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GAIT IN RELATION TO AGEING AND IDIOPATHIC PARKINSONISM

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ABSTRACT. Distance/time measures of gait in 105 sufferers from idiopathic Parkinsonism, who were able to walk unaided, and 144 healthy controls were examined systematically. Those sufferers with overt fluctuations in control were assessed during their "therapeutic window". Free walking speed was lower for a given cadence in the sufferers, but reached a plateau whilst cadence could still be increased. Age, cognitive function and the range of passive hip flexion were important determinants of gait in them. Even minor degrees of cognitive impairment were associated with reduced free walking speed in sufferers: it appears unwise that they were prescribed more sedatives than the controls. The potential benefit of physiotherapy in maintaining joint flexibility was noted. The deficits in speed of individual sufferers, and hence the estimated potential for prophylaxis and treatment, were unrelated to age at presentation. There was no evidence for a limited period of responsiveness to levodopa therapy in this cross-sectional study.

Key words: Parkinsonism, gait, cognitive function, hip flexion, physiotherapy.

Both a slow speed with low cadence (stride frequency) and a shuffling gait with a high cadence are held as typical of Parkinsonism. We have examined the relationship of free walking speed to cadence and age in sufferers from idiopathic Parkinsonism, whose ages spanned five decades, as compared with healthy control subjects. Factors influencing gait in Parkinsonism are described, with the aim of identifying adverse influences, which may be susceptible to therapy, and beneficial interventions, whose use might be adopted more generally.

SUBJECTS AND METHODS

One hundred and five volunteers with idiopathic Parkinsonism (up to a maximum of 12 men and 12 women in each decade between 40 and 89 years) gave informed consent to take part in the study, which had local ethics committee approval. Parkinsonism had been diagnosed for a mean (SD) of 73 (64), range < 1 to 336, months. Of the 105 sufferers, 93 were receiving medication to treat Parkinsonism. Those whose performance fluctuated in relation to individual doses of anti-Parkinsonian medication were studied in their "therapeutic window", defined here as the period, in the dosage interval, during which optimal effects of medication occur. Untreated subjects were excluded, if it was considered that they might benefit from such medication.

Two of the four cardinal signs (brady/hypokinesia, rigidity, tremor, and postural abnormality) were required for diagnosis. Alternative causes of Parkinsonism were excluded (17), but a "$\leqslant$50% improvement on adequate dopamine replacement therapy" was not necessary for entry. Some had never received such therapy, and in others the response had not been quantified. There was no history of other specific neurological disorder, or of musculoskeletal disorder. All had English as their first language, and were able to walk for well over 20 m, or 30 s, without fatigue, dyspnoea, angina, claudication or musculoskeletal pain, and without a walking aid. Sufferers exhibiting clinical dementia (or with a cognitive function score of $\leqslant$8/16 (7)), clinical depression or other mental illness were excluded, as were those with gross abnormality of lower limbs, previous orthopaedic surgery to spine or lower limbs, or pain in relevant joints.

Data from 144 healthy volunteers, comprising 12 men and 12 women in each of the six decades between 30 and 89 years, are used for comparison (8).

Distance/time measurements of gait in shod subjects were obtained at free walking speed, using the gait assessment trolley (21). This is a computerized method, based on infrared telemetry, which allows each subject to walk freely in a non-laboratory environment. Subjects walked a marked distance of 20 m, or for up to 30 s, in a 2.5 m wide, empty corridor.

The following were recorded:

(a) *common physical variables* (age, height and weight),
(b) *mean standing body sway* (for three consecutive minutes (22)),
(c) *functional anatomy of spine and lower limbs and strength* (14) *in corresponding muscle groups* (active forward and lateral flexion of spine; range of passive movements, at hip, knee, ankle, subtalar, mid-tarsal and great toe metatarso-phalyngeal joints, using commercially available goniometers),
(d) *psychological variables* (cognitive function (7), affect (1) and consumption of sedatives and alcohol),
(e) *Parkinsonian variables* (Hoehn & Yahr staging (9), Webster rating (20) and the time from diagnosis),

(f) *treatment-related variables* (whether receiving anti-Parkinsonian medication and, if so, its nature. In those receiving levodopa: duration of therapy, daily dose, and plasma concentrations of levodopa and 3-O-methyldopa (30MD), its long half-time, peripheral metabolite, in a blood sample taken immediately after gait assessment (3)).

