3.2C). With a delay of between 500 ms and 8 s, a fairly horizontal plateau was reached, with an ellipse orientation tending to be aligned with the target array, that is, orthogonal to movement direction (see Rossetti et al., 2000, figure 10). Third, the orientation of the constant error vector in space was also found to follow



**Figure 3.2 (continued)**

(C) Effect of delay on the distribution of pointing scatters. Schematic drawing of pointing scatters observed for immediate (delay = 0 s) and delayed movements (delay = 8 s) when a unique proprioceptive target or six targets were presented on an arc array, a line array, or an inverted arc array. Whereas no specific orientation of the pointing scatter is observed when an immediate response is produced (in the case of proprioceptive targets), after the delay, the scatter main axis tends to align with the target arrays, revealing an allocentric coding of the target location: In the case of the arc array, it tends to reach  $90^\circ$  for delayed pointing movements. On the contrary, in the case of a line array aligned with the direction of the movement, the scatter orientation tends to be about  $180^\circ$ . Although the two types of responses can be considered as voluntary actions, the reactive mode and the controlled mode clearly exhibit different properties. (See also Rossetti, 1998, and Rossetti and Pisella, 2002.)

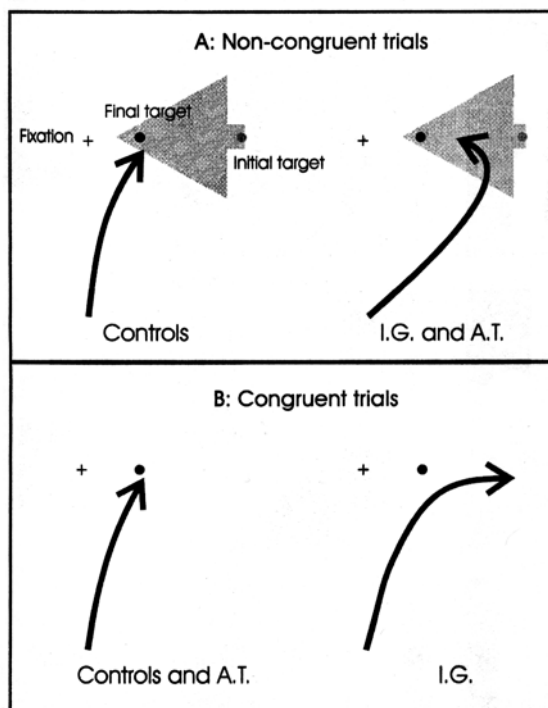
a similar two-slope trend. These results indicate that a different type of sensorimotor process is at work in the immediate and in the delayed condition. A short-lived *egocentric* representation of the target location seems to be used to guide immediate actions, whereas *allocentric* coding of the visual target seems to participate in the delayed action, which is affected by the global spatial context of the experiment extracted by a trial-to-trial integration over time. Similar results have been observed for delayed pointing to proprioceptively defined targets (Rossetti and Régner, 1995; Rossetti et al., 1996; for review, see Rossetti and Pisella, 2002). This contextual integration confirms the hypothesis that the indirect responses produced in delayed tasks rely on complex spatial representations that are compatible with intentional rather than automatic control.

Delayed tasks have also been given to neurological patients with a lesion of the dorsal or ventral stream. The visual agnosia patient D.F. could correctly reach to and grasp objects she could not describe, but lost this preserved motor ability when her action was delayed by only 2 s (Goodale et al., 1994). Conversely, optic ataxia patient A.T., described by Milner and colleagues (1999), performed imprecise reach and grasp movements when instructed to act immediately to objects, but (paradoxically) improved when a delay was introduced between stimulus and pointing response (see also Milner and Dijkerman, 2001; Dijkerman et al., 2001; McIntosh et al., 2001). These results further support the idea that immediate and delayed actions rely on two different processes; furthermore, they suggest that these two different processes rely on the dorsal and the ventral streams. Indeed, a lesion of the dorsal stream (optic ataxia) affects the system underlying immediate actions, whereas a lesion of the ventral stream (visual agnosia) affects the system underlying delayed and pantomimed actions. "Action-blindsight" and "action-numbsense" have also been shown to be disrupted when a delay is introduced between stimulus and response (see Rossetti, 1998; Rossetti and Pisella, 2002).

