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Relationships Between Balance and Cognition in Patients With Subjective Cognitive Impairment, Mild Cognitive Impairment, and Alzheimer Disease

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Background. Balance impairments are common in patients with Alzheimer disease (AD), but which aspects of balance are affected, at which stage of cognitive impairment, and their associations with cognitive domains remain unexplored.

Objectives. The aims of this study were: (1) to explore differences in balance abilities among patients with subjective cognitive impairment (SCI) or mild cognitive impairment (MCI), mild AD, and moderate AD and (2) to examine the relationship between the various aspects of balance and cognitive domains.

Design. This was a cross-sectional study.

Methods. Home-dwelling patients with SCI or MCI (n=33), mild AD (n=99), and moderate AD (n=38) participated in this study. The Balance Evaluation Systems Test (BESTest), comprising 6 subscales—"Biomechanical Constraints," "Stability Limits/Verticality," "Anticipatory Postural Adjustments," "Postural Responses," "Sensory Orientation," and "Stability in Gait"—was used to assess balance. Cognitive domains were assessed using the following measures: Mini-Mental Status Examination, Word-List Learning Test from the Consortium to Establish a Registry for Alzheimer's Disease (CERAD), Verbal Fluency Test, Clock Drawing Test, and Trail Making Test, parts A and B (TMT-A and TMT-B, respectively). Two-way between-group analyses of variance, adjusted for age, were used to analyze differences among the groups. Multiple linear regression analysis was used to explore the associations between balance and cognition.

Results. Differences were found between the groups on all BESTest subscales; the moderate AD group had the worst scores. The TMT-B (measuring executive function) was associated with all of the BESTest subscales after controlling for demographic factors.

Limitations. The cross-sectional design hampered interpretation of the development of balance impairments.

Conclusions. The study findings indicate that all aspects of balance control deteriorate with increasing severity of cognitive impairment and that executive function plays an important role in balance control. Physical therapists should pay attention to these findings both in clinical practice and in future research.

G.G. Tangen, PT, MSc, Department of Health Sciences, Institute of Health and Society, University of Oslo, PO Box 1089 Blindern, Oslo 0317, Norway. Address all correspondence to Ms Tangen at: g.g.tangen@medisin.uio.no

K. Engedal, MD, PhD, Norwegian Centre for Aging and Health, Vestfold Health Trust, Tønsberg, Norway.

A. Bergland, PT, PhD, Oslo and Akershus University College of Applied Sciences, Oslo, Norway.

T.A. Moger, PhD, Department of Health Management and Health Economics, Institute of Health and Society, University of Oslo.

A.M. Mengshoel, PT, PhD, Department of Health Sciences, Institute of Health and Society, University of Oslo.

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Dementia is among the leading causes of disability and death in the elderly population. The majority (about 60%–70%) of people with dementia have Alzheimer disease (AD),¹ and in the United States—with its increasing proportion of elderly people—the prevalence of AD is estimated to rise from 4.7 million in 2010 to 13.8 million in 2050.² Alzheimer disease is a progressive neurodegenerative disease without any known cause or treatment. Symptoms of AD are associated with cognitive, psychiatric, and physical impairments and lead to inability to live independently, causing a heavy burden on both relatives and health care systems. Safe and independent mobility is essential to perform activities in everyday life and depends highly on intact balance control. Falls and fall-related injuries are more common in patients with AD than in their healthy peers.^{3–7} In general, reduced balance control and cognitive impairment are both well-established risk factors for falls among elderly people.^{8,9}

The current dominant theory of balance control is the systems theory approach.^{10–13} Balance, in this approach, is seen as a result of complex integration and coordination of several underlying systems covering sensory/perceptual processes, cognitive influences (eg, attention, motivation, intention) and motor pro-

cesses.^{11,13,14} Clinical studies have shown that impaired balance, as a general construct, is more common in patients with AD than in healthy controls^{15–19} and that impaired balance becomes more prevalent with increasing severity of AD.²⁰ Experimental laboratory studies of patients with AD have examined single aspects of balance, and impaired sensory organization for balance control was found,²¹ as well as correlations between anterior-posterior postural sway and orientation for time and place¹⁶ and an increased impact of cognitive distraction on sway in patients with AD compared with healthy controls.²² However, for physical therapists, it is important to get a more nuanced understanding of how cognitive impairment may influence the various aspects of balance to inform their clinical work.

Physical therapists assess balance for various reasons: to determine the presence of a balance problem, to monitor changes, and to identify which aspects of balance control are affected. A recent study compared 25 patients with AD and 25 healthy elderly individuals on a broad set of balance measures that involved both quiet stance and dynamic tasks, as well as balance during a dual task.¹⁹ The authors concluded that balance impairments in patients with AD were of global character, as they performed worse than the controls on almost all measures.¹⁹ The recently developed Balance Evaluation Systems Test (BESTest) provides a framework for the assessment of aspects of balance control in line with the systems theory. The BESTest provides subscales developed to represent systems important for balance control as well as a total score.¹⁰ Accordingly, we used this assessment tool to obtain information on the various aspects of balance control of clinical relevance for physical therapists.