We have attempted an empirical approach to explain the variability in distance/time measures of gait in terms of subject characteristics in sufferers from Parkinsonism. The approach is more systematic than any which, to our knowledge, has previously been reported. The data were subjected to simple and multiple linear regression analysis, using distance/time measures of gait as dependent variables. Independent variables considered were from data sets a) to e), cadence and (when modelling for double support time and stride length) free walking speed. Values for each dependent variable, corrected for the influences seen in the "overall" multiple linear regression models, were compared for the drug treatment categories of data set (f). In those receiving levodopa, alone or in combination, the contribution of the quantified treatment-related variables to the overall models was assessed. The critical level of significance was taken as $p=0.01$, and assumptions of normality and homogeneity of variance were checked.

RESULTS

Quantitative description of gait in Parkinsonism

Free walking speed in the sufferers from Parkinsonism was approximately 76% of that of healthy controls (median difference adjusted to age 60 years, 0.23 $m \cdot s^{-1}$ (95% C.I. 0.17, 0.28), $p<0.0001$) and their cadence was lower, (median difference adjusted to 60 years, 5.61 (2.32, 8.73) min^{-1}), $p=0.001$). The relationship between speed and cadence (Fig 1*a*), in those with and without Parkinsonism, was best described by a parallel quadratic model (adjusted R^2 60%).

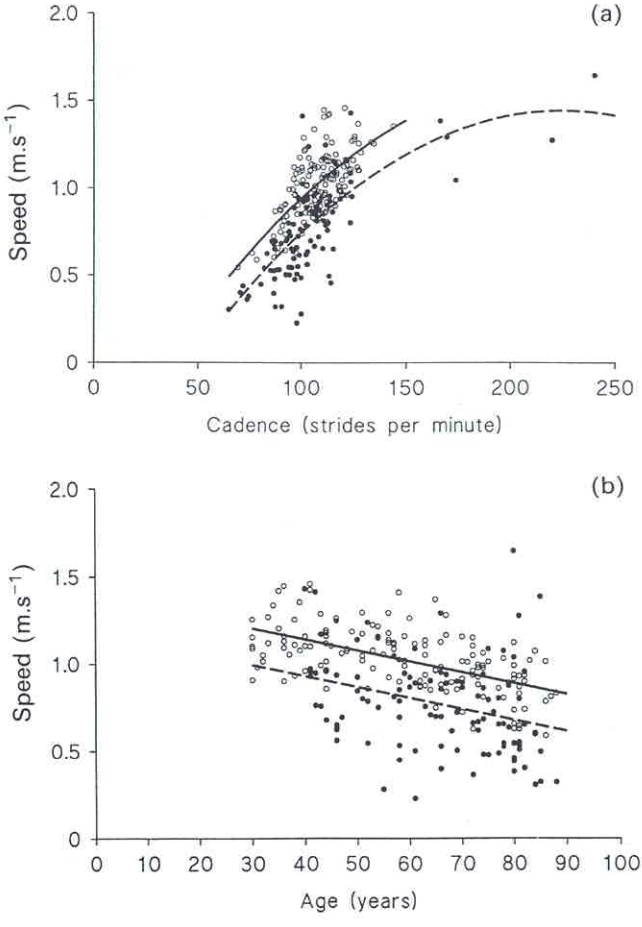

Fig. 1. Plot of free walking speed against (*a*) cadence and (*b*) age in subjects with (●) and without (○) Parkinsonism. The lines for subjects with (– – –) and without (——) Parkinsonism show the model which best describes the data from both groups.

Influences on speed

Statistically significant influences, and trends and negative findings of importance, were as follows:

(a) Common physical variables. The relationship between speed and age was significant in both sufferers from Parkinsonism (slope −0.0063, s.e. 0.0019, $m \cdot s^{-1} \cdot y^{-1}$, $p=0.001$) and controls (slope −0.0063, s.e. 0.0008, $m \cdot s^{-1} \cdot y^{-1}$, $p<0.0001$) and was best described in all 249 subjects by a parallel linear model (R^2 37%) (Fig. 1*b*). Individual sufferers' potential for prophylaxis or treatment, as measured by deficit in speed, was independent of age at presentation ($p=0.7$).