Our recent series of experiments to further explore the control of action in optic ataxia (Dijkerman et al., 2001; McIntosh et al., 2001; Rossetti and Pisella, 2002) gave a striking demonstration of the link between delayed tasks and intentional control. In trials with optic ataxia patient I.G., we first confirmed that delayed pointing improves performance, which suggests that optic ataxia involves a deficit of on-line sensorimotor processing, but that a temporal delay allows a cognitive representation of the target to emerge that can be used by the intentional action system. If this interpretation is

correct, it should be possible to generate conflict between intentional and reflexive action control. Visual target was presented to optic ataxia patients A.T. and I.G. for 2 s, hidden for 5 s, then presented again. These subjects were required to point toward the target as soon as it was presented for the second time. In a minority of trials, however, the target was displaced between first and second presentations. In these critical trials, A.T. and I.G. both tended to respond to the remembered location of the first presentation rather than to the actual location of the target at second presentation (figure 3.3A; a closely similar result was obtained for grasping simple objects of different sizes; Milner et al., 2001). This behavior contrasts with that of control subjects, who responded exclusively to the actual location of the target at second presentation. These results confirm that sensorimotor and cognitive representations have different time constraints (see Rossetti, 1998). Whereas sensorimotor representations can be elaborated in real time but are extremely short-lived, the cognitive representation needs more time to emerge but can be evoked off-line in the intentional organization of action. We also observed an interesting difference between the two patients. When I.G. became aware that the target was sometimes displaced during the delay period, she began to produce correction-like modifications of her ongoing movements toward stationary targets, which would drive her hand away from them (figure 3.3B). At the end of the testing, she explained that sometimes she was not sure whether the target had been displaced, and therefore modified her trajectory when she thought so. Her hand movements were (slowly) corrected according to her belief, irrespective of the actual target location and of a change in target location. By contrast, A.T. was never aware of our covert target displacements and did not produce this intentional correction-like behavior. Presumably, in the absence of the dorsal stream responsible for automatically controlling the action, the prefrontal cortex can elaborate predictions about external events and generate appropriate responses. Because of associated problems in peripheral vision such as simultanagnosia, these predictions appear to be defective.

All these results converge to support the conclusion that when action is delayed and the object has disappeared, the parameters of object position and characteristics used by the action system can only be accessed from a sustained cognitive representation compatible with perceptual awareness and intention. This type of representation and the immediate action system obviously rely on different frames of reference. Furthermore, the neuropsychy-



**Figure 3.3**

Conflict between intention and automatism. Patients A.T. and I.G. having a bilateral posterior parietal cortex lesion were presented with a visual target for 2 s, which was hidden for 5 s, then shown again; they were required to respond as soon as it was uncovered. In a minority of trials, however, the target was displaced between first and second presentations. (A) In these critical, noncongruent trials, A.T. and I.G. both tended to respond to the remembered location of the first target rather than to the physically present “second” target. (B) Interestingly, in the congruent trials, the two patients exhibited different behaviors: A.T. did not become aware that the target could change location during the delay and behaved just like a normal subject; I.G. became aware of the change and consequently performed some anti-corrective corrections, as if the object had jumped during the delay. This striking effect shows that I.G.’s belief that the object had changed location could not be checked by on-line input about the real position of the target and therefore contaminated the action by generating intentional changes of goal. (Adapted with permission from McIntosh et al., 2001.)

chological data suggest that the dorsal stream is able to build a short-lived sensorimotor representation of the target that is only available for immediate, reactive actions rather than for intentionally controlled actions.

### 3.5 Mirror Tasks

Tasks requiring the motor response to be produced in a direction opposite to the stimulus have been investigated with two main types of effectors: the eye and the hand. In such indirect "mirror tasks," subjects are typically asked, in effect, to inhibit "utilization behavior" in their response to the stimulus, thus generating a more sophisticated stimulus-response translation.

