EXPERIMENT 1

Method

Participants

Nine patients with Alzheimer's disease (2 female, 7 male; aged 60-78, mean age 70.22 years, *SD* = 6.09 years), 10 older adults of similar age (3 female, 7 male; aged 60-78, mean age 69.40 years, *SD* = 5.56 years), and 10 young adults (5 female, 5 male; aged 20-28, mean age 23.90 years, *SD* = 3.07 years), participated in the study. The educational level was rather high in all groups. While the younger adults had, on average, 13.4 years of education (*SD* = 1.26 years, *range* 13 to 17 years), the older adults had, on average, 14.0 years of education (*SD* = 3.39 years, *range* 9 to 17 years), and the Alzheimer's patients, on average, 12.78 years of education (*SD* = 3.52 years, *range* 8 to 17 years). The educational status did not differ between the three groups ($F(2,28) = 0.42$, $MSe = 3.53$, $p = .66$). The mean educational status of the sample, however, was higher as compared to a representative sample of the same age group (BASE; *M* = 10.2 years, *SD* = 2.4; M. Baltes & Lang, 1997).

Recruitment

Patients suffering from Alzheimer's disease were recruited via announcements from the Cognitive Clinics of Free University Berlin, Department of Geriatric Psychiatry, Humboldt University Berlin, Department of Neurology, and Krankenhaus Hellersdorf, Department of Geriatric Psychiatry, Berlin, over a period of 9 months in 2001. Dementia diagnosis was made according to specified research criteria ("Clinical diagnosis of probable Alzheimer's disease" after NINCDS-ADRDA; McKhann et al., 1984). Specifically, all patients underwent medical history taking, clinical examination, laboratory testing, brain imaging and neuropsychological testing at the three cognitive clinics. The clinical diagnosis of probable Alzheimer's disease according to the NINCDS-ADRDA criteria requires the presence and neuropsychological documentation of deficits in two or more areas of cognition, present over the course of six month, and severe enough to cause disturbances in everyday functioning. Furthermore, the exclusion of causes other than Alzheimer's disease is required through clinical examination, laboratory testing, and brain imaging (compare McKhann et al., 1984). The clinical diagnosis made by the cognitive clinics was reassessed for plausibility and completeness by the author of the study.

In order to ascertain that participants were able to perform the tasks in this experiment and were able to give informed consent on their own behalf, only patients with mild dementia were selected (compare Helmchen, 1982). The MMSE (Mini Mental State Examination; Folstein, Folstein, & McHugh, 1975) is a well-established measure of cognitive decline in and degree of dementia. Specifically, the inclusion criterion was a score in the MMSE of above 18 points.[6]

Although attempts were made to select an equal number of male and female patients, only 2 women suffering from Alzheimer's disease could be recruited in the study. The higher response rate in males might be due to several reasons. First, male patients are overrepresented in cognitive clinics (Kühl & Ferszt, 2001). Second, either wife or daughter accompanied all seven male patients who participated in this study during all sessions. The female patients, however, were all widowed or divorced. It may be that the presence of a caregiver may have increased the motivation to participate in the study, or to make an appointment at a cognitive clinic in the first place (Haupt & Lauter, 1997). Thus, the high rate of female caregivers caring for male dementia patients (Zank & Schacke, 1998) may have affected the recruitment process.

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[6] Due to a communication error in one cognitive clinic, two patients with scores on the MMSE below 18 were recruited for this study. After informed assent and consent procedures were completed with both the patient and the primary caregiver, a short version of the Experiment, including only the stable platform condition and the 0-Back cognition, was carried out with these patients. Data are not reported here.

Older participants were recruited from the participant pool of the Max Planck Institute for Human Development, Berlin, and were selected to match Alzheimer's patients' age and gender. Young participants were recruited via announcements on the University campus of Free University, Berlin.