(b) Body sway. In sufferers from Parkinsonism, mean sway, on average, was approximately 131% of that of controls (median difference adjusted to age 60y, $1.70° \cdot min^{-1}$ (95% C.I. 0.81, 2.68) min^{-1}, $p=0.0002$), but sway did not influence speed significantly in either group.

(c) Psychological variables. Sufferers from Parkinsonism had a slightly lower cognitive function score (median difference 0.5/16 (95% C.I. 0/16, 1/16), $p=0.0002$). In the sufferers, the lower the cognitive function score, the slower was the speed (slope 0.064, s.e. 0.015, $m \cdot s^{-1}$, $p<0.0001$). They were more depressed (median difference on the Hopelessness Scale 3/20 (95% C.I. 2/20, 3/20), $p<0.0001$) and consumed less alcohol (median difference 1 unit (95% C.I. 0, 2), in previous 24 *h*, $p=0.0001$), but more sedatives (χ^2, $p<0.0001$). Of the 105 sufferers, 48 were not consuming any medicine known to be sedative [scored 1], 48 were consuming a medicine with drowsiness as a side effect [scored 2], and 9 were consuming a drug with drowsiness as its therapeutic effect [scored 3] (4). Of the 144 without Parkinsonism, 140 scored 1 according to these criteria, one scored 2, and three scored 3. These variables did not influence speed in sufferers.

(d) Functional anatomy and muscle strength. Range of movement was less in the sufferers from Parkinsonism ($p<0.01$) for almost all movements tested. Hip flexion was a particularly important determinant of speed (slope 0.0084, s.e. 0.0019 $m \cdot s^{-1} \cdot °^{-1}$, $p<0.0001$) in sufferers. The median difference between sufferers and controls was 7.0° (95% C.I. 5.0°, 9.5°, $p=0.0001$). The effect of reduced muscle strength on speed ($p=0.04$) did not reach the required level of significance.

(e) Parkinsonian characteristics. Global ratings, Hoehn & Yahr staging (median III) and Webster

Table I. *Nature of (i) overall model, and of (ii) alternative models using variables selected from all but speed and cadence for gait, in Parkinsonian subjects*

	(i)		(ii)	
Dependent variable	Independent variables	Parameter estimate (s.e.)	Independent variables	Parameter estimate (s.e.)
Free walking speed ($m \cdot s^{-1}$) ($\times 10^2$)	1†	−25.0 (17.8)	1	−77.0 (25.4)
	Cadence (min^{-1})	0.766 (0.066)***	Hip flexion	0.714 (0.177)***
	Age (y)	−0.579 (0.121)***	Cognitive function	5.36 (1.43)**
	Hip flexion (°)	0.544 (0.124)***		
Mean stride length (mm)	1	781 (13)	1	623 (198)
	Speed ($m \cdot s^{-1}$)	1139 (15)***	Age	−6.80 (1.38)***
	Cadence (min^{-1})	−7.48 (0.17)***	Hip flexion	6.35 (1.41)***
Log (mean) double support time (s)) ($\times 10^2$)	1	−156 (8)	1	1.29 (45.05)
	Speed ($m \cdot s^{-1}$)	−142 (10)***	Cognitive function	−10.2 (2.5)***
			Hip flexion	−1.11 (0.31)**

† constant

** (≤ 0.001) and *** (≤ 0.0001): *p*-values associated with removal of that independent variable separately from the model.

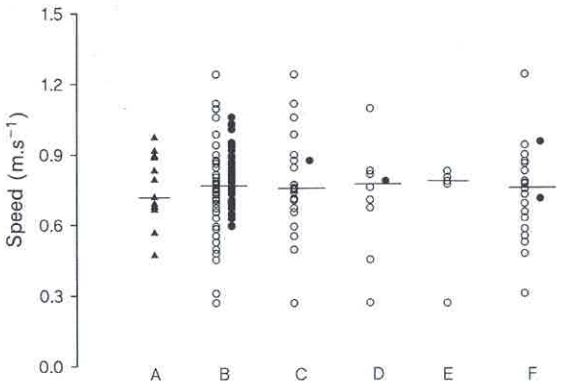

Fig. 2. Effect of drug treatment, and its nature, on free walking speed in 105 subjects with idiopathic Parkinsonism. The drug treatment categories were (A) no anti-Parkinsonian medication (▲), and (B to F) the five categories of medication given alone (●), or in combination (○) with one or more drug from other categories. Medications were B, levodopa/decarboxylase inhibitor, C, selegiline, D, bromocriptine or apomorphine, E, amantadine and F, benzhexol or orphenadrine. Speed has been corrected for the influences defined by the overall model (Table I).