#### Antisaccade

Every day, we perform thousands of reflexive eye movements to visual stimuli appearing or moving within our peripheral visual field. In a much more pronounced way than for hand movements, a vast majority of our eye movements cannot be considered voluntary. To investigate the voluntary control of eye movements, a novel task was therefore introduced: the anti-saccade task (Hallet, 1978), in which the subject is asked to perform a saccade to a virtual point that matches the mirror location of the stimulus with respect to the fixation point (for review, see Everling and Fisher, 1998). The antisaccade task requires subjects to inhibit their "reflexive" prosaccade to a flashed visual stimulus and to generate the opposite movement, namely, an antisaccade. Earlier latency studies (e.g., Fisher and Weber, 1992) suggested that the coordinates that specify the location of the visual stimulus are simply mirror reflected rather than rotated through  $180^\circ$ . Thus a deficit in voluntary control would be manifested as a significant number of prosaccades performed in the place of antisaccades. The main difference between immediate prosaccades and antisaccades is that antisaccades have longer latencies, which suggests that this task generates a conflict between the two responses, one that appears to be more pronounced for targets presented in the peripheral than in the central visual field (Logan and Irwin, 2000), which in turn suggests that peripheral eye movements are more reflexive than central movements. The pattern of errors observed for visually guided antisaccades, unlike the pattern for prosaccades, resembles that of the memory-guided antisaccades (Krappmann, 1998). Thus the nature of the difference between pro- and antisaccades should resemble that of the difference between immediate and delayed saccades.



Antisaccade tasks have been used with many groups of patients (for review, see Everling and Fisher, 1998). Direct evidence for a frontal lobe involvement in antisaccade generation was obtained from several studies showing that patients with unilateral lesion of the frontal lobe had greater difficulty producing antisaccades, although focal lesion of the frontal eye field (FEF) or the supplementary eye field (SEF) do not increase the error rate in this task. As for the stop signal paradigm, it is rather odd that more studies investigated antisaccades in psychiatric disorders than in neurological disorders. The common assumption in these studies remains that the frontal cortex, basal ganglia, or both participate in antisaccades.

To address the issue of dorsal versus ventral stream within this framework, Dijkerman and colleagues (1997) investigated antisaccades in the visual agnosia patient D.F. They demonstrated that her bilateral occipitotemporal lesion did not impair her ability to perform immediate prosaccades, as had been the case for pointing (Goodale et al., 1994). But their most interesting finding was that D.F.'s ability to perform antisaccades was severely impaired, which suggests that the human ventral stream is necessary to the voluntary control of eye movements, whereas the dorsal stream would only allow direct prosaccades. The anatomical correlates of human "antimovements" will be further addressed in the next section.

### **Antipointing**

Day and Lyon (2000) used a pointing task in which the target could be displaced during the hand movement. Subjects were asked to produce either a corrective movement toward the new target location (direct pointing) or to redirect their hand movement in a direction opposite to the actual target jump (antipointing). As in Pisella et al., 2000, fast movements were shown to be under the control of automatic processes, which could participate in the direct pointing performance, but not in the antipointing task derived from the antisaccade paradigm, which they even counteracted. The incompatibility between automatic processes and antimovement tasks is also apparent when the orientation of attention is investigated. The automatic anticipatory orientation of attention that is observed during a saccade preparation around the final position of the saccade being prepared is not observed in the case of antisaccades (see Schneider and Deubel, 2002).

A recent fMRI investigation (Connolly et al., 2000) found that the neural network participating in direct pointing in humans was activated during antipointing as well, although areas that were prefrontal eye field

and presupplementary motor area (lying anterior to areas activated during both direct pointing and antipointing) were selectively activated during antipointing, which confirms that more anterior frontal areas are implicated in the inhibition of automatic responses. Interestingly, a few areas were activated only during direct pointing and direct saccades, and not during antisaccades and antipointing. All three of these areas are located along the medial wall of the frontoparietal cortex, that is, in the most dorsal position within the visuomotor network, a result consistent with the view that the dorsal end of the visuomotor network is mainly involved in the automatic on-line control that we called the parietal automatic pilot (Pisella et al., 2000; Rossetti and Pisella, 2002).