In order to exclude participants with severe medical conditions affecting balance and gait, further criteria were implemented from medical history taking. Specifically, exclusion criteria were the presence of a set of neurological (polyneuropathy, Parkinson's disease, epilepsy, stroke, peripheral paresis, and severe vertigo), psychiatric (depression, psychosis), cardiovascular (dysrhythmia, myocardial infarction, decompensated cardiac failure, severe hypertension or hypotension), metabolic (diabetes, severe arthrosis, severe osteoporosis), and surgical (fractures within the last years, hip fracture) disorders (compare Hawken, Jäntti, & Kennard, 1993). All Alzheimer's patients were screened for these diagnoses by the cognitive clinics they attended prior to recruitment.[7] In the healthy young and older adults, a standardized questionnaire on medical diagnoses was used (compare Steinhagen-Thiessen & Borchelt, 1999). None of the young and older adults suffered from any of the diagnoses that served as exclusion criteria. With regard to health status, the number of diagnoses other than dementia did not differ between the healthy old (M = 2.30, SD = 0.95) and the Alzheimer's patients (M = 2.87, SD = 0.99) group ($t(17) = 1.08$, $p = .29$). There was, however, a significant difference from the older to the young adults (M = 0.10, SD = 0.32) group ($t(18) = 6.69$, $p < .001$). The number of diagnoses in both older groups (healthy and Alzheimer's disease) was lower than data from a representative sample suggest[8]. With regard to

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[7] Due to a communication error in one cognitive clinic, one patient with a severe gait disorder was recruited for the study. A short version of the Experiment, including only the training sessions in cognition, was carried out with this patient.

[8] In the Berlin Aging Study (BASE), 94% of the participants had five or more than five diagnoses (Steinhagen-Thiessen & Borchelt, 1999). However, the history taking approach

subjective bodily health, rated on a five point scale from 1 to 5, there was no difference between the healthy older adults (*M* = 2.10, *SD* = 0.32), the Alzheimer's patient (*M* = 2.37, *SD* = 0.52), and the young adults (*M* = 2.40, *SD* = 0.70) (*F*(2,27) = 1.47, *MSe* = .48, *p* = .24).

All participants were given general information about the study, and received detailed information, including informed consent procedures, in writing. Written informed consent was obtained from all participants. Approval from the Ethics Committee of Free University Berlin, Medical School, was obtained. Participants were refunded DM 20 (US $ 10) for travel expenses. Alternatively, Alzheimer's patients were entitled to the coverage of transportation cost by taxi (7 out of 10 patients chose this option).

Cognitive and Sensorimotor Status

Since the relation between cognitive and sensorimotor functioning was at the core of this study, descriptive assessment further included basic cognitive and sensorimotor measures. An overview is given in Table 1.

The cognitive battery consisted of measures of working memory (Forward Digit Span) and perceptual speed (Digit Symbol Substitution) from the mechanic (fluid) domain, and verbal knowledge (Spot-a-Word) from the pragmatic (crystallized) domain. A detailed description of the full battery can be found elsewhere (Lindenberger, Mayr, & Kliegl, 1993).

The Forward Digit Span test consists of 10 blocks of each 5 rows of numbers ranging from 3 to 12 numbers in length. While the numbers were read out one at a second, the participants' task was to repeat the full sequence after all numbers have been read out. The maximum score is 12.

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in this study may have been less sensitive than the complete medical examination provided in the BASE study.

Table 1

Description of Healthy Young and Older Adults,
and Alzheimer's Patients in Experiment 1

Variable	Young (*N* = 10)	Older (*N* = 10)	Alzheimer (*N* = 9)
Age (years)	23.90 ± 3.07	69.40 ± 5.56	70.22 ± 6.09
Education (yrs)	13.40 ± 1.26	14.00 ± 3.39	12.78 ± 3.52
MMSE	29.80 ± 0.44	29.44 ± 0.73	21.11 ± 3.85
Digit Span	07.20 ± 0.60	06.77 ± 0.67	05.44 ± 1.13
Digit Symbol	62.55 ± 5.85	44.70 ±11.71	24.66 ± 10.82
Clock-Drawing	06.30 ± 0.82	06.25 ± 0.88	03.50 ± 1.43
Reitan Trail A	12.36 ± 4.28	19.57 ± 4.86	39.50 ± 17.69
Spot-a-Word	25.10 ± 3.51	28.50 ± 1.94	26.80 ± 1.87
Tinetti (s)	06.00 ± 1.41	07.63 ± 1.18	08.20 ± 2.15
Grip (kp)	21.06 ± 6.14	10.93 ± 3.77	10.23 ± 1.53
Leg Strength (kp)	27.96 ± 4.97	20.03 ± 5.85	16.30 ± 7.49
Hearing (dB)	14.88 ± 6.60	34.20 ± 7.53	33.98 ± 8.21
Visual Acuity	01.00 ± 0.00	00.97 ± 0.05	00.94 ± 0.08

Table 1. Data represent means ± standard deviations. MMSE = Mini-Mental State examination. Hearing Threshold represents a mean of all thresholds within the speech range (500-2000Hz). Visual acuity represents best-corrected distant vision (1.0 equals 100%).

The Wechsler Digit Symbol Substitution test (Wechsler, 1955) was designed to measure perceptual and cognitive speed. A template with the digit-symbol mapping were presented on two sheets. The first sheet served as an example. On the second sheet, 88 digits were presented. Moving from left to right, participants were to write down the corresponding symbol for each digit.

In order to minimize visual acuity confounds, digits and letters were written in large, bold fonts. Possible scores range from 0 to 88.

The Spot-a-Word test consists of 35 items containing one word and four non-words. Blocks of five words were presented in a paper-and-pencil version of the test. Three practice items were given, and time was not limited. Scores range from 0 to 35.

The Reitan Trailmaking A test (a German version was used; [Zahlenverbindungstest, Nürnberger Altersinventar], Oswald & Fleischmann, 1990) is considered a measure of processing speed and consists of four sheets of encircled numbers that have to be connected with a pencil mark as fast as possible. The time needed to complete each sheet was summed up to form the overall score.

Cognitive assessment further included performance on a set of tests sensitive for dementia (MMSE; Folstein et al., 1975; Clock-Drawing; Salmon & Butters, 1992). The MMSE consists of 30 items that measure orientation, registration, calculation, recall, and language. Scores range from 0 to 30. While the MMSE is a sensitive screening instrument for dementia, the Clock-Drawing test has been designed to measure executive control in dementia (Shulman, 1993). Executive function encompasses the control, planning, sequencing and execution of goal-directed activities (Duke and Kaszniak, 2000). The rating scheme proposed by Shulman (Shulman, 1993) was used, rating the correct position of the digits 1 to 12, the correct position of these digits on the clock, and the correct position of the two indicators. Scores range from 0 to 9.

Significant differences between the groups were found for Forward Digit Span ($F(2,27) = 9.01$, $MSe = 6.35$, $p < .001$), Digit Symbol Substitution ($F(2,27) = 40.41$, $MSe = 3666.91$, $p < .001$), MMSE ($F(2,27) = 41.77$, $MSe = 348.11$, $p < .001$), Reitan Trailmaking ($F(2,27) = 5.84$, $MSe = 4612.36$, $p < .01$), and Clock-Drawing ($F(2,27) = 20.60$, $MSe = 30.80$, $p < .001$). In all cases, the young adults scored better than the older adults, who scored better than the Alzheimer's patients (all *ps* $< .01$). On the Spot-a-Word test, too, a significant difference was found ($F(2,27) = 4.23$, $MSe = 25.78$, $p < .05$). Closer scrutiny revealed that this difference was in fact due to the younger adults' scores, which were significantly lower than the healthy older adults' ($t(18) = 2.64$, $p < .01$).

Sensorimotor assessment included the assessment of size and body weight, strength, mobility, and objective measures of visual and auditory acuity. Motor functioning was assessed using a mobility assessment, Tinetti's objective mobility test (Tinetti, 1986), and two measures of strength (grip strength and leg strength). Grip strength was measured with a handheld dynamometer (compare Steinhagen-Thiessen & Borchelt, 1999). Leg strength was measured with two assessments of quadriceps and tibialis strength. A strap connected to a spring gauge (Stamina GmbH, Germany) was placed around the shin to measure quadriceps strength and around the forefoot to measure tibialis strength. Visual acuity was measured with standard reading tables. Auditory thresholds were determined binaurally at eight different frequencies (0.25, 0.5, 1.0, 2.0, 3.0, 4.0, 6.0, 8.0 kHz) using a Bosch ST-20-1 pure tone audiometer. Significant differences between the groups were found for the Tinetti test ($F(2,27) = 5.42$, $MSe = 13.95$, $p < .05$), grip strength ($F(2,27) = 17.14$, $MSe = 299.96$, $p < .001$), leg strength ($F(2,27) = 9.83$, $MSe = 348.11$, $p < .001$), and auditory thresholds ($F(2,27) = 19.05$, $MSe = 77.95$, $p < .001$). All subjects had normal or corrected to normal vision. In all cases, the young adults scored better than the older adults (all *ps* $< .01$). There was no significant difference between the healthy older adults and the Alzheimer's patients with respect to all sensorimotor measures (all *ps* $> .14$).

Apparatus

The stimuli for the cognitive task were presented using a Power Macintosh 7100/80 computer in the single-task condition. In the dual-task condition, a Pentium III personal computer was used to present the stimuli. Stimuli were presented on a 22'' Sony monitor. After each trial, a preprogrammed dialogue was used to enter the number of correct responses. Timing was in "tick" accuracy (1 tick = 16.63 ms) on the Apple computer. On the PC, timing accuracy was at 75 Hz (= 13.33 ms).

Figure 6

Balance Measurement

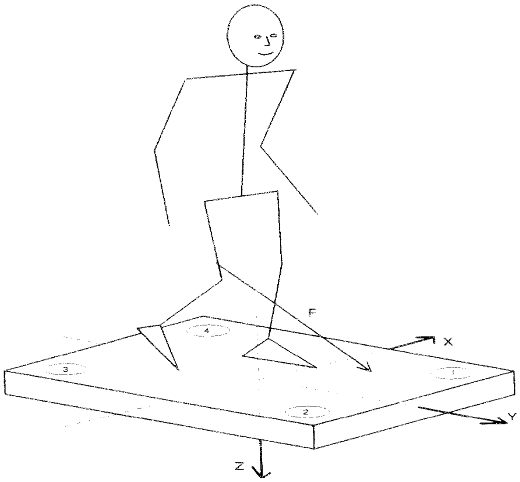

Figure 6. A schematic representation of the forces measured by the platform. Piezoelectric sensors are able to record pressure in the anterior-posterior (y), lateral (x), and vertical (z) plane. See text for details.

Balance was assessed using a 40 x 60 cm Kistler 9286A multicomponent force platform (Kistler Instrumenten AG, Winterthur, Switzerland). The platform records three force components along with the lateral, vertical, and anterior-posterior horizontal axes, as well as three respective moment components by means of four piezoelectric sensors located at each corner of the platform. The platform was built in a mechanical frame, driven by a robotic axis (Power Cube Rotari PR 110, mcm Prüfsysteme GmbH, Berlin, Germany), allowing for continuous movement of up to 20° in the anterior-posterior horizontal plane.

The measurement platform was surrounded by a second platform (120 x 140 cm), connected to an overhead frame that allowed to place security belts from mountain climbing (Liberty Adjust Type D, Mammut, Cologne, Germany). A schematic representation of the force platform is given in Figure 6.

The platform records forces in three axes. The center of pressure (COP) can be calculated at every given moment in time from these forces. The area covered by the trajectory of the COP is referred to as area of COP movement and has been used as an indicator of sway in a variety of studies (compare Barin, 1992). Data from a stable and a moving platform trial are shown in Figure 7.

Figure 7

Area of Center of Pressure Movement as a Measure of Sway

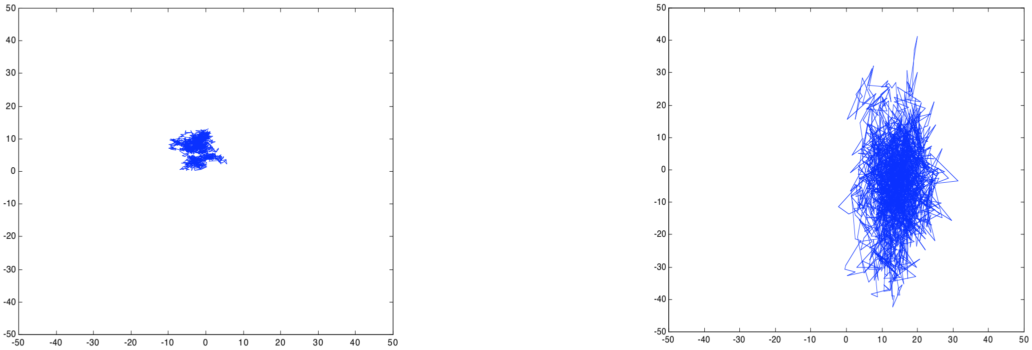

Figure 7. Area of COP movement on under stable (left) and moving (right) platform conditions. Deviations in mm.

For both the control of speed and angle of platform movement, as well as the preprocessing, amplification, and integration of primary data, a measurement computer (-M-S Eth-RJ45, mcm Prüfsysteme GmbH, Berlin, Germany) was used, which was connected to the platform via CAN-Bus connection. The measurement computer was connected to an optosensor (mcm

Prüfsysteme GmbH, Berlin, Germany), which allowed for measuring the onset of stimulus presentation on the screen. The measurement computer had a sampling rate of 1000 Hz. The measurement computer was connected to the Pentium III PC via Ethernet.

The monitor used for the presentation of visual stimuli was placed in front of the platform on a positioning table which was equipped with a lever mechanism (Baumeister Telerohr T 165), which allowed to position the monitor at each participants' eye level.

Tasks and Stimuli

N-Back

In the N-Back task, digits from a list of numbers ranging from 0 to 9 were visually presented. Digits were embedded in a white, 8 x 8 cm square that was surrounded by an otherwise black screen. Digits were presented in a large, bold font (Helvetica, font size 200), resulting in a height of about 6 cm, and a width of about 4 cm, depending on the digit. Digit sequences were randomized under the following constraints: No numerically adjacent digits appeared together in a list. Furthermore, digits were not repeated until the third following digit. Presentation rate was 1 digit per 2.5 seconds (i.e., stimulus onset asynchrony (SoA) was 2500 ms). In the 0-Back condition, participants were asked to read out the currently presented digit. In the 1-Back condition, participants were instructed to read out the preceding digit as soon as the following digit appeared. In the 2- Back condition, participants were instructed to read out the penultimate digit. In the 0-Back condition, 10, in the 1-Back condition, 11, and in the 2-Back condition, respectively, 12 digits were presented in one trial. Adjusting the time until the first digit appeared, each trial lasted about 30 s. The type of task was stated at the beginning of each trial.

Balance Task

The balance task was described as "Standing as stable as possible on a stable or moving platform". Participants were asked to assume a comfortable position, arms hanging to the side. Participants were tested wearing sport shoes (an equal model was bought for all participants in all shoe sizes), and the foot position was recorded by drawing around the feet with a marker on geometric paper to assure equal foot positioning during all trials. Under stable platform conditions, the platform was not tilted. Under moving platform conditions, the platform was tilted in a sinusoidal, continuous movement in the anterior-posterior plane at a speed of 3Hz and an angle of 0.3°. Balance performance was assessed both under conditions of offline feedback (i.e., feedback was given at the end of each trial) and online feedback (i.e., the area of center of pressure movement was shown online on the screen).

Measures such as center of pressure (COP), may be considered indirect measures (for review, see Slobounov, Moss, Slobounova, & Newell, 1998), as they infer body sway from the movement of the body's center of gravity, yet do not measure the relation of the motion to a stability boundary. In order to overcome this flaw, the assessment of sway tolerance, the amount of sway an individual is willing and able to tolerate, has been proposed. Such an assessment is the functional stability boundary (FSB), which was assessed in each participant in the present study (compare Slobounov et al., 1998). To that end, participants were instructed to stand with their hands on their hips and move, with their body maintaining a straight line, as far in two given directions as possible. The position of the body was further specified by instructing participants to maintain their knees, hips and back straight and distribute their weight, in the anterior-posterior position, from heels to toes without lifting their feet. “To move as far as possible” was further specified as the maximum amount of leaning in one direction without feeling unsafe or being afraid to fall. Four directions were given in the instruction: 1) anterior-posterior; 2) lateral; 3) diagonal right; 4) diagonal left. These directions are given in Figure 8, together with a typical pattern of trajectories of COP during such trials. From these trials, the maxima in each direction can be computed, and the area of the FSB can thus be calculated.

Figure 8

Functional Stability Boundary as an Individual Criterion for Sway Tolerance

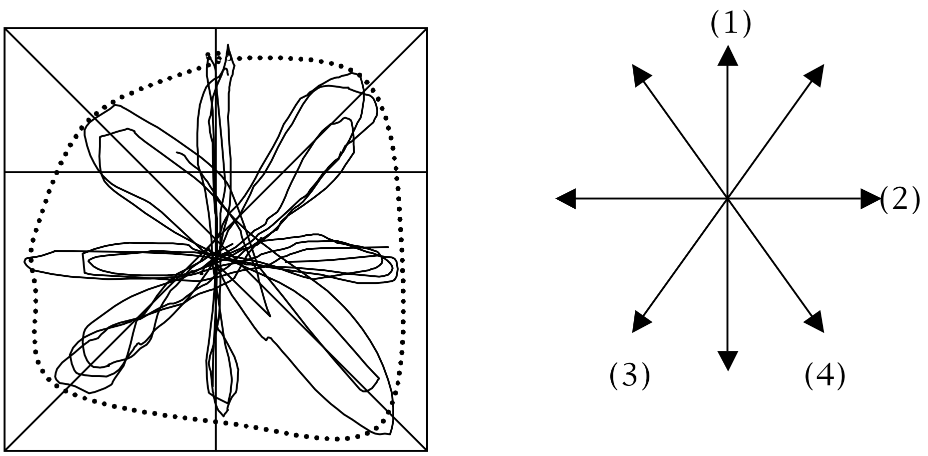

Figure 8. Functional Stability Boundary. The maximal amount of self-induced sway tolerated by an individual is measured in the anterior-posterior (1), lateral (2), and two diagonal directions (3,4). The corresponding area (dotted line) reflects the sway capacity in an individual.

Dual-Task

Under dual-task conditions, participants were instructed to stand as stable as possible and at the same time try to solve the cognitive task as well as possible. All three N-Back conditions (0-Back, 1-Back, and 2-Back) were combined on the stable and the moving platform. Feedback for both the cognitive task (number of items correct) and the balance task (area of COP movement) were given after each trial. The number of items correct was scored after each trial.

Procedure

The experiment consisted of eight sessions. An overview of the experiment is given in Table 2.

Table 2

Overview of Experiment 1

Session	Assessment
All sessions	Demographic Assessment, Informed Consent, Cognitive Battery, Sensorimotor Assessment
Session 1-3	Training to criterion in 0-Back, 1-Back, 2-Back, and N-Back Count
Session 4	Baseline: 5 trials single-task on a stable and moving platform; 5 blocks of dual-task (0-Back, 1-Back, 2-Back) on a stable platform
Session 5	5 blocks of dual-task (0-Back, 1-Back, 2-Back) on a moving platform
Session 6	Functional Stability Boundary Assessment
Session 7	As session 5
Session 8	5 blocks of dual-task (0-Back, 1-Back, 2-Back) on a stable platform Posttest: N-Back; Balance on a stable and a moving platform

Table 2. Overview of the Experiment.

Participants were tested individually at the Max Planck Institute for Human Development, Berlin. All sessions took place in a sound resistant, well-lit room, with only one participant per session. The final debriefing session took place in a conference room, with groups in the young and healthy older adults groups and single sessions with Alzheimer's patients. During the first session, participants were given a questionnaire to collect biographical background information and medical history. The cognitive battery, including Forward Digit Span, Digit Letter, Spot-a- Word, (see Lindenberger