rating (median 10/30) explained only 9% and 17%, respectively, of the variance in speed. The ratings for tremor and rigidity on the Webster scale did not influence speed.

(f) Treatment-related variables. The overall multiple linear regression model for free walking speed is shown in Table I: the linear modelling was not significantly influenced by whether subjects were receiving anti-Parkinsonian medication or, if so, its nature (Fig. 2). In the 83 subjects receiving levodopa, there was a tendency ($p=0.02$) for an association between plasma levodopa concentration and free walking speed (an increase in speed of 0.07 $m \cdot s^{-1}$ per 500 $ng \cdot ml^{-1}$ increase in concentration). Younger sufferers had been taking levodopa for longer ($p<0.01$) and were receiving higher doses ($p<0.001$), but there was no association between speed and duration of therapy, daily dose or plasma 3OMD concentration.

Models for free walking speed, stride length and double support time in Parkinsonism

The nature of the multiple linear regression models for these variables are also shown in Table I. (A $\log_e$ transformation was necessary for double support time to ensure that the assumptions of normally distributed residuals and equality of variance were valid.) The variance explained by the overall models for free walking speed, stride length and double support time was 65, 98 and 65%, respectively. "Alternative" models were constructed, using only independent variables, which were not themselves measures of gait: these explained 25, 35 and 24% of the respective variances. Thus, nearly two-thirds of the variance in the free walking speed of sufferers was explained by an equation containing cadence, a quarter by patient characteristics alone. Similarly, nearly two-thirds of the variance in mean double support time was explained by speed, less than a quarter by patient characteristics alone. Of course, mathematically, speed and cadence define mean stride length but, in their absence, it was possible to explain a third of its variance in sufferers.

DISCUSSION

Opinions as to what may or may not affect outcome in idiopathic Parkinsonism easily become established as dogma, and professional conservatism then inhibits the necessary radical approach to rationalising therapy. Another major hurdle to overcome is that methods for evaluating traditional practice and potential advances, which are appropriate for use in the disabled are not always readily available. The emphasis needs to be shifted from arbitary, and often unrealistic, expectations of benefit to convincing objective measures of outcome, which are suitable for the sufferers. Measures of the impact of Parkinsonism, relied upon in clinical practice, are often subjective and designed with young adult patients in mind, and the global score holds hegemony. These global ratings may include questions so diverse that the effect of any particular influence is masked, or be so much of an overview as to be insensitive to influences which are therapeutically useful. Indeed, in the present study, free walking speed, a major component of disability, was poorly reflected by the Webster rating of the severity of Parkinsonism, and by the Hoehn and Yahr staging. The need for accurate quantification of disability seems obvious. However, simple timed tests advocated may not be sensitive enough to detect beneficial or adverse influences (2). Here we have used gait analysis under standardised conditions as a measure of disability, having previously demonstrated its sensitivity to treatment effects in Parkinsonism in old age (3).

Gait was examined at free walking speed since this

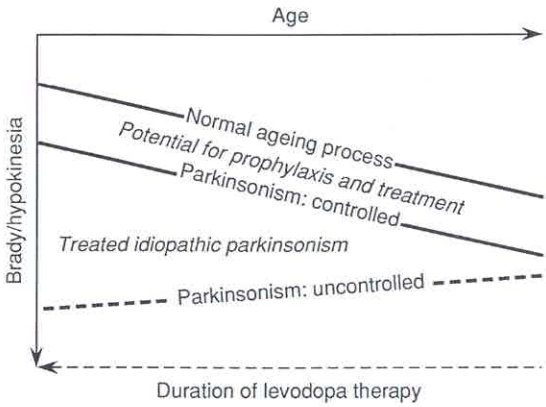

Fig. 3. Model for brady/hypokinesia in relation to ageing and Parkinsonism. In those with overt fluctuations in relation to dosing, controlled refers to ability during the therapeutic window. A hypothetical relationship (- - -) between disability in the uncontrolled state and the duration of levodopa therapy is superimposed.

has proved reproducible in healthy subjects, not only within but also between (16) sessions. A maximal performance test might be expected to be less spontaneous and more dependent on motivation.