### 3.6 Other Indirect Tasks

#### Matching and Pantomimed Tasks

If one considers the motor abilities left intact in optic ataxia patients to be intentionally controlled, then matching tasks are good candidates for exploring intention. As mentioned earlier, patients with optic ataxia exhibit difficulties in reaching to or adjusting their finger grip to an object. In contrast, they seem to remain able to indicate the size of a stimulus with their finger grip while the hand remained away from the stimulus (see Jeannerod et al., 1994). As pointed out by several authors (e.g., Milner and Dijkerman, 2001), the boundary between matching tasks and pantomime tasks can be rather fuzzy. In Goodale et al., 1994, the kinematic structure of pantomimed movements was found to be similar to that of movements delayed by 2 s or 30 s, underscoring the necessity for motor representations to have on-line access to target parameters. The effect of subtle changes in the type of motor output requested from subjects can also strongly affect the type of processing involved. A rather clear example has been provided by Bridgeman (2002), who compared communicative pointing to instrumental pointing. Subjects were asked either to point at an object or to act on it by pushing it down. The latter response provided a stronger difference from the perceptual tasks used in the same experiment, suggesting that the former response could be considered an imitation of the actual action.

#### Sequential Tasks

Also included among simple tasks where intention can be obviously, though indirectly, expressed are sequential tasks. It has long been known

that performing a movement to grasp an object can be strongly influenced by the planned use of this object. Thus we do not grasp a pen in the same way when we intend to write as when we intend to pass it to someone else. Experiments have shown that the reach-to-grasp movements performed toward an object to be placed on a platform exhibit different duration and different kinematic patterns depending on whether the platform is tiny or large (Marteniuk et al., 1987). In the same way, the first stroke of sequential pointing to a first (standard) target and a second target varying in size is affected by the ultimate goal of the whole action, that is, by the target of the second stroke. This pattern of results is quite robust and seems to be observed even in schizophrenic patients (Saoud et al., 2000).

The sequential task paradigm can inform us of pathological alterations of intention. For many years, it was thought that hemispatial neglect might consist at least partly of a deficit in intention directed to the left side of space. Several experiments using various types of manipulandum have nicely shown that the direction of the final effector (e.g., a cursor) is less relevant than the direction of the real arm action performed by the patient (for review, see Heilman, forthcoming), although whether the direction of the movement being *programmed* or the movement *intended* is the crucial parameter is difficult to determine under experimental conditions. When neglect patients are asked to first reach to and grasp a ball placed in front of them and then to throw it to the left or right, the initial reach-to-grasp movement is modulated by the final direction of the whole action. Reaching movements before a throwing movement to the left are slower than those before a throwing movement to the right (figure 3.4). This pattern of results is fully consistent with the hypothesis that there is an intentional component in the deficit exhibited by neglect patients. Interestingly, this pattern can be reversed by a short session of adaptation to right-deviating wedge prisms, which demonstrates that confounding factors such as biomechanical constraints are not responsible for the difference found before neglect was improved by the adaptation (as shown on various neglect tests: Rossetti et al., 1998, 1999; Rode et al., 1999, 2001; Pisella et al., 2002; Farnè et al., 2002). The chief advantage of sequential tasks is that they allow researchers to observe intention in an altogether indirect way, at a stage of the action that is remote from its actual final goal, though strictly dependent on this goal. Their chief disadvantage, however, is that, relying on low-level kinematic parameters to indicate intentional

