Abstract
This study compared the postural strategies adopted by patients with Parkinson’s disease (PD; n=16) during locomotion to those of elderly controls (n=16). We focused mainly on the head and trunk stabilization modes in sagittal and frontal planes. Subjects were asked to walk at their natural speed on an uniformly gray, flat ground. Gait data were recorded before and 1 h after L-dopa intake and were analyzed by an automatic motion analyser (Elite system). The modes of segmental stabilization adopted by each group were determined by means of the anchoring index, associated with cross-correlation functions between angular movements of pairs of segments. The major findings were: (a) PD patients generally had shorter step length, greater step width, and slower gait velocity than the healthy elderly. (b) No difference in angular dispersion of any anatomical segment studied was observed between the two groups. (c) PD patients had adopted a strategy of head stabilization on the shoulder (“en bloc” functioning of the head-shoulder unit) about the roll axis only. (d) PD patients displayed head and shoulder angular movements around the roll axis that were more correlated than those of controls, confirming their more en bloc functioning. (e) Shoulder and hip were equally stabilized in space in the two groups around the roll axis. (f) There was no difference between the two groups about the pitch axis where an en bloc functioning of the whole trunk was shown. These results are discussed with respect to the similarities observed between the visuo-locomotor PD performances and those of children.

Key words
Gait analysis · Parkinson’s disease · Segmental stabilization strategies · Visual cues

Introduction
Walking abilities are almost always impaired in patients with Parkinson’s disease (PD). Generally gait disorders are associated with a loss of independence and an increased incidence of falls (Koller et al. 1989; Morris et al. 1994). The gait of PD patients is very stereotyped and clearly recognizable. Gait hypokinesia (slowness) is one of the primary and most frequent movement disorders in PD. During the past 20 years the results of several quantitative studies of walking performances have been published. These mainly demonstrate a decrease in gait velocity associated with a decreased step length, with a relatively maintained cadence (Azulay et al. 1996; Blin et al. 1990; Knutsson 1972; Marsden 1994; Murray et al. 1978). Diener et al. (1990) has reported that electromyographic activities of lower limbs are altered and latencies of muscular responses. A decrease in limb flexion-extension has also been described (Fosberg et al. 1984; Stern et al. 1983). Reduced hip, knee, and ankle rotations in the sagittal plane have been shown to depend on the stage of PD (Murray et al. 1978). In fact, Zijlmans et al. (1996) have distinguished the gait pattern of patients with vascular parkinsonism from that of patients with idiopathic PD, in whom gait velocity was equally reduced. Patients with vascular parkinsonism showed less flexion dystonic posture of the elbow, hip, knee, and trunk throughout the gait cycle than patients with PD. This clearly implies a precise selection of patients with idiopathic PD when analyzing their gait disorders. Until now, although many kinematic data are available on this population, little is known about the angular movements of the upper trunk and the head in walking by PD patients.

An improvement in PD patients’ gait by sensory cueing has been demonstrated by several authors. As regards the visual contribution to locomotor control and the effects of visual defects in parkinsonism (Mestre et
al. 1990), however, they are still only little understood, since visual cues may improve gait velocity as well as induce both festination and freezing (Glickstein and Stein 1991). In fact, transverse visual stripes placed on the floor have been shown to definitely improve gait hypokinesia (Azulay et al. 1999; Martin 1967). The latter authors have reported that this improvement, demonstrated by an increase in step length and mean velocity, results mainly from to the dynamic flow of the retinal image due to the locomotor movements, since the gait pattern remains unchanged when the stripes are viewed under stroboscopic illumination. This improvement in the gait pattern due to visual flow leads to the question of head movements during locomotion.

Human locomotion is a rhythmic activity that induces corresponding rhythmic oscillations of the trunk and the head in both the sagittal and the frontal planes (Grossman et al. 1988). The orientation of the head with respect to space, however, may have to be maintained to serve as an egocentric reference value both for controlling the movement trajectory and for improving the processing of the sensory feedback from the head required to maintain balance (Amblard et al. 1997; Berthoz and Pozzo 1988). In healthy walking adults an efficient stabilization of the head (Berthoz and Pozzo 1988; Grossman et al. 1988) and of the gaze in space (Grossman et al. 1989) have been demonstrated, and it emerges that head orientation along a vertical axis is fairly well stabilized during various locomotor task. Moreover, healthy adults have been shown selectively to adopt a strategy of head stabilization in space in the case of lateral balance difficulty (Assaiante and Amblard 1993). Given the increased visual dependence of PD patients for postural control (Bronstein 1988; Bronstein et al. 1990) and their suspected balance impairment even while walking on flat ground, we could expect that head stabilization in space strategy is a key factor in their locomotor performance.