Sufferers from Parkinsonism had a higher cadence than normals for any given speed, as well as longer double support times and shorter strides (11, 15). The variability in the measures of gait was greater in those with Parkinsonism than in those without. However, the "normal" effect of the ageing process on free walking speed (8) was only partially obscured here by the presence of Parkinsonism. In general, fewer influences on gait (which were not themselves distance/time measures) were isolated and a smaller percentage of the variability in gait was explained in the sufferers (8). However, the work not only defined the potential for prophylaxis and rethinking of treatment, but also allowed therapeutic myths and dogma to be examined.

Speed, as a measure of the bradykinesia of Parkinsonism, did not appear to be influenced by variables relating to the other cardinal signs (ratings of tremor and rigidity, and body sway as a measure of postural instability). There was no evidence to suggest that the deficit in speed in individual Parkinsonians, relative to age-matched controls, differed with age at presentation. The data support the hypothesis of Calne & Langston (5), which superimposes an environmental insult onto the age related decline in dopamine, rather than the earlier accelerated ageing hypothesis. There is, thus, no reason to suggest that the potential for prophylaxis and further treatment is not the same in young and old, but, of those controlled by current therapy, the older ones have more brady/hypokinesia (Fig. 3). However, in practice, severe uncontrolled end of dose freezing is more common in the young sufferer. In general, they have been on levodopa treatment for a longer time than older sufferers (13): freezing may be due to an adverse effect of prolonged therapy, or the higher dosage which comes with it.

Although our sufferers from Parkinsonism had only slightly lower cognitive function scores (19) than controls, this appeared relevant to free walking speed. Indeed, cognitive ability was selected for the model for speed from which cadence had been excluded. Iatrogenic sedation appears unwise in such patients, particularly when they, themselves, choose to drink less alcohol (6). Neither these exogenous substances, nor depression (18), altered performance under test conditions, but they may well do so during daily living.

Poor nutrition due to swallowing difficulties and, possibily, increased resting energy expenditure (12), plus poverty of movement, result in disuse atrophy of muscle and decreased range of joint movement. Reduced muscle strength was not an important determinant of gait over a 20 m or 30 s walk, but may assume importance when walking to a symptomatic end point. The importance of hip flexion (11, 15) in the linear modelling emphasises that of physiotherapy in maintaining joint flexibility, both as an end in itself and in allowing the full potential of anti-Parkinsonian medication to be realised. Indeed, in trials of efficacy of medication with mobility as the outcome criterion, it is essential that the patients be kept at the optimum that they can achieve by physiotherapy throughout.

Speed, even after adjustment for the major influences of cadence, age and hip flexion, was not influenced by the nature of anti-Parkinsonian medication when subjects were assessed in their "therapeutic window" (where relevant). There was a tendency towards a small positive effect of the plasma levodopa concentration on speed, but no negative effect of the 3OMD concentration (10). In this cross-sectional study, we found no evidence of a limited duration of responsiveness to levodopa therapy, suggesting that chronicity alone should not be a bar to active management.