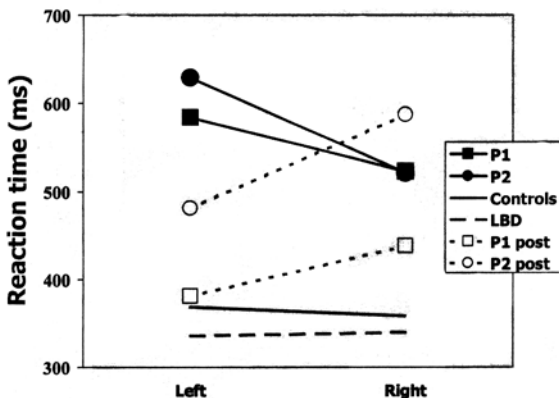


Figure 3.4

Indirect task demonstrating an intentional modulation of action in hemispatial neglect. We investigated whether the left hypokinesia found in hemispatial neglect would be observed in a grasping action when the subsequent movement was directed to the left. Subjects had to reach and grasp a tennis ball placed on their sagittal axis and then throw it into a left or a right basket; neglect patients were slower to initiate their movements ending to the left as compared to right (solid symbols). No comparable effect was found in the control group. This result suggests that the preparation of a movement sequence ending to the left is subjected to unilateral neglect. Anticipation of the ultimate goal of an action may lead to a retrograde transfer of the neglect bias onto action elements which have no left-right component by themselves. Unexpectedly, this trend was reversed after a short wedge-prism adaptation session (open symbols). (Adapted from Rode et al., 2000.)

modulation, sequential tasks can explore only a limited range of action qualities.

### Distractor Avoidance Tasks

Sequential and distractor avoidance tasks may be considered mirror images: In the first, stimulus must be reached, whereas, in the second, it must be avoided, before the ultimate goal of the action can be achieved. The main difference between the two types of tasks would be that, in distractor avoidance tasks, this stimulus has to resemble the action goal (Humphreys and Riddoch, 2000), whereas, in sequential tasks, it does not. The distinction between positive and negative effects of distractors (see Tipper, 2001) would provide an efficient way to discriminate between environment dependency and its intentional inhibition.

Still another good way to ensure that a movement is controlled by intention is to require subjects to *imagine* preparing and performing an ac-

tion (see Frith et al., 2000). Imagined movements seem to share several properties with actual movements (see Jeannerod 2001; Danckert and Goodale, chapter 2; Jeannerod, chapter 5; and Sirigu et al., chapter 6, all this volume), and the inhibition of overt action is a good marker that subjects are intentionally performing the task. Although we have long known that the duration of a mental action is proportional to that of the real one, it is obviously difficult to control for the correctness of the execution of such an action, which may explain why relatively few patient categories have been investigated using such tasks. In particular, it would be interesting to investigate how patients with prefrontal lobe lesion would perform imaginary actions without producing covert movements (see Jeannerod, 2001).

The above list of indirect tasks to explore the intentional control of action is by no means exhaustive. At this stage, however, too few neuropsychological studies have made use of even these tasks to accurately assess their efficiency and practical relevance.

### 3.7 Intention Is Slower than Reaction

Several authors have proposed that conscious awareness is slower than reactions to many sensory stimuli (for review, see Rossetti, 1998). If intention is dependent on consciousness, then at least the same temporal dissociation should apply to intention and these reactions. Some of the experiments reviewed above suggest that some sensorimotor reactions can be produced even before the intention to react to the stimulus has time to take charge of the response. This is particularly clear when intention and the sensorimotor reaction to a target are in conflict for the control of an ongoing movement (as in Pisella et al., 2000).

As we noted above for pointing, when I.G. was asked to delay her grasping action, she improved her poor ability to perform accurate actions (for review, see Milner and Dijkerman, 2001). Knowing that the effect of a memory delay is different from that of a long presentation of a stimulus in normals (see Rossetti and Pisella, 2002), we investigated this possibility with I.G. She exhibited a better performance in both tasks, suggesting that the long presentation and the delay enabled her to form a representation of the object that could be used by the action system. Given her bilateral lesion of the posterior parietal cortex, this representation was postulated to be formed via the ventral stream (see also Milner et al., 1999). An interesting question arises whether it is possible to generate a conflict between this