Given the lack of information about the various aspects of balance control in patients with AD, knowledge on deterioration of these aspects throughout the course of AD also is inadequate. People with subjective cognitive impairment (SCI) or mild cognitive impairment (MCI) have noticeable memory deficits but no functional impairment.^{23,24} Contrary to former beliefs,^{25,26} physical functions, such as gait speed, might start to decline simultaneously with, or even before, the decline in cognitive function.^{27,28} Furthermore, the degree of lower limb impairment (a global score of gait and balance tasks) in patients with MCI has been associated with the risk of later development of AD.²⁹ Studies have shown worse balance performance in people with MCI than in healthy controls,^{16,30,31} although this finding has not been reported consistently in all studies.¹⁸

To our knowledge, no study has examined the differences in the underlying aspects of balance control between people with SCI or MCI and people with mild and moderate AD. This information may help to direct interventions to the affected aspects of balance and to decide at which stage of cognitive impairment interventions should be initiated. Cognitive function is similar to balance in that it comprises several interrelated domains such as memory, language, reasoning, visuospatial ability, and executive function. Executive function is not a unitary construct but includes attention, planning, set shifting, and flexible, goal-oriented behavior.^{32–34} *Attention*, defined as the individual's information-processing capacity, is thought to be particularly important for balance.³⁵ Impaired executive function was associated with worse gait-related performances in people with cognitive impairment and dementia.^{36–39} In older adults without known cognitive impairments,



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- **eFigure:** Mean Score and 95% Confidence Intervals for the 6 Subscales of the Balance Evaluation Systems Test for the Groups With Subjective or Mild Cognitive Impairment, Mild Alzheimer Disease, and Moderate Alzheimer Disease

poor executive function⁴⁰ and poor visuospatial ability and memory⁴¹ were associated with an increased risk of falls. However, the relationship among the different aspects of balance, executive function, and other cognitive domains remains unexplored in people with AD. We suggest that such knowledge may generate new ideas on the content of balance interventions for people with cognitive impairment.

Therefore, this study addressed 2 aims: (1) to examine whether there were any differences among patients with SCI or MCI, mild AD, and moderate AD with regard to each of the subscales as well as the total score of the BESTest and (2) to examine which cognitive domains were associated with impaired balance control when controlled for demographic and health-related characteristics.

Method

Design and Participants

The present study had a cross-sectional design. Patients included in the Norwegian Dementia Registry (NDR) at Oslo University Hospital were screened consecutively for eligibility and, if deemed suitable, were invited to participate. Simultaneously, we also recruited patients through a local authority dementia team in a rural area outside Oslo. The inclusion period lasted from January 2011 to August 2012. To address the first aim of the study, we used the whole sample of included participants, whereas for the second aim, we used a subset of our participants who had completed all of the cognitive tests.

To be included in the study, the patients had to have a clinical diagnosis of SCI, MCI, or AD and had to be home dwelling. They needed to understand Norwegian and to be able to walk comfortably without a walking device. The diagnosis of SCI was used for patients who experi-

enced subjective memory problems but still had normal performance on a comprehensive test battery at the memory clinic.⁴² The diagnosis of MCI was based on the Winblad criteria: subjective memory problems and a slight deterioration in the cognitive testing results but no functional impairment.²⁴ The participants with SCI and MCI were analyzed as one group, as patients with these 2 diagnoses have memory complaints but still do not meet the criteria for dementia. We applied the *International Statistical Classification of Diseases and Related Health Problems*, 10th edition, (ICD-10) diagnostic criteria for research to diagnose AD and to categorize patients with AD as having dementia of a mild or moderate degree.⁴³ These criteria emphasize the ability of independent living to differentiate between mild and moderate stages of AD. Exclusion criteria were severe stage of AD, another diagnosis of dementia, severe hearing or vision impairments, neurologic conditions such as Parkinson disease, stroke

with motor symptoms, or musculoskeletal conditions causing moderate to severe pain or impairing gait. An experienced geriatric psychiatrist (K.E.) who was blinded to the results of the balance testing reviewed the clinical diagnosis to ensure consistent use of the diagnostic criteria. All participants gave written informed consent prior to the study.

Demographic and Clinical Information

Information on demographic characteristics, medical conditions, medications, cognitive assessments, and walking habits were retrieved from the NDR or from the patients' medical records. We used the results from the cognitive testing done within the previous 6 months, and 80% of the balance assessments were done within 3 months of the cognitive testing. Additional tests were not performed if the results were not found in the NDR or the patient's medical record. The NDR does not contain information about musculoskeletal problems, so we additionally

The Bottom Line

What do we already know about this topic?

Balance impairments occur frequently in patients with mild cognitive impairment and Alzheimer disease. However, we have little information about which aspects of balance are affected and about their relationship to cognitive domains.

What new information does this study offer?

We found that performances on all 6 aspects of balance measured by the BESTest became increasingly worse with severity of cognitive impairment. Executive function was associated with all of these aspects of balance.

If you are a patient or a caregiver, what might these findings mean for you?

If a family member is starting to have cognitive impairments, the family may consider contacting a physical therapist for a balance assessment and advice about how to best preserve the individual's balance and mobility.

asked all patients: “Do you have any injury or condition, such as arthritis, hip prosthesis, or previous fractures, that may affect your balance?” We used this question as a dichotomous variable (yes/no) for the regression analysis. Information on physical activity was obtained through the walking habit questions: the number of days a week a patient walked outside multiplied by how long those walks generally lasted.⁴⁴ The information from these questions and information from the NDR were based on agreement between the participants’ own statements and those from their next of kin.

Cognitive Assessments

The Mini-Mental Status Examination (MMSE) was used to assess global cognition and consists of items concerning orientation, registration and recall, attention, language, following commands, and figure copying. The MMSE can be scored from 0 to 30, where a higher score indicates better performance.⁴⁵ The Trail Making Test, part A (TMT-A) was used to test attention and processing speed.⁴⁶ In this test, the participants were asked to draw a line between circles in increasing order (1–25). The Trail Making Test, part B (TMT-B) was used to test executive function and set shifting (the ability to go back and forth between multiple tasks).⁴⁶ The participants were asked to draw a line to connect circles in increasing order and to alternate between numbers and letters (1–A–2–B–3. . .). Performances on both TMTs were timed, and attempts were stopped after 5 minutes. We divided the timed scores into 4 categories based on normative age-adjusted time intervals for both tests⁴⁷: 0=cannot complete, 1=slower than –2 standard deviations of the norms, 2=between –1 and –2 standard deviations, and 3=better than –1 standard deviation. The ordinal scoring was used to avoid floor effects when participants were unable to complete the task.

The Clock Drawing Test (CDT) was used to evaluate visuoconstructive abilities.⁴⁸ The participants were presented with a piece of paper with a circle and were asked to draw the numbers so that the circle looks like the face of a clock and then to draw the hands of the clock to read “10 after 11.” We used the 6-point scoring method as described by Shulman (0–5, where 5 is best).⁴⁸

The Word-List Learning Test from the Consortium to Establish a Registry for Alzheimer’s Disease (CERAD) was used to evaluate the learning aspect of memory.⁴⁹ A list of 10 words was presented in 3 trials, and the scoring represents the total number of correct words learned (0–30, where 30 is best).

The Verbal Fluency Test from the CERAD was used to assess semantic verbal fluency.⁵⁰ In this test, the participants were asked to name as many animals as possible within 1 minute.

The medical doctors at the memory clinic administered the cognitive tests. The cognitive tests have high interrater reliability in patients with dementia,^{45,48,50} but reliability has not yet been examined for patients with SCI. For the TMTs, reliability has not been established for people with dementia or SCI, but it is high for healthy people.⁵¹

Balance Assessment

Balance performance was evaluated with the BESTest, which was developed to target 6 underlying systems of balance control.¹⁰ The BESTest consists of 36 items grouped into 6 subscales: I—Biomechanical Constraints, II—Stability Limits/Verticality, III—Anticipatory Postural Adjustments, IV—Postural Responses, V—Sensory Orientation, and VI—Stability in Gait. Each item was scored on a 4-point ordinal scale, where 0 is the worst performance

and 3 is the best performance. The sum scores for each subscale and the total score were converted to percentage scores (0%–100%, where 100% is best). The balance assessments were conducted in a quiet setting. All tasks were performed with the participants barefooted except for those in subscale VI (Stability in Gait). The physical therapist gave repeated instructions and demonstrations of the task when necessary. Verbal cueing was used if the participant hesitated in performing the timed tasks. In the last item, the Timed Up and Go Dual Task, we used the “random numbers” alternative as the cognitive task for all participants. We aimed to score the participants’ first attempt. For the 3 items of compensatory stepping responses in subscale IV (Postural Responses), we allowed up to 3 attempts because many participants did not lean sufficiently beyond their stability limits at the first attempt. The same physical therapist (G.G.T.) tested all except 3 participants. High levels of test-retest and interrater reliability have been reported for the BESTest.^{10,52,53} So far, there have been no studies on the validity or reliability of the BESTest among populations with cognitive impairment.

Data Analysis

Data were analyzed using IBM SPSS Statistics version 20 (IBM Corp, Armonk, New York). The level of significance was set at $P < .05$. Descriptive statistics are reported as the mean and standard deviation when normally distributed or as the median with interquartile range if showing a skewed distribution. Numerator and percentages are reported for categorical variables. Differences between groups concerning patient characteristics were analyzed using chi-square tests for categorical variables and using one-way analysis of variance (ANOVA) for normally distributed continuous variables. Comparisons between par-

ticipants with complete and missing data for the regression analysis were performed using Student *t*, Mann-Whitney *U*, chi-square, or Fisher exact test.

To analyze the differences on each of the balance subscales adjusted for age among the groups of patients with SCI or MCI, mild AD, and moderate AD, we conducted a 2-way between-groups ANOVA. We controlled for age (categorized into 3 groups: 51–69, 70–79 and 80–92 years) because the group of participants with moderate AD was significantly older than the other 2 groups. We focused on the main effects of the 3 groups and performed Bonferroni post hoc comparisons to analyze any differences among the groups. As the first aim of our study was to examine differences among groups with different degrees of cognitive impairment, we did not perform further analysis of the interactions between groups and age. For the 3 subscales in the BESTest with skewed distributions (I, IV, and V), we also used Kruskal-Wallis tests (although it was not possible to adjust for age) to ensure that any differences among groups remained significant when using nonparametric tests.

To address the study’s second aim, we used the subset of participants who had completed all of the cognitive tests. The associations between the BESTest scores and the cognitive tests, adjusted for demographic factors, were analyzed by multiple linear regression. Demographic factors were chosen based on clinical experience and results from previous studies. We checked bivariate correlations among the independent variables for collinearity, and we inspected the residual plots to ensure that model assumptions were not violated. The independent variables were entered into the models in 2 blocks. Block 1 contained the

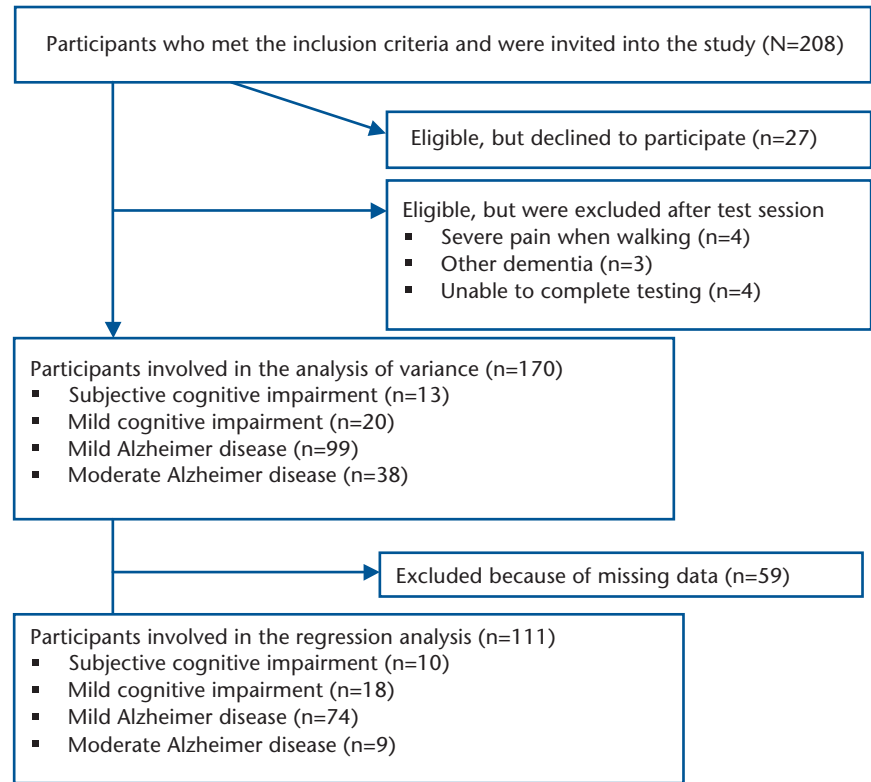


Figure. Flow chart of participants’ involvement in the study.

demographic factors that we aimed to control in our analyses: age, sex, comorbidity, education, and walking habits. Block 2 contained the cognitive measures: MMSE, 10 Word Test, CDT, Verbal Fluency Test, and TMT-A and TMT-B. To explore which cognitive measures were independently associated with the scores of the BESTest, we performed backward removal analyses on the variables in block 2: we removed the cognitive measures with lowest association one by one until only significant variables were left. The final model was evaluated through analysis of explained variance.

We then repeated the same strategy for multiple linear regression analyses for each of the BESTest subscales to examine which cognitive measures might be associated with the separate subscales.

Results

Of the 208 patients screened and eligible for our study, 181 (83.0%) consented to participate (Figure). Of those, 11 participants were later excluded because they did not fulfill the inclusion criteria or they were not able to follow the instructions throughout the entire BESTest. Thus, the sample for the ANOVA consisted of 170 participants: 33 in the SCI/MCI group (13 with SCI, 20 with MCI), 99 with mild AD, and 38 with moderate AD. Participant characteristics are presented in Table 1. The group of patients with moderate AD was older and had a lower education level than the other 2 groups.

Adjusted for age, the 3 groups performed significantly differently from each other on all 6 subscales of balance as well as on the total score (Tab. 2; eFigure, available at ptjournal.apta.org). The largest dif-

Balance and Cognition in Patients With Cognitive Impairment and Alzheimer Disease

Table 1.

Characteristics of Participants With Subjective or Mild Cognitive Impairment, Mild Alzheimer Disease, and Moderate Alzheimer Disease^a

Variable	Total Sample (N=170)	SCI/MCI Group (n=33)	Mild AD Group (n=99)	Moderate AD Group (n=38)	P
Sex (male), n (%)	85 (50)	16 (48.5)	56 (56.6)	13 (34.2)	.06 ^b
Age (y), \bar{X} (SD)	72.4 (9.1)	68.1 (7.7)	71.6 (8.8)	78.1 (8.1)	<.001 ^c
Years of education, \bar{X} (SD)	12.7 (3.6)	14.0 (3.1)	13.3 (3.5)	9.8 (2.4)	<.001 ^c
Employment status, n (%)					
Working	22 (12.9)	10 (30.3)	12 (12.1)	0 (0)	<.001 ^d
Sick leave/disability benefit	24 (14.1)	3 (9.1)	13 (13.2)	8 (21.0)	.32 ^b
Retired	117 (68.8)	19 (57.6)	71 (71.7)	27 (71.1)	.30 ^b
Other	7 (4.2)	1 (3.0)	3 (3.0)	3 (7.9)	.07 ^d
Mini-Mental Status Examination, median (IQR) ^e	25.0 (6)	29.0 (3)	25.0 (5)	19.0 (5)	
Body mass index (kg/m ²), \bar{X} (SD)	24.4 (3.9)	25.4 (4.3)	24.0 (3.7)	24.5 (3.7)	.21 ^c
Walking habits, n (%)					
<75 min/wk	40 (23.5)	2 (6.1)	26 (26.3)	12 (31.6)	.01 ^b
75–149 min/wk	39 (22.9)	9 (27.3)	20 (20.2)	10 (26.3)	
150–299 min/wk	41 (24.1)	7 (21.2)	27 (27.3)	7 (18.4)	
≥300 min/wk	37 (21.8)	13 (39.4)	22 (22.2)	2 (5.3)	
Missing	13 (7.6)	2 (6.1)	4 (4.0)	7 (18.4)	
Cholinesterase inhibitors, n (%)	51 (31.1)	0 (0)	32 (32.7)	19 (55.9)	<.001 ^b
Medical conditions, n (%)					
Musculoskeletal disorders	71 (41.8)	12 (36.4)	44 (44.4)	15 (39.5)	.68 ^b
Cardiovascular diseases	71 (41.8)	11 (33.3)	50 (50.5)	10 (26.3)	.02 ^b
Neurologic disorders	19 (11.2)	2 (6.1)	11 (11.1)	6 (15.8)	.43 ^b
Diabetes mellitus	9 (5.3)	2 (6.1)	4 (4.0)	3 (7.9)	.65 ^b
Condition of importance for balance ^f	62 (36.5)	10 (30.3)	37 (37.4)	15 (39.5)	.70 ^b

^a SCI=subjective cognitive impairment, MCI=mild cognitive impairment, AD=Alzheimer disease, IQR=interquartile range.

^b Chi-square test.

^c One-way analysis of variance.

^d Fisher exact test.

^e Range of scores=0–30, where a higher score indicates better performance.

^f As judged by the participant and relatives.

ferences among the groups were found in the “Stability in Gait” subscale ($F=29.55$, $P<.001$). Large effect sizes were seen for the total score ($\eta_p^2=0.24$) and for the “Anticipatory Postural Adjustments” subscale ($\eta_p^2=0.18$) and “Stability in Gait” subscale ($\eta_p^2=0.27$), and the other subscales had medium effect sizes ($\eta_p^2=0.07-0.10$).

The subset with a complete dataset for the regression analysis consisted of 111 participants (65.3% of those included). Participants with moderate

AD had the most missing data (Tab. 3). The main sources of missing data were the TMTs and the Word-List Learning Test, each with missing data for 30 or more participants.

All independent variables were associated with the BESTest total score in the bivariate analysis. The TMT-B was the only cognitive measure significantly associated with the BESTest total score after controlling for demographic factors (Tab. 4). Demographic factors explained 51% of the variance in the BESTest total score,

and the TMT-B explained an additional 13% of the variance. The effect size (f^2) of the final model was 1.94. For the corresponding multiple linear regression analysis with each of the BESTest subscales as the dependent variable, the TMT-B was consistently in the remaining subsets, in addition to the demographic factors of age and comorbidity (4 of the 6 subscales) (Tab. 5). The adjusted explained variance ranged from 0.20 for the “Sensory Orientation” subscale to 0.52 for the “Stability in Gait” subscale. The range of

Table 2.

Comparisons of Performance on the BESTest Among Participants With Subjective or Mild Cognitive Impairment, Mild Alzheimer Disease, and Moderate Alzheimer Disease^a

BESTest Scales	SCI/MCI Group (n=33)	Mild AD Group (n=99)	Moderate AD Group (n=38)	Main Effects ^b		Contrasts: Mean Difference (95% CI)		
	\bar{X} (SD)	\bar{X} (SD)	\bar{X} (SD)	F	P	SCI/MCI Group vs Mild AD Group	Mild AD Group vs Moderate AD Group	SCI/MCI Group vs Moderate AD Group
I. Biomechanical Constraints	87.5 (13.7)	77.0 (18.2)	65.3 (18.4)	8.15	<.001	10.5 (3.4, 17.6) ^c	11.7 (5.0, 18.4) ^d	22.2 (13.9, 30.6) ^d
II. Stability Limits	89.8 (7.2)	85.0 (9.2)	75.8 (10.3)	9.17	<.001	4.7 (0.7, 8.8) ^e	9.2 (5.4, 13.1) ^d	13.9 (9.1, 18.8) ^d
III. Anticipatory Postural Adjustments	84.7 (10.9)	75.3 (14.0)	60.5 (16.0)	17.09	<.001	9.4 (4.0, 14.8) ^d	14.7 (9.6, 19.9) ^d	24.2 (17.8, 30.6) ^d
IV. Postural Responses	91.1 (11.3)	81.5 (18.0)	68.9 (20.7)	5.57	.005	9.5 (2.1, 17.0) ^c	12.7 (5.6, 19.8) ^d	22.2 (13.4, 31.1) ^d
V. Sensory Orientation	93.5 (7.0)	86.3 (13.4)	75.1 (17.0)	5.92	.003	7.2 (1.4, 13.0) ^c	11.2 (5.8, 16.7) ^d	18.5 (11.6, 25.3) ^d
VI. Stability in Gait	88.6 (10.5)	72.6 (17.3)	51.5 (17.5)	29.55	<.001	16.0 (8.8, 23.2) ^d	21.1 (14.3, 27.9) ^d	37.1 (28.6, 45.6) ^d
Total	89.1 (6.6)	79.5 (11.5)	65.8 (12.9)	25.4	<.001	9.7 (5.5, 13.8) ^d	13.7 (9.7, 17.6) ^d	23.3 (18.4, 28.3) ^d

^a BESTest=Balance Evaluation Systems Test (0–100, where 100 is best), SCI=subjective cognitive impairment, MCI=mild cognitive impairment, AD=Alzheimer disease, 95% CI=95% confidence interval.

^b Two-way between-groups analysis of variance with Bonferroni post hoc comparison.

^c $P < .01$.

^d $P < .001$.

^e $P < .05$.

the effect sizes was from medium ($f^2=0.32$) for the “Sensory Orientation” subscale to large for the other subscales ($f^2=0.54-1.22$).

Discussion

The main findings of this study were that, for each subscale and for the total score of the BESTest, the mild AD group performed worse than the SCI/MCI group and that the moderate AD group performed worse than the other groups. Furthermore, we found that executive function, as measured by the TMT-B score, was associated with all of the BESTest subscales, even after adjusting for demographic factors.

The differences among the groups were not equally pronounced across all of the subscales. The highest scores in all 3 groups were found for the “Stability Limits,” “Sensory Orientation,” and “Postural Responses” subscales. The “Stability Limits” and “Sensory Orientation” subscales reflect aspects of balance during quiet stance, and our findings

correspond well with those of previous studies. Increased postural sway has been observed across 3 stages of AD,⁵⁴ and worse performance on sway velocity and limits of stability has been reported in patients with mild and moderate AD compared with healthy elderly people.¹⁹ In the

1-year follow-up, however, there were no differences in the rate of change of these measures between the healthy elderly group and patients with AD.⁵⁵ Based on these previous results and the present findings, we suggest that although balance control while standing still is affected in

Table 3.

Characteristics of Participants Included in the Regression Analysis and Comparison With Those Who Were Excluded From the Regression Analysis Because of Missing Data^a

Variable	Participants Included in the Regression Analysis (n=111)	Participants Excluded From the Regression Analysis (n=59)	P
Age (y), \bar{X} (SD)	70.3 (8.7)	76.2 (8.5)	<.001
Sex (male), n (%)	56 (50.5)	29 (49.2)	.87
Years of education, \bar{X} (SD)	13.6 (3.3)	10.9 (3.5)	<.001
Mini-Mental Status Examination, ^b \bar{X} (SD)	25.1 (3.6)	21.8 (5.1)	<.001
Cognitive impairment group, n (%)			<.001
SCI/MCI	28 (25.2)	5 (8.5)	
Mild AD	74 (66.7)	25 (42.4)	
Moderate AD	9 (8.1)	29 (49.2)	

^a SCI=subjective cognitive impairment, MCI=mild cognitive impairment, AD=Alzheimer disease.

^b Range of scores=0–30, where a higher score indicates better performance.

Balance and Cognition in Patients With Cognitive Impairment and Alzheimer Disease

Table 4.

Associations Between the Balance Evaluation Systems Test Total Score and Cognitive Assessments, Adjusted for Demographic Factors (n=111)^a

Measure	Simple Estimates			Adjusted Estimates: All Variables			Adjusted Estimates: Backward Removal Analysis			
	B ^b	95% CI	P	B ^b	95% CI	P	B ^b	95% CI	P	Adjusted R ²
Mini-Mental Status Examination	0.96	0.43, 1.49	.001	-0.33	-0.87, 0.22	.238				
Word-List Learning Test	0.80	0.45, 1.15	<.001	-0.03	-0.34, 0.29	.869				
Clock Drawing Test	2.62	1.24, 4.00	<.001	0.17	-1.04, 1.39	.777				
Verbal Fluency Test	0.88	0.57, 1.19	<.001	0.28	-0.35, 0.60	.081				
Trail Making Test, part A	4.22	1.84, 6.60	.001	0.94	-0.93, 2.82	.321				
Trail Making Test, part B	3.53	2.15, 4.91	<.001	2.70	1.31, 4.09	<.001	3.03	2.05, 4.01	<.001	.64 ^c

^a Demographic factors of age, sex, and comorbidity contributed to the final model; education and walking habits did not. 95% CI=95% confidence interval.

^b Unstandardized coefficient.

^c The R² value for the entire model, including demographic factors.

people with AD, it is in general better preserved than dynamic balance control.

To our knowledge, postural responses involving reactive responses to external perturbation have not been examined separately in patients with AD. Being able to respond quickly and appropriately to slips and pushes is essential for avoiding a fall. A reduction in reactive responses is a typical trait of parkinsonism,⁵⁶ and we were expecting severe impair-

ments on this subscale because parkinsonian signs are commonly observed in patients with AD.^{57,58} The first attempts at tasks involving reactive responses are thought to give a greater disturbance to balance than subsequent attempts.⁵⁹ As mentioned in the "Method" section, we allowed many of our participants several attempts at the compensatory stepping response items because they did not comprehend the instructions the first time. This approach might have resulted in

these individuals receiving a better score than if they had had a valid first try, so we might have underestimated the impairments in this subscale.

The largest differences among the groups, and the lowest scores, were found in the "Stability in Gait" subscale. The items of this subscale examine stability and speed during walking in different challenging situations (such as when performing head turns and pivot turns and step-

Table 5.

Associations Between the Subscales of the Balance Evaluation Systems Test and Cognitive Assessments, Adjusted for Demographic Factors (n=111)^a

Measure	I. Biomechanical Constraints				II. Stability Limits			
	B ^b	95% CI	P	Adjusted R ^{2c}	B ^b	95% CI	P	Adjusted R ^{2c}
Trail Making Test, part B	2.41	0.45, 4.36	.017	.37	1.90	0.78, 3.02	.001	.31
Measure	III. Anticipatory Postural Adjustments				IV. Postural Responses			
	B ^b	95% CI	P	Adjusted R ^{2c}	B ^b	95% CI	P	Adjusted R ^{2c}
Trail Making Test, part B	2.27	0.71, 3.82	.005	.43	3.96	2.06, 5.86	<.001	.38
Measure	V. Sensory Orientation				VI. Stability in Gait			
	B ^b	95% CI	P	Adjusted R ^{2c}	B ^b	95% CI	P	Adjusted R ^{2c}
Verbal Fluency Test					0.66	0.16, 1.17	.010	
Trail Making Test, part B	2.55	0.78, 4.32	.005	.20	3.64	1.61, 5.67	.001	.52

^a Demographic factors: age contributed to all final models, sex contributed only to model III, comorbidity contributed to final models I, III, V, and VI. Education did not contribute to any of the final models. Cognitive tests: the Mini-Mental Status Examination, 10 Word Test, Clock Drawing Test, and Trail Making Test, part A, did not contribute to any of the final models.

^b Unstandardized coefficient.

^c The R² value for the entire model, including demographic factors.

ping over obstacles). Walking over obstacles has been examined previously, and patients with AD landed closer to the obstacle and were more likely to touch the obstacle during walking than were healthy controls.⁶⁰ Our finding of apparent deterioration of gait performance in the present cross-sectional study when comparing the 3 groups is in line with findings from longitudinal studies: deterioration in gait-related measures was found both in home-dwelling patients with early-onset AD (aged less than 65 years)⁶¹ and in older patients with AD.⁶²⁻⁶⁴ Studies have even identified a slow gait speed as a predictor for cognitive decline among elderly people who are cognitively healthy.^{27,28} Our study extends the existing findings on gait function by indicating that balance in such tests also is altered, along with the severity of cognitive impairment.

To our knowledge, the present study is the first to use the BESTest among participants with dementia. We found the test feasible in that no negative incidents occurred during testing, and only 4/174 patients (2.3%) were unable to complete the test because they could not follow the instructions. The BESTest also was able to discriminate among all 3 groups. The BESTest total score is a global measure of balance control, and results can be associated with other clinical measures of balance such as the Berg Balance Scale (BBS).⁶⁵ A previous study that used the BBS to assess balance showed no differences between individuals with mild AD and a healthy control group,⁶⁶ and the authors commented that this finding could be explained by the well-known ceiling effect of the BBS.⁶⁷ Our SCI/MCI group, with mean age of 68 years, performed slightly worse than healthy people between 60 and 69 years of age in a recent study.⁶⁸ We are well aware of the limitations of a

cross-sectional design, but our findings indicate a continuous deterioration of balance with increasing severity of cognitive impairment that should be further examined in longitudinal studies.

Our second question was to examine which cognitive domains were associated with impaired balance control when controlled for demographic factors. The demographic factors of age, sex, and comorbidity were all associated with balance, which is in line with previous findings.²⁰ Global cognition, as measured by the MMSE, was highly correlated with the BESTest total score in the bivariate analysis but did not contribute to the final model. Executive function, as measured with the TMT-B, was still independently associated with both total score and each of the subscale scores of the BESTest. The only other cognitive test that remained in one of the final models was the Verbal Fluency Test, which was associated with the "Stability in Gait" subscale. This verbal task is often thought to reflect aspects of executive function as well, because those who perform well are likely to develop strategies for organizing their recall.³⁴ Other studies have linked executive function, gait performance, and future fall risk in both healthy older people and people with dementia,^{36,69-71} but our study extends these findings to include balance control. However, increased postural sway was associated with reduced blood flow in the frontal lobes in a small cross-sectional study of patients with AD.⁵⁴ Executive function also is closely linked to the functions of the prefrontal cortex in the frontal lobes, so that study might support our findings.

The TMT-B added 13% to the explained variance of the BESTest total score. This percentage may seem low, but it is above what we expected, and it is above the

explained variance of the TMT-B on gait speed and of the Timed "Up & Go" Test in patients with MCI.³⁷ The consistent association of executive function with each of the subscales as well as the total score underscores the control function of executive function. This finding also lends support to a nonrandomized study of older people with AD who demonstrated improvements on both balance performance and executive function after an intervention where they combined physical activity with cognitive tasks.⁷² We also suggest that special attention should be paid to those who exhibit impairments of executive function because they are likely to have balance impairments and be at risk for future falls.

A limitation of our study was the cross-sectional design, which relied heavily on a valid categorization of the participants into the 3 different groups. In addition, the physical therapist who tested the participants was not blinded to their preliminary diagnosis. However, we sought to reduce the risk of bias by assigning the diagnostic work to an experienced geriatric psychiatrist blinded to the results of the balance assessments. We ended up with unequal sizes of the groups, which could have caused us to make type II errors. However, we were still able to detect differences among the groups on every measure of the BESTest. We acknowledge that by treating SCI and MCI as one group, we had a very heterogeneous group where several patients will never develop dementia, as their memory complaints may have other reasons than incipient AD. Still, their memory complaints have caused them to seek medical attention, and we believe they contribute to how we interpret the relationship between balance and cognition in our study.

Another limitation in our study involved the missing data associated

with the cognitive tests used in the regression analysis, which resulted in a smaller sample for the regression analysis compared with the ANOVAs. When individuals had severe problems in completing the MMSE and CDT, or displayed considerable lack of motivation during cognitive testing, most clinicians at the memory clinic chose to refrain from further testing out of ethical considerations. These concerns occurred most frequently in patients with severe cognitive impairments; therefore, the information was not missed at random. Consequently, we can only generalize the results from the regression analyses to patients with a mild to moderate degree of cognitive impairment.

The present study had several strengths, including the use of a comprehensive clinical test of balance in conjunction with evaluation of multiple cognitive domains. Furthermore, we found a consistent association between balance control and executive function, adjusted for demographic factors and in the presence of other relevant cognitive domains. Although most patients were recruited through the memory clinic, we believe that our results will be relevant for home-dwelling people with cognitive impairment and AD in the general population. The inclusion of patients with comorbidities such as arthritis or joint replacement would make it harder to associate the balance impairments with AD pathology. However, none of our patients used a walking device or experienced the testing as painful, and our findings were adjusted for the presence of comorbidities in the regression analysis. The clinical implications of the present study are that physical therapists should be aware that reduction in balance starts at an early stage of cognitive impairment, so it might be useful to initiate balance training

before balance problems become too pronounced.

Future Directions

We found differences in all aspects of balance control reflected by the BESTest across patient groups with various levels of cognitive deficits. The worst balance performance was found in the group of patients with the most severe cognitive impairment. These findings are important, as the research within physical therapy focusing on these patient groups is yet at an early stage. Future longitudinal studies are needed to confirm the trajectory of deteriorating balance with the development of AD. The executive function component, as measured with the TMT-B, was associated with all aspects of balance control after controlling for demographic factors such as age, sex, and comorbidity.

Ms Tangen, Dr Engedal, Dr Bergland, and Dr Mengshoel provided concept/idea/research design. Ms Tangen, Dr Moger, and Dr Mengshoel provided data analysis. Ms Tangen, Dr Engedal and Dr Mengshoel provided project management. Dr Engedal provided institutional liaisons. Ms Tangen and Dr Mengshoel provided fund procurement. Ms Tangen and Dr Engedal provided study participants, data collection, and facilities/equipment. All authors provided writing and consultation (including review of manuscript before submission).

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The Regional Committee for Medical and Health Research Ethics in the Southeast of Norway approved the study.

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Balance and Cognition in Patients With Cognitive Impairment and Alzheimer Disease

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Gro Gujord Tangen, Knut Engedal, Astrid Bergland, Tron Anders Moger and Anne Marit Mengshoel
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