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REFERENCES

1. Beck, A. T. & Beamesderfer, A.: Assessment of depression: the depression inventory. *In* Psychological measurements in psychopharmacology. Vol. 7, Modern problems in Pharmacopsychiatry (ed. P. Pichot), pp. 151–159. Karger, Basel, 1974.
2. Bowes, S. G., Clark, P. K., Charlett A, O'Neill, C. J. A., Leeman A. L., Weller, C., Nicholson, P. W., Deshmukh, A. A., Dobbs, S. M. & Dobbs, R. J.: Outcome criteria in trials of anti-Parkinsonism therapy in the elderly: sensitivity, specificity and reliability of measures of brady- and hypokinesia. Br J Clin Pharmac *31:* 295–304, 1991.
3. Bowes, S. G., Clark, P. K., Leeman, A. L., O'Neill, C. J. A., Weller, C., Nicholson, P. W., Deshmukh, A. A., Dobbs, S. M. & Dobbs, R. J.: Determinants of gait in the elderly Parkinsonian on maintenance levodopa/carbidopa therapy. Br J Clin Pharmac *30:* 13–24, 1990.
4. British National Formulary No. 15: British Medical Association and the Pharmaceutical Society of Great Britain. London, 1988.
5. Calne, D. B. & Langston, J. W.: Aetiology of Parkinson's disease. Lancet ii: 1457–1459, 1983.
6. Carlen, P. L., Lee, M. A., Jacob, M. & Livshits, O.: Parkinsonism provoked by alcoholism. Ann Neurol *9:* 84–86, 1980.
7. Denham, M. J. & Jefferys, P.: *In* Source book of geriatric assessment. Vol 2, p. 52, Karger, Hampshire, 1984.
8. Dobbs, R. J., Lubel, D. D., Charlett, A., Clark, P. K., Bowes, S. G., O'Neill, C. J. A., Weller, C., Hughes, J., Walker, C. A., Deshmukh, A. A., Dobbs, S. M.: Hypothesis: age-related changes in gait encompass a tendency towards Parkinsonism. Age Ageing, 1992 (In Press).
9. Hoehn, M. M. & Yahr, M. D.: Parkinsonism: Onset, progression and mortality. Neurology *17:* 427–442, 1967.
10. Hughes, J. R., Bowes, S. G., Leeman, A. L., O'Neill, C. J. A., Deshmukh, A. A., Nicholson, P. W., Dobbs, S. M. & Dobbs R. J.: Parkinsonian abnormality of foot strike: a phenomenon of ageing and/or one responsive to levodopa therapy? Br J Clin Pharmac *29:* 179–186, 1990.
11. Knutsson, E.: Analysis of Parkinsonian gait. Brain *95:* 475–486, 1972.
12. Levi, S., Cox, M., Lugon, M., Hodkinson, M. & Tomkins, A.: Increased energy expenditure in Parkinson's disease. Br med J *301:* 1256–1257, 1990.
13. Ludin, S. M. & Ludin, H. P.: Is Parkinson's disease of early onset a separate disease entity? J Neurol *236:* 203–207, 1989.
14. Medical Research Council.: Memorandum No. 45. Aids to the examination of the peripheral nervous system. Her Majesty's Stationery Office, London, 1975.
15. Murray, M. P., Sepic, S. B., Gardner, G. M. & Downs, W. J.: Walking patterns of men with Parkinsonism. Am J Phys Med *57:* 278–294, 1978.
16. O'Neill, C. J. A., Charlett, A., Dobbs, R. J., Deshmukh, A. A., Bowes, S. G., Weller, C., Nicholson, P. W., Milledge, A. & Dobbs, S. M.: Effect of captopril on functional, physiological and biochemical outcome criteria in aged heart failure patients. Br J Clin Pharmacol *33:* 167–178, 1992.
17. Quinn, N. P. & Hussain, F. A.: Parkinson's disease . Br med J *293:* 379–381, 1986.
18. Sloman, L., Berridge, M., Homatides, S., Hunter, D. & Duck, T.: Gait patterns of depressed patients and normal subjects. Am J Psychiat *139:* 94–97, 1982.
19. Visser, H.: Gait and balance in senile dementia of Alzheimer's type. Age Ageing *12:* 296–301, 1983.
20. Webster, D. D.: Clinical analysis of the disability of Parkinson's disease. Modern Treatments *5:* 257–282, 1968.
21. Weller, C., Dobbs, R. J., Tate, M. A., Telford, A., Klenerman, L.: Monitoring gait characteristics in orthopaedic and neurological patients by infra-red telemetry. *In* Biotelemetry X. Proceedings of tenth international symposium on biotelemetry (ed. C. J. Amlaner), pp. 575–580. The University of Arkansas Press, Fayetteville, 1989.
22. Wright, B. M.: A simple mechanical ataxia-meter. J Physiol (Lond) *218:* 27P–28P, 1971.

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