sustained cognitive representation necessary for intention and the more automatic short-lived representations. Together with David Milner and Chris Dijkerman, we designed an experiment in which an object was presented for 2 s, then hidden behind a panel for 8 s, then presented again. Under these conditions, I.G. improved her grip scaling with respect to an immediate action condition. When, however, the object was unexpectedly replaced by a larger or smaller one, she initially scaled her grip to her internal representation rather than to the actual object she was reaching to (see Rossetti and Pisella, 2002: figure 19). Control subjects tested under the same conditions exhibited an on-line grip formation that was adapted to the object actually in front of them at the time of the grasp (see also Milner and Dijkerman, 2001). In addition to the effect found on grip size, the time to maximal grip aperture was reached earlier in the "large→small" condition with respect to the large condition for each of the six control subjects, whereas I.G. exhibited a similar value in the two conditions. In the particular trials where she "correctly" opened her hand widely on "small→large" catch trials, the wide grip aperture actually occurred abnormally late in the movement. This result strongly suggests that I.G. could not process the change in size that had occurred during the delay fast enough to early update her ongoing movement.

These results clearly confirm that sensorimotor and cognitive representation have different time constraints. They also suggest that responses produced by normal subjects in serial experimental conditions can be triggered even before the intention to control the action has been formed.

### 3.8 Intention: Parietal-Frontal versus Dorsal-Ventral

As predicted by Lhermitte et al. (1986), the environmental dependency syndrome described in patients with a frontal lesion appears to result from the release of parietal lobe activities. The main brain areas where a lesion may induce a dysinhibition syndrome lie in the orbitofrontal and basotemporal cortex, predominantly in the right hemisphere (for review, see Starkstein and Robinson, 1997), as was already indicated in the case of epileptic seizures by Penfield (1975). After reviewing studies on patients with closed head injuries, brain tumors, stroke lesions, and focal epilepsy, Starkstein and Robinson (1997, p. 112) concluded: "Based on the phylogenetic origin of these cortical areas and their main connections with dorsal regions related to visuospatial functions, somatosensation, and spatial mem-

ory, the orbitofrontal and basotemporal cortices may selectively inhibit or release motor, instinctive, affective, and intellectual behaviors elaborated in the dorsal cortex." Although some (e.g., Rolls, 1999) have claimed that the automatism released following a frontal lesion may be linked to a basal ganglia activity, others (e.g., Pisella et al., 2000; Rossetti and Pisella, 2002) propose that the posterior parietal cortex is a key structure for the automatic control of action.

The findings that automatic corrections in response to a change in target location are disrupted in optic ataxia whereas these corrections are fully released following a lesion of the frontal cortex suggest the existence of a double dissociation between parietal and frontal patients for the control of very simple visual pointing (Pisella et al., 2000). Frith and colleagues (2000) also describe optic ataxia and anarchic hand syndrome as involving mirror deficits. Whereas optic ataxia patients cannot form representations of objects needed to make the appropriate movements to reach to and grasp them, anarchic hand patients cannot prevent the sight of the objects from eliciting those movements.

That the posterior parietal cortex is involved in the release of automatic behavior is consistent with the most recent versions of the dorsal-ventral distinction (e.g., Rossetti et al., 2000; Pisella et al., 2000). Indeed, we have proposed that a specific activation of the dorsal stream, at least of the superior parietal cortex, would occur only in the case of automatic on-line control of an ongoing action, whereas tasks such as movement initiation would involve the inferior parietal cortex, and more indirect tasks (e.g., identification) would depend on the ventral stream (for review, see Rossetti and Pisella, 2002). (It should be remembered here that complex behavior can be initiated by frontal patients or during epileptic seizures and sleep, but by contrast to normal conditions, this initiation is strongly linked to an alteration of consciousness that is obvious at least during seizures and sleep related motor disorders [see Revonsuo et al., 2000].) In the postulated gradient of activity ranging from on-line action control to action initiation to action planning to cognitive tasks, the precise distribution of frontal projections of the various pathways remains unclear. Nevertheless, analysis of the visuomotor networks involved in action control (see Burnod, 1999; Rossetti et al., 2000; Pisella and Rossetti, 2000; Marconi et al., 2001; Rossetti and Pisella, 2002) shows that several frontal areas may be involved separately. In particular, because projections from the ventral stream extend into the more anterior frontal areas, the indirect tasks left intact in optic

ataxia may share some neurological substrate with the frontal areas involved in intentional aspects of behavior. On the other hand, the frontal projections from the posterior parietal cortex involved in the hand automatic pilot seem to be directly connected to the premotor areas, which may not primarily participate in intentional action.