The present experiment compared the postural strategies of segmental stabilization (those of the head, shoulders, trunk, and pelvis) adopted by PD patients while walking to those of normal elderly subjects in both the sagittal and the frontal planes. We also addressed the question of the possible effect of levodopa on the efficiency of these strategies. PD patients were thus analyzed both before and after treatment with L-dopa.

### Materials and methods

#### Subjects

Thirty-two subjects were included in this study: 16 patients with idiopathic PD (9 men, 7 women; mean age 68.8±4 years) and the same number of age-matched controls (7 men, 9 women; mean age 67.5±5 years). All patients were clinically diagnosed as having idiopathic PD according to the United Kingdom Brain Bank diagnostic criteria (Gibb and Lees 1988) and had experienced sustained improvement with dopaminergic treatment: 11 PD patients were in stage II (Hoehn and Yahr) and 5 in stage III. The mean disease duration was 6.3 years. The recordings were carried out at the same hour in the morning. All patients and controls participat-

#### Protocol

PD patients fasted overnight, without treatment for at least 12 h. They were analyzed in two successive experimental sessions, the first one before (P1) and the other at least 1 h after treatment (P2). After three consecutive walks in each session to accustom them to the task, subjects were instructed to perform normal locomotion at their natural speed, looking ahead with no specification made about foot positioning. All subjects were walking on an uniformly gray flat ground. The study was performed on a 10-m walkway, and the gait pattern was analyzed during a 3-m walk after the subjects had already walked 4 m.

#### Data collection

The kinematics of the body movements were analyzed by means of an optical TV image processor (Elite system) working at 100 Hz and based on passive markers. The four cameras were placed behind the subjects, at 3.5 m of the useful acquisition volume (2.5×3.5×2 m). Under these conditions the system accuracy was such that the error of a single measurement was less than 1.5 mm on the marker three-dimensional position and about 1° on the measured angles.

Fifteen retroflective markers (6 mm in diameter) were placed symmetrically in pairs on the subject’s back at the following sites: first metatarsus joint, external malleolus, tibial plate, posterio-superior iliac crest, acromion, and the base of occipital bone; the three last markers were placed on the sacrum, at the seventh thoracic vertebra, and at the seventh cervical vertebra (Fig. 1). This arrangement of the markers was aimed mainly at analyzing angular movements of the head, shoulder, hip, trunk, and thigh around the anteroposterior and transversal axes.

Data were stored on the hardisk of a PC. Three-dimensional markers coordinates recorded underwent an off-line processing, consisting of tracking, three-dimensional reconstruction and digital filtering for noise reduction by means of a finite impulse response filter (D’ Amico and Ferrigno 1990).

#### Data analysis

The following parameters were considered in evaluating the subject’s performance under the experimental conditions:

- Four gait parameters were calculated in each trial: mean velocity, stride length, cadence, and the gap between the centers of rotation of ankles during double support phases (step width).
- The mean angular and linear head accelerations in the frontal plane in each trial were the averaged values over the whole duration of the trial.
- The angular dispersion $\sigma_b$ of any body segment measured was 1 SD of its absolute angular distribution (with respect to external axes) in each trial.

The anchoring index (AI) was used to compare the stabilization of a given segment with respect both to external space and to the inferior anatomical segment (Amblard et al. 1997; Assaiante and Amblard 1993). AI was given in each trial by the following formula:

$$AI=[(\sigma_b^2)-(\sigma_a^2)]/[(\sigma_b^2)+\sigma_a^2]$$

where $\sigma_b$ is as previously defined and $\sigma_a$ is the standard deviation of the relative angular distribution (with respect to axes linked to the inferior anatomical segment) of the segment being considered. For example, a positive value of the head AI indicates a better head stabilization in space than on the shoulder (articulated operation of the head-shoulder unit), while a negative value indicates a better head stabilization on the shoulder than in space (“en bloc” functioning of the head-shoulder unit) (Assaiante and Amblard 1993).