Exp Brain Res (2001) 137:478–486
DOI 10.1007/s002210000672

RESEARCH ARTICLE

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The Multiple Tasks Test. Strategies in Parkinson's disease

Received: 20 July 2000 / Accepted: 7 December 2000 / Published online: 20 February 2001

Abstract The clinical balance tests presently used cannot predict falls in Parkinson's disease (PD), perhaps because they probe fairly isolated "components" of postural control. The Multiple Tasks Test (MTT) is a new balance test that simultaneously assesses multiple components of postural control. We investigated whether this MTT can detect postural abnormalities in PD patients. Fifty young controls (mean age 27.6 years), 20 elderly controls (mean age 62.5 years), and 20 PD patients (mean age 61.8 years, mean Hoehn and Yahr stage 2.2) participated. The MTT consisted of eight separate tasks of increasing complexity, which were executed sequentially. These tasks were composed of several motor components (standing up, walking, avoiding obstacles, touching the floor, turning around, and sitting down) and one cognitive component (answering serial questions). Four additional components included carrying an empty or loaded tray, wearing slippery shoes, and reduced illumination. All components within each task had to be performed simultaneously or directly sequentially. Errors were defined as Hesitations (slowed performance) or Blocks (complete cessation), which were scored separately for execution of the motor and cognitive components. Speed of performance was not stressed, but we did measure the time taken to complete all tasks. The complete MTT was performed by all subjects, except for a subgroup of seven patients and seven elderly controls who performed a shortened version, with only three of the eight sequential tasks (simple, intermediate, and most difficult). The number of subjects that produced Hesitations or Blocks for the motor components differed between the three groups [two-way repeated measures MANOVA, *F*(2,7)=20.56; *P*<0.001], patients making more errors than young and elderly controls. Furthermore, the number of subjects that made motor errors increased as the tasks became more complex [*F*(2,7)=6.69; *P*<0.001]. This increase differed across the three groups [significant interaction effect; *F*(2,7)=3,31; *P*<0.001] because particularly patients produced motor errors during the more complex tasks. In both control groups, 62% performed all eight consecutive tasks without errors in the motor components. In contrast, only 8% of the patients completed all tasks without motor errors (log rank test, *P*<0.0001). This difference between patients and controls disappeared if the cognitive component was also scored, because more controls made cognitive errors during complex tasks than patients. Controls apparently gave priority to execution of the motor components, which they performed significantly faster than the patients. Both patients and controls made more errors during the shortened MTT, suggesting that learning effects (gain in performance through practice) influenced performance on the complete test. The MTT is a new balance test that clearly discriminates between healthy subjects and PD patients. Unlike controls, PD patients lend less priority to motor tasks over cognitive tasks. In addition, impaired motor learning may partially explain the higher error rate in PD. Future studies must determine if impaired MTT performance can predict actual falls in daily life.

Keywords Balance · Dual task · Parkinson's disease · Postural instability · Multiple tasks test

Introduction

Postural instability is a hallmark of idiopathic Parkinson's disease (PD) (Bloem 1992; Koller et al. 1989). It is one of the most incapacitating features of the disease because postural instability is difficult to treat (Bloem et al. 1996; Bonnet et al. 1987) and frequently leads to falls, even in

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relatively early stage PD (Bloem et al. 1998a). Prevention of these falls is important. Several strategies may be effective (Bloem et al. 2000a; Tinetti et al. 1994). To implement such prevention programs, fallers must be identified at an early stage, but this proves difficult. History taking is unreliable, as many patients forget their falls (Cummings et al. 1988), and presently used balance tests fail to predict falls in PD (Bloem et al. 1998a).

Falls are probably difficult to predict due to their multifactorial pathophysiology. Yet, most clinical balance tests investigate just one component of postural control, such as leg strength or undisturbed gait. Very few tests are specifically designed to measure the multifactorial character of postural instability. An exemption is the “stops walking when talking” test (Lundin-Olsson et al. 1997), which simultaneously challenges a motor component (walking) and a cognitive component (maintaining a conversation) of postural control. Elderly individuals who stopped walking while talking had an increased risk of falls (Lundin-Olsson et al. 1997). Apparently, walking when talking poses a “central processing challenge”. When this challenge can no longer be met, the risk of falling increases.

Multiple task performance may be particularly informative in PD patients because they cannot process simultaneous or sequential tasks adequately (Brown and Marsden 1991; Marsden 1982) and are easily distracted by irrelevant stimuli (McDowell and Harris 1997). PD patients also have difficulty with a second task while walking (Camicioli et al. 1998; Morris et al. 1996; Nisipeanu and Inzelberg 1997; Nutt et al. 1992) or even standing (Bazalgette et al. 1986). Interestingly, patients appear to have extra difficulties when the secondary task is more demanding (Bond and Morris 2000). In addition, many interacting factors contribute to balance impairment in PD (Bloem et al. 2000a; Rogers 1996), suggesting that simple assessment of isolated postural components may not suffice. Finally, PD patients may improve their motor performance (including balance and gait) by using external cues or by focusing attention on the task at hand, allowing the frontal cortex to compensate for the defective basal-ganglia circuitry (Dietz et al. 1993; Kitamura et al. 1993; Morris et al. 1994). These “conscious” motor strategies make PD patients vulnerable during performance of secondary tasks that distract their attention.

With these ideas in mind, we studied “stops walking when talking” in PD (Bloem et al. 2000b). To our initial surprise, the test was rarely abnormal and, moreover, did not predict falls in PD. The most likely explanation was that cognition was preserved in our patients, whereas most elderly persons described by Lundin-Olsson et al. (1997) were demented or depressed. Impaired dual-task performance thus seems a marker for falls associated with cognitive impairment, but not for falls caused by (extrapyramidal) motor disability (Bloem et al. 2000b).

It is possible that simultaneously challenging multiple postural components might better predict falls (particularly those that are related to motor disability) than a strictly dual-task design (Mulder et al. 1993). Before prediction of falls could be investigated, the present study was performed with two goals. First, we studied whether simultaneous performance of truly multiple (i.e., more than two) tasks could discriminate between healthy subjects and PD patients. For this purpose, we used a recently developed test battery (termed the Multiple Tasks Test or MTT), which exposes subjects to different combinations of up to eight different functional tasks (Bloem et al. submitted). Our second goal was to study the strategies for increasingly complex postural tasks in PD. Several studies have suggested that healthy subjects adopt a “priority strategy” that assures safe execution of certain task components at the expense of others (Mulder and Geurts 1991). This approach resembled the “posture first” strategy described for less-complex dual tasks (Chen et al. 1996; Shumway-Cook et al. 1997).

According to this view, patients might reveal various abnormalities. One possibility is that patients also employ such intended “priority processes”. Due to their underlying balance impairment and restricted central processing resources, patients would need to prioritize (make “errors”) during less complex tasks than healthy subjects. Patients and controls would thus show resemblance, albeit at differing task difficulties. This phenomenon indeed occurs in healthy subjects who show Parkinson-like impairments on cognitive tasks if sufficiently distracted by resource-demanding secondary tasks (Brown and Marsden 1991). Alternatively, patients may have lost the ability to lend priority to complete particular components of a complex task. If this were true, performance of the postural task would deteriorate by a challenge to multiple components of postural control. Patients might even be expected to fall, while attempting to continuously perform all components of the task. To answer these questions, we studied strategies for increasingly complex postural tasks in PD.

Materials and methods

Subjects

We studied 20 patients with idiopathic PD (Table 1). Fifty young, healthy subjects and 20 elderly subjects, which will be described in more detail elsewhere (Bloem et al. submitted) are also included here for comparison (Table 1). Patients were recruited from all consecutive appointments at our outpatient department. We included subjects who were ambulant community residents (with or without walking aids) and able to follow simple instructions [Mini Mental State Examination (MMSE) ≥24]. Subjects with other neurological, visual, or orthopedic problems were excluded. We also excluded patients with severe PD (Hoehn and Yahr stage 4 or 5) because the added benefit of a screening test for falls would be greatest in more moderately affected patients. Sixteen age-matched partners of the patients participated as controls. The remaining four controls were healthy hospital employees whose age, sex, and domestic variables were matched to those of the patients. All subjects gave informed consent as approved by the Ethical Committee of the Leiden University Medical Center.

Experimental design

Baseline clinical examination

One investigator (BRB) examined all subjects (patients approximately 1 h after intake of their usual antiparkinson medication).

Table 1 Baseline characteristics of patients and controls. Data are displayed as means (standard deviation in *parentheses*) or as individual counts (percentage in *parentheses*). The P-values refer to the difference between elderly controls and patients. *N.A.* Not available, *N.S.* no significant difference

	Young controls (n=50)	Elderly controls (n=20)	Patients (n=20)	P-value
Demography				
Age (years)	27.6 (6.6)	62.5 (6.9)	61.8 (7.1)	N.S.
Women	29 (58.0%)	11 (55.0%)	8 (40.0%)	N.S.
Highest educational level				
Primary education	1 (2.0%)	8 (40.0%)	9 (45.0%)	N.S.
Secondary education	20 (40.0%)	10 (50.0%)	10 (50.0%)	N.S.
University	29 (58.0%)	2 (10.0%)	1 (5.0%)	N.S.
Neurological examination				
Duration of disease (years)	–	–	6.7 (3.9)	–
Hoehn and Yahr stage	–	–	2.3 (0.6)	–
UPDRS motor score	–	–	30.1 (11.0)	–
UPDRS total score	–	–	49.1 (15.2)	–
MMSE	N.A.	29.0 (1.2)	27.9 (1.9)	0.05
Fall history				
Fallers (≤6 months)	N.A.	4 (20.0%)	6 (30.0%)	0.06
Number of falls (≤6 months)	N.A.	0.3 (0.5)	2.1 (5.4)	N.S.
Fallers with injury (≤6 months)	N.A.	7 (35.0%)	15 (75.0%)	0.01
Fear of falling	N.A.	2 (10.0%)	8 (40.0%)	<0.05
Restriction of activities	N.A.	5 (25.0%)	13 (65.0%)	0.01
Problems with multiple tasks	N.A.	1 (5.0%)	11 (55.0%)	<0.005
Gait and balance				
Retropulsion test	N.A.	0.1 (0.2)	0.3 (0.4)	N.S.
Tinetti balance score	0.0 (0.0)	0.1 (0.2)	2.7 (2.6)	<0.001
Tinetti gait score	0.0 (0.0)	0.0 (0.0)	1.7 (1.4)	<0.001
Tinetti total score	0.0 (0.0)	0.1 (0.2)	4.3 (3.6)	<0.001
Stops walking when talking	0 (0.0%)	0 (0%)	3 (15%)	N.S.
Sharpened Romberg	N.A.	0 (0%)	9 (45%)	<0.005
Tandem gait	N.A.	4 (20%)	10 (50%)	<0.05

All elderly controls and PD patients received a detailed clinical evaluation, which consisted of a medical interview, evaluation of falls during the previous six months (using a standardized questionnaire), and a neurological examination, including the modified Hoehn and Yahr stages, the Unified Parkinson's Disease Rating Scale (UPDRS) (Lang 1995), and the Mini Mental State Examination (MMSE) (Folstein et al. 1975). Individual Hoehn and Yahr scores were stage 1 (n=1), stage 1.5 (n=3), stage 2 (n=5), stage 2.5 (n=6), and stage 3 (n=5). Subjects were regarded as fallers if they reported at least one prior fall. Equilibrium and mobility were tested with Tinetti's balance and gait evaluation (optimal total score = 0; worst total score = 28) (Tinetti 1986), the sharpened Romberg test, and tandem gait. As reported elsewhere for a different group of PD patients (Bloem et al. 2000b), we also administered the "stops walking when talking" test (Lundin-Olsson et al. 1997). Young controls were screened to exclude neurological, orthopedic or visual disorders, and received Tinetti's balance and gait evaluation plus the "stops walking when talking" test.

The multiple tasks test (MTT)

The MTT will be described in more detail elsewhere (Bloem et al. submitted). Briefly, the MTT is new balance test that is based upon simultaneous assessment of multiple (>2) postural components. The test was designed to represent everyday situations and should have the potential of being applicable without specialized equipment by clinicians. For this purpose, relevant risk factors for falls were identified from an orienting literature review. We only selected risk factors that were independently (in multivariate analyses) and consistently (across studies) associated with falls in the elderly and that could be transformed into functional tasks for use in a consulting room. We also identified actual fall circumstances from an earlier prospective survey in PD patients (Willemsen et al. 2000). These risk factors and fall circumstances were then "transformed" into functional tests (or postural "components") that resembled everyday situations (Table 2). These components were largely motor (e.g., undisturbed walking), cognitive (answering repetitive questions), visual (reduced illumination), or mixed (e.g., carrying a loaded tray). In addition, during several tasks, subjects wore shoes with slippery soles. Given the difficulties in selecting an appropriate secondary cognitive task, we did not attempt to include a second, different cognitive task. All these components were subsequently combined to yield the MTT, which consists of eight sequential tasks of increasing difficulty, due to simultaneous challenge of an increasing number of postural components.

The MTT was performed in a quiet room (8×3 m, linoleum floor) that was adequately illuminated and ventilated. A chair was placed at each end of the room. Three obstacles (two were 9 cm wide and 3 cm high, one was 36 cm wide and 1.5 cm high) were positioned on the floor at variable distances (between 1 and 2 m).

During the first task, subjects stood up from a chair, walked along a predefined course, turned 180°, and sat down again at the end of the course. This was repeated seven times, but each time an extra component was added to the previous and otherwise identical task. During the second task, subjects answered a continuous series of brief questions while walking. The examiner walking besides the subject posed each next question (from a standard list of

Table 2 Components selected for use in the multiple-tasks test are shown in the *first column*, while the respective tasks are shown in the *top row*. The table also shows which components were used (indicated by a "+" sign) during each of the eight consecutive tasks. *Asterisks* indicate the components that were used for scoring purposes

Components	Respective tasks							
	One	Two	Three	Four	Five	Six	Seven	Eight
1. Standing up*	+	+	+	+	+	+	+	+
2. Undisturbed walking*	+	+	+	+	+	+	+	+
3. Turning around*	+	+	+	+	+	+	+	+
4. Sitting down*	+	+	+	+	+	+	+	+
5. Answering questions*	–	+	+	+	+	+	+	+
6. Avoiding obstacles*	–	–	+	+	+	+	+	+
7. Carrying empty tray	–	–	–	+	+	+	+	+
8. Carrying loaded tray	–	–	–	–	+	+	+	+
9. Slippery shoes	–	–	–	–	–	+	+	+
10. Tipping the floor*	–	–	–	–	–	–	+	+
11. Reduced illumination	–	–	–	–	–	–	–	+

150 different questions about simple, everyday circumstances) directly after the answer to the previous question was given. During the third task, subjects avoided three obstacles on the floor of differing height and width. During the fourth task, subjects carried an empty tray. During the fifth task, the tray was loaded with two hard-boiled eggs in cups and one loosely rolling egg. During the sixth task, subjects wore indoor shoes with slippery soles. During the seventh task, subjects squatted and tipped the floor halfway in the obstacle course. During the eighth task, subjects wore sunglasses, while illumination was reduced.

Subjects were instructed to execute all components of each task simultaneously, but at their own preferred speed. Some motor components were in fact executed directly after each other, such as touching the floor while walking, or sitting down after walking. Nothing was suggested regarding the priorities of the respective components. During all tasks, the investigator walked beside the subject to prevent falls. Performance was recorded on videotape.

The same investigator (MS) scored the MTT for all subjects directly during the test. Four components (carrying the unloaded or loaded tray, wearing slippery shoes, and reduced illumination) could not be scored independently, but served to complicate the task and, thus, facilitate production of errors (see Table 2). Scoring was performed separately for the "motor" components (standing up, walking, avoiding obstacles, touching the floor, turning around, and sitting down) and the one "cognitive" component (answering questions). Impaired multiple-task performance can be reflected by slowing (Camicioli et al. 1997; Lundin-Olsson et al. 1998; Means et al. 1998) or a complete stop (Lundin-Olsson et al. 1997; Morris et al. 1996) in executing one or more components. Therefore, the eight tasks were scored as follows: rapid performance of all components within the task ("Normal"); obvious slowing in one or more components within the task ("Hesitation"); complete stop or inability to perform one or more components within the task ("Block"). Only one patient had an imminent fall during the test, which was scored as a motor Block. To detect slowed performance, the individual baseline speed of answering was first determined while subjects were seated. Similarly, speed of walking, standing up, turning, and sitting down was compared to baseline performance during the Tinetti Mobility Index. For those patients who already had slowed performance during the Tinetti Mobility Index (this was the case in most patients), a Hesitation was scored if patients executed a task (e.g., walking) slower than during rating of the Tinetti Mobility Index. Blocks never occurred during rating of the Tinetti Mobility Index.

Hesitations and Blocks are analyzed separately, but are also jointly referred to as "errors" to facilitate their joint description in the text. The score was determined for all eight consecutive tasks of the MTT. Because we were interested in individual performance, our scoring system produced the *number* (or, expressed as a percentage of the total group, *proportion)* of subjects with either a completely error-free performance or at least one error during any given test. Hence, subjects received an abnormal test score if they made at least one error (Hesitation or Block) during a given task. Conversely, subjects only received a normal score if they performed all components within a given task without any error. The absolute number of errors (either Hesitations or Blocks) for each task was not scored, because scoring individual performance is more helpful from a clinical perspective as a diagnostic tool. Although subjects were left to execute the test at their own preferred speed, we used the videotapes to measure the time between start (standing up) and end of each task (seated position) as an extra outcome variable.

Experiment 1. All 50 young controls, the first 13 elderly controls [six women, mean (±SD) age: 62.0±7.8 years], and the first 13 patients (six women, mean age: 62.2±7.5 years) completed all eight tasks of the MTT in order of increasing difficulty.

Experiment 2. To investigate the potential influence of learning (performance gain) through practice, seven other elderly controls (five women, mean age: 61.1±6.2 yeas) and seven other patients (two women, mean age: 63.4±4.9 years) performed a shortened version of the MTT. This included only the second task (walking and answering questions), the fifth task (avoiding obstacles and carrying a loaded tray), and the eighth task (touching the floor, wearing slippery shoes, and reduced illumination). These three tasks were also presented in order of increasing difficulty.

Statistical analyses

Variables of the baseline clinical examination were compared between elderly controls and PD patients with the unpaired *t*-test, the Pearson Chi-square test, or Fischer's exact test. For variables available for all three groups, analysis of variance (ANOVA) was used. A two-way (sequence direction by task complexity) MANOVA for repeated measures was used to compare the number of subjects who produced errors (i.e., Hesitations or Blocks) for each task across the three groups. Greenhouse-Geisser Epsilon was used to correct for non-sphericity. The MANOVA was followed by post-hoc multiple comparisons using Tukey's test to correct for multiple comparisons. In addition, we compared the proportions of subjects who made errors for each individual task using the Chi-square test. The same analyses were used to compare the number of subjects who produced errors for each task across the two groups who received the shortened version of the MTT. The time taken to complete each task was compared between young and elderly subjects using a two-way (group by task complexity) MANOVA for repeated measures, followed by post-hoc comparisons using Tukey's test to correct for multiple comparisons.

Table 3 Performances for the motor components within each of the eight tasks of the multiple-tasks test (for tasks, see Table 2). The numbers of subjects are shown (percentage in *parentheses*) with a normal, rapid performance (*N*), a motor Hesitation (*H*) or a motor Block (*B*). Hesitations or Blocks in the cognitive component (answering serial questions) were ignored for this analysis. Main effects for task complexity, group, and their interaction are described in the text. The *P*-values refer to differences between the three groups for each of the eight tasks (Chi-square test). Comparable results emerged from the post-hoc comparisons using Tukey's test. *N.S.* No significant difference

Task	Young controls (n=50)			Elderly controls (n=13)			Patients (n=13)			*P*-value
	N	H	B	N	H	B	N	H	B	
1	50(100)	0 (0)	0 (0)	13(100)	0 (0)	0 (0)	13(100)	0 (0)	0 (0)	–
2	46 (92)	2 (4)	2 (4)	12 (92)	0 (0)	1 (8)	10 (77)	3 (23)	0 (0)	N.S.
3	46 (92)	2 (4)	2 (4)	12 (92)	0 (0)	1 (8)	10 (77)	2 (15)	1 (8)	N.S.
4	50(100)	0 (0)	0 (0)	11 (84)	1 (8)	1 (8)	8 (62)	3 (23)	2 (15)	0.001
5	47 (94)	3 (6)	0 (0)	10 (77)	1 (8)	2 (15)	9 (70)	2 (15)	2 (15)	<0.05
6	41 (82)	9 (18)	0 (0)	12 (92)	1 (8)	0 (0)	8 (62)	4 (30)	1 (8)	N.S.
7	47 (94)	3 (6)	0 (0)	9 (70)	2 (15)	2 (15)	5 (39)	3 (23)	5 (39)	<0.001
8	47 (94)	3 (6)	0 (0)	13(100)	0 (0)	0 (0)	10 (77)	2 (15)	1 (8)	N.S.

Subjects who walked faster would perhaps be more inclined to make errors. We therefore studied whether time taken to complete the task was related to the total number of subjects who made Hesitations or Blocks, using regression analysis. Because making errors also negatively influences the time taken to complete a task, we used movement time for the first task (undisturbed walking), where no subject made errors.

The log-rank test was used to study whether the number of subjects that performed all eight tasks without errors differed between the three groups. Relative risks (and 95% confidence intervals) of making an error in at least one component of the test were calculated using a Cox-proportional hazards model.

Results

Baseline examination

The baseline characteristics are shown in Table 1. The educational levels were comparable for patients and elderly controls, but the proportion of subjects with university education was higher among young controls than both other groups (P<0.01). The MMSE was slightly lower for patients than for elderly controls. The number of prior falls and the percentage of prior fallers tended to be higher for patients than for elderly controls, but these differences were not significant. However, the percentage of injurious fallers was significantly higher for patients than for elderly controls. Furthermore, more patients expressed a fear of falling and restricted their daily activities because of this fear. More than half the patients reported problems with performance of simultaneous tasks in daily life, whereas only one elderly control subject reported this. As expected, virtually all balance and gait tests were more impaired in PD than in elderly controls. However, neither the retropulsion test nor the "stops walking when talking" test differed significantly between patients and elderly controls. In fact, none of the elderly control subjects and only three patients stopped walking when talking.

Multiple tasks in Parkinson patients

All patients completed the eight functional tasks of the MTT, except for one patient who had an imminent fall during the eighth task that was prevented by the examiner (Table 3). The number of subjects that produced Hesitations or Blocks for the motor components differed between the three groups [F(2,7)=20.56, P<0.001], patients making more errors than young and elderly controls. Furthermore, the number of subjects that made motor errors increased significantly as the tasks became more complex [F(2,7)=6.69, P<0.001]. This increase differed across the three groups [significant interaction effect of Task × Group; F(2,7)=3.31, P<0.001] because particularly patients produced errors during the more complex tasks. Task four, five, and seven showed the greatest differences between patients and controls (Table 3).

Only 7.7% of the patients performed the entire MTT without any motor Hesitation or Block (Figure1), and this differed significantly from both control groups (log-rank test, P<0.0001). Patients made more motor errors than both young controls (RR=4.4; 95% confidence interval 2.1–9.1) and elderly controls (RR=3.8; 95% confidence interval 1.3–10.9). Note that Fig. 1 provides complementary information to Table 3, which shows performance for *all* subjects for *each* task. In contrast, the survival analysis presented in Fig. 1 implies that anyone who produced an error during a given task did not proceed to the next task. This explains, e.g., why the Kaplan-Meier curve remains horizontal at task 7, even though many patients made errors during this task (Table 3). These patients had already made different errors during earlier tasks as well and, therefore, no longer appeared in the Kaplan-Meier curve.

Table 4 shows the proportion of subjects in each of the three groups who produced cognitive errors. The number of subjects that produced Hesitations or Blocks for the cognitive components did not differ significantly between the three groups [F(2,7)=0.26, P=0.77]. However, for most tasks (except the most difficult one), less pa-

Table 4 Performances for the cognitive components within each of the eight tasks of the multiple-tasks test (for tasks, see Table 2). The numbers of subjects are shown (percentage in *parentheses*) with a normal, rapid performance (*N*), a cognitive Hesitation (*H*), or a cognitive Block (*B*). Main effects for task complexity, group, and their interaction are described in the text. The *P*-values refer to differences between the three groups for each of the eight tasks (Chi-square test)

Task	Young controls (*n*=50)			Elderly controls (*n*=13)			Patients (*n*=13)			*P*-value
	N	H	B	N	H	B	N	H	B	
1	50(100)	0 (0)	0 (0)	13 (100)	0 (0)	0 (0)	13(100)	0 (0)	0 (0)	–
2	46 (92)	3 (6)	1 (2)	13 (100)	0 (0)	0 (0)	12 (92)	1 (8)	0 (0)	0.81
3	46 (92)	2 (4)	2 (4)	12 (92)	3 (23)	0 (0)	12 (92)	0 (0)	1 (8)	0.10
4	44 (88)	6 (12)	0 (0)	12 (92)	1 (8)	0 (0)	12 (92)	0 (0)	1 (8)	0.16
5	41 (82)	7 (14)	2 (4)	12 (92)	1 (8)	0 (0)	12 (92)	1 (8)	0 (0)	0.77
6	39 (78)	10 (20)	1 (2)	11 (85)	2 (15)	0 (0)	12 (92)	1 (8)	0 (0)	0.78
7	36 (72)	13 (26)	1 (2)	11 (85)	2 (15)	0 (0)	11 (85)	2 (15)	0 (0)	0.78
8	39 (78)	11 (22)	0 (0)	6 (46)	6 (46)	1 (8)	8 (62)	5 (38)	0 (0)	0.06

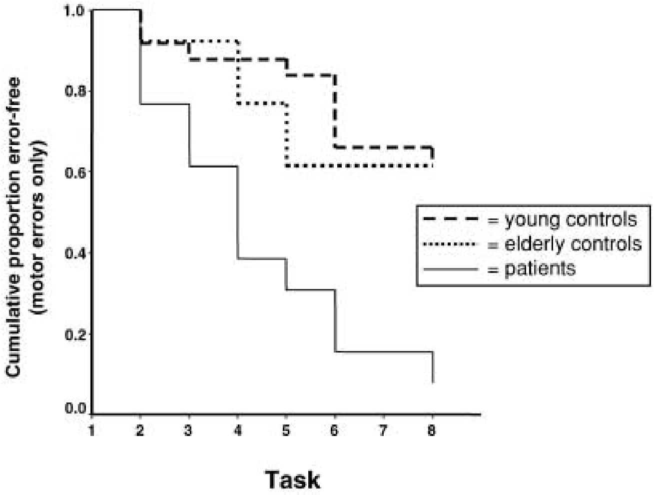

Fig. 1 Kaplan-Meier curves for the cumulative proportion of subjects with a completely error-free performance for all motor components within each respective task of the Multiple-Tasks Test. Subjects who made an error (Hesitation or Block) for at least one motor component of any given task were excluded from the following tasks. Errors in the cognitive component (answering serial questions) were ignored for this analysis. Only 7.7% of the patients had an error-free performance, as opposed to 62.0% in both control groups (*P*<0.0001)

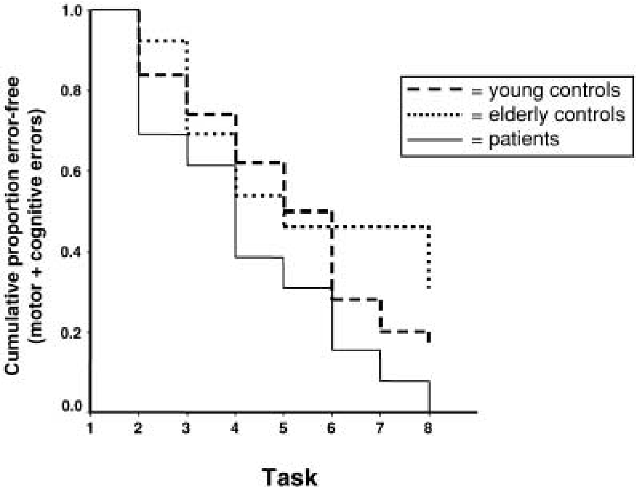

Fig. 2 Kaplan-Meier curves for the cumulative proportion of subjects with a completely error-free performance for all components (both motor and cognitive) within each respective task of the Multiple-Tasks Test. Subjects who made an error for at least one component of any given task were excluded from the following tasks. Sixteen percent of the young controls, 30.8% of the elderly controls, and none of the patients completed the test without any errors (no significant difference)

tients tended to make cognitive errors than young and elderly controls. The number of subjects that made cognitive errors increased significantly as the tasks became more complex [$F(2,7)=4.64$, $P<0.001$]. This increase did not differ across the three groups [no significant interaction effect of Task × Group; $F(2,7)=1.28$, $P=0.23$].

The Kaplan-Meier curve (Fig. 2) again presented complementary information. None of the patients completed the MTT without any errors when both the cognitive and motor components were scored (Fig. 2). However, the proportion of subjects without any motor or cognitive errors did not differ between the three groups. This was caused by the fact that the number of subjects who, during at least one of the tasks, made cognitive errors increased less for patients than for controls as the tasks became more complex.

Influence of movement time

The total time to complete the entire MTT is shown in Table 5 for all three groups. The total time to complete the MTT differed between the three groups [$F(2,7)=34.59$, $P<0.001$] because patients performed all eight tasks slower than both control groups. In addition, elderly subjects performed somewhat slower than young subjects, particularly during the eighth and most difficult task ($P=0.02$). Furthermore, movement time increased significantly as the tasks became more complex [$F(2,7)=234.12$, $P<0.001$]. This increase in movement time differed across the three groups [significant interaction effect of Task × Group; $F(2,7)=21.96$, $P<0.001$] because movement time increased more steeply in patients than controls.

Table 5 Time (s) taken to complete each task of the multiple-tasks test (for tasks, see Table 2). Ranges are displayed in *parentheses*. Main effects for task complexity, group, and their interaction are described in the text. The *P*-values refer to significant post-hoc multiple comparisons using Tukey's test. Significant differences were consistently seen between patients and both control groups, and between young and elderly subjects for task 8 (*P*=0.02)

Task	Young controls (*n*=50)	Elderly controls (*n*=13)	Patients (*n*=13)	*P*-value
1	8.0 (6.1–10.5)	8.6 (6.1–11.7)	10.5 (6.6–18.1)	<0.0005
2	9.1 (5.7–18.8)	11.3 (7.5–22.5)	14.9 (8.5–24.6)	<0.0001
3	8.6 (5.9–13.1)	9.7 (7.0–15.7)	14.6 (8.5–25.0)	<0.0001
4	9.1 (5.3–17.3)	10.8 (7.0–16.2)	15.9 (8.1–37.3)	<0.0001
5	11.5 (5.1–19.3)	12.8 (9.8–18.5)	19.1 (12.2–36.3)	<0.0001
6	12.8 (8.6–21.7)	13.4 (7.7–18.6)	22.3 (13.4–59.3)	<0.0001
7	18.0 (9.5–25.7)	20.9 (10.1–31.6)	39.8 (19.4–81.3)	<0.0001
8	18.5 (10.8–26.2)	23.8 (15.7–34.1)	34.0 (20.9–69.5)	<0.0001
Total	95.9 (68.5–130.7)	107.3 (82.8–150.2)	171.1 (114.0–349.3)	<0.0001

In all three groups, the number of Hesitations or Blocks was unrelated to baseline movement time, as measured during the first task where no Hesitations or Blocks occurred (*r*=0.02; *P*=0.52 for young controls; *r*=0.01; *P*=0.90 for elderly controls; *r*=0.13; *P*=0.20 for patients).

Shortened MTT

Both elderly controls and patients made more motor errors during all tasks of the shortened MTT, as compared with the complete MTT. For example, during the complete MTT, none of the 13 elderly controls produced motor errors during the eighth and most difficult task, whereas three of the seven elderly controls (42.9%) produced errors during the same task as part of the shortened MTT. Only two elderly subjects (29%) and none of the patients performed the three consecutive tasks without any motor errors. Only during the fifth task was the percentage of patients with motor errors identical (30%) for the shortened and complete MTT.

Interestingly, as a consequence of this higher error rate in *both* groups, the number of subjects who made Hesitations or Blocks during the shortened MTT did not differ significantly between elderly controls and patients. This was true for both the motor and cognitive errors. Thus, there was no difference in the number of subjects that produced motor and/or cognitive errors between elderly controls and patients [*F*(1,2)=1.83, *P*=0.20]. For example, during the eighth and most complex task, two subjects in each group had motor Hesitations and one subject in each group had a complete motor Block. The number of subjects that made motor and/or cognitive errors did not increase as the tasks became more complex [*F*(1,2)=0.35, *P*=0.71], and there was no interaction effect of Task × Group [*F*(1,2)=2.19, *P*=0.13].

The time taken to complete each of these tasks again increased for patients, as was the time taken to complete the entire shortened MTT (56.4 s for controls versus 78.2 s for patients). These differences did not reach statistical significance [*F*(1,2)=2.74, *P*=0.12], probably due to the small groups.

Discussion

Compared with healthy subjects, patients made considerably more errors while performing the motor components of the MTT. The difference between patients and controls disappeared if errors were scored for both motor and cognitive components. This suggests that, for complex tasks, patients were less able to lend priority to motor performance than controls. Indeed, all patients performed the first task without errors, but 92% of them made at least one motor error during the more complex tasks. Cognitive errors also increased with increasing task complexity, but less so than in controls. Patients thus seemed less able than controls to employ a "posture first" strategy, but instead attempted to perform all tasks simultaneously. However, due to their balance impairment and restricted processing resources, neither motor nor cognitive components were executed very successfully. This might be interpreted as a form of "risky" behavior that might lead to falls in daily life.

Patients performed the MTT considerably slower than controls. This slowed performance may again index their problems with multiple simultaneous tasks, but could also reflect the bradykinesia that is inherent to the disease. We investigated whether this difference in speed of task performance explained the results. Healthy subjects moved much faster than patients, which may have increased their liability to make errors, particularly for the cognitive test. However, baseline movement time during the first "undisturbed" task was unrelated to the number of errors made by either controls or patients.

It is likely that learning affected the results of the first experiment, where the sequential tasks were consistently presented in order of increasing difficulty (a new component was always added to the previous and otherwise identical task). We considered administering the separate tasks to all subjects in a random sequence, but this requires enormous sample sizes to obtain statistically meaningful results for each test sequence. In a different experiment, learning effects were studied in more detail by presenting the eight tasks to a different group of young healthy subjects in reverse order, i.e., the most difficult test first (Bloem et al. submitted). The results showed that young persons made more errors during the most difficult task when it was presented first, i.e., without prior "learning" during the previous and less difficult tasks, suggesting that learning effects indeed took place. These learning effects seemed less pronounced for patients, because they made more (motor) errors during the complex tasks. Such a "motor learning defect" would have augmented differences between patients and controls for the more complex tasks. However, whether "motor learning" (skill acquisition or a gain in performance through practice) is indeed impaired in PD remains difficult to answer. Depending on the experimental design and the employed definition of "learning", several studies reported impairments in PD, particularly in more severely affected, untreated or demented patients (Harrington et al. 1990; Heindel et al. 1989; Soliveri et al. 1997).

To evaluate this further, we administered a shortened version of the MTT (to reduce learning opportunities) to a new group of patients and controls. We assumed that, if learning effects had confounded the complete MTT, both groups would make more errors during the shortened MTT. Furthermore, the number of errors should increase more equally in both groups for the complex tasks of the shortened MTT. Evaluation of a shortened MTT was also attractive because it is less time-consuming.

Both effects were observed. Elderly subjects and patients made more motor errors during the shortened MTT than during the complete test. Furthermore, the differences between both groups were smaller with the shortened MTT. Although the relatively small group size precludes definitive conclusions, both findings suggest that learning influences MTT performance. Furthermore, our findings suggest that motor learning was impaired in PD, causing greater difficulty with the complete MTT. These observations on learning effects may have practical implications. For example, it is possible that simple tests (although less time-consuming) may reveal fewer abnormalities in patients than lengthier tests, such as the complete MTT.

Our results suggest that the MTT (which consists mainly of multiple motor components) is particularly informative for subjects with mainly *motor* disabilities, such as PD patients. In contrast, a dual-task design with a combination of motor and cognitive tasks seems more suitable to detect abnormalities in patients with mainly *cognitive* decline. For example, cognitively impaired elderly subjects often stopped walking while talking, and this abnormality is a good predictor of falls (Lundin-Olsson et al. 1997). However, this test is usually normal in PD patients with normal MMSE-scores and does not predict their falls (Bloem et al. 2000b). While these considerations apply to patients with more chronic deficits, we should note that combinations of motor and cognitive tasks might also be informative in patients with acute lesions, even in the absence of cognitive deficits, for monitoring a motor-learning process (Geurts et al. 1991). It would be interesting to evaluate the MTT in subjects with acute lesions, or in subjects with more prominent cognitive decline than our patients, whose MMSE was only slightly lower than in controls (MMSE-scores <24 were an exclusion criterion), and to compare the results to dual-task impairment (Camicioli et al. 1997).

Although cognition was largely preserved, patients did have more difficulties integrating multiple tasks than controls. Educational differences did not explain the difference between patients and elderly controls. The results therefore confirm the assumption that assessment of multiple (>2) postural components is more sensitive for detecting balance impairment than a strictly dual-task design, such as "stops walking while talking" (Mulder et al. 1993). Bond and Morris (2000) recently arrived at the same conclusion, when they observed that PD patients had more difficulty walking while carrying a loaded tray as opposed to an empty tray. Indeed, baseline evaluation showed that most postural control measures were impaired in our patients. A notable exception was the retropulsion test, which is commonly used to probe balance impairment in PD (Bloem et al. 1998b; Lang 1995; Nutt et al. 1992). The MTT apparently reveals postural abnormalities earlier than the retropulsion test, which uses an unnatural stimulus (shoulder pull) and measures only few postural components (righting and stepping responses).

Interestingly, more than half our patients reported difficulties with simultaneous tasks in daily life. Furthermore, during a prospective survey, almost half of the PD patients fell while attempting to perform multiple tasks (Willemsen et al. 2000). This included simultaneous motor tasks, such as carrying a tray while walking. In fact, many patients described falls during situations that resembled the most complex tasks of the MTT. These observations underscore the clinical relevance of balance tests based upon a multiple-task principle.

The MTT revealed clear abnormalities in relatively mildly affected patients. This suggests that the MTT may be used for screening purposes. We are now prospectively measuring falls in larger groups of tested subjects, and such follow-up might unveil whether the MTT can predict falls in daily life. Such a prospective study is more reliable than correlating MTT performance to historical falls, in light of the common amnesia for falls. This is exemplified by the fact that the number of prior falls and the percentage of prior fallers only tended to be higher for patients than for elderly controls, but these differences were not significant [possibly due to a recall bias (Cummings et al. 1988)]. In contrast, PD patients had much higher fall rates than controls during our prospective follow-up study (Willemsen et al. 2000). This study also showed that PD patients underestimated their prior-fall frequency. Interestingly, in the present study, the percentage of injurious fallers (which are likely better remembered than falls in general) was significantly higher for patients than for elderly controls. Finally, we realize that the MTT in its present form is not an "end product". We acknowledge that our subjective "clinical" scoring system, while advantageous for clinical use in a consulting room, has its shortcomings in terms of reliability and is potentially subject to individual bias. The fourth and seventh task currently discerned best between patients and controls, along with movement time, but our study was not designed to answer in detail what elements of the MTT caused most problems with multiple-task performance. A shortened MTT should probably include elements of the fourth and seventh task, although inclusion of a dual task that includes a cognitive component remains attractive for more directly revealing whether a "posture first" strategy is used. Again, prospective studies should demonstrate which key elements could be distilled for a brief and simpler clinical-screening procedure for postural instability and falls.

Acknowledgements Mr. G. van der Giessen is acknowledged for his assistance. We thank Prof. R.A.C. Roos, Prof. T. Mulder, and Prof. J. Duysens for their critical comments, and Dr. A.H. Zwinderman for his statistical analyses.

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