Thus the dissociation proposed between dorsal and ventral streams may not be the most relevant distinction to the issue of intention. Rather, the processes governing automatic and intentional behavior appear to be associated with posterior parietal and prefrontal areas respectively.

### 3.9 Conclusion

Intention lies at the intersection of several approaches. To experimentally explore intention, we need to arrive at a pragmatic definition and operating criteria. This task becomes very difficult when global functions are concerned, as is the case with neuropsychology or clinical neurology. Although there is no unified framework in which we might describe a specific "pathology of intention," and, in particular, no positive symptomatology of intention disorders, neuroscientists seem less reluctant to refer to "intention" than to "consciousness," perhaps because intention is attached to behavior—to overt phenomena—whereas consciousness remains largely a covert phenomenon. Thus it seems easier to distinguish between automatic and intentional than between conscious and nonconscious processes. Nevertheless, there is a strong link between intention and consciousness. Even though consciousness does not imply intention, intention implies consciousness (cf. Revonsuo and Rossetti, 2000). Indeed, it is only when a subject has conscious knowledge of the elements of a given situation that an intentional project can emerge. This functional property is consistent with the thesis that lesion of both orbitofrontal and basotemporal areas may result in dysinhibited behavior (Starkstein and Robinson, 1997).

Intentional behavior can be characterized by two main features: (1) the ability to inhibit immediate reactions to external stimuli; and (2) the ability to plan a goal-oriented organized sequence of actions. Indirect tasks, because they better express the freedom of the individual to respond or not to respond to a given stimulus, seem to be more relevant to the issue of intention than most classical motor psychophysics tasks, all of which allow investigators to specifically activate the temporoprefrontal network rather than the dorsal stream (cf. Rossetti and Pisella, 2002).



One should carefully consider the theoretical distinction between intention and automatism. Although they are less direct responses to stimuli than immediate responses, delayed tasks may be well conditioned, as can be seen in animal experiments. And although no-go tasks may appear to be typical intentional tasks, in the case of overtraining, the boundary between intentional and automatic responses becomes fuzzier. Indeed, intense training may transform an intentional response of an automatic conditioned reaction into a stimulus. This aspect of the relationship between intentional and automatic control of behavior is worth keeping in mind before making firm conclusions about the neurobiology of intention.

Because particular aspects of sensory processing for the purpose of action, and especially for movement guidance, remain fully independent of conscious perception (Pélisson et al., 1986), action can be directed to unconsciously perceived stimuli, even though conscious awareness allows for a perceptual control of action (Pisella et al., 2000). Specifically, conscious visual perception and intention select the goal for the action, but the triggering and the realization of the action may escape their control.

We have proposed elsewhere (Rossetti et al., 2000; Pisella and Rossetti, 2000; Rossetti and Pisella, 2002) that the temporal dimension is a key to understanding complex interconnected networks such as the visual brain. Because the relationship between perception and action and that between conscious awareness and intention are linked, we submit that temporal factors may be relevant to the latter as well. As proposed by Milner and Dijkerman (2001), the primary role of consciousness may be to delay action in order to gain behavioral efficiency, just as an animal's ability to slow, delay, or inhibit immediate actions may also help it achieve a more useful (hidden external or internal) goal (Rossetti and Pisella, 2002). The prospective memory paradigm may offer an optimal tool to explore the ability to plan—and hold an intention toward—future behavior. In this regard, it is interesting that patients with frontal lobe lesion may exhibit a deficit in prospective memory without a corresponding deficit in retrospective memory (Cockburn, 1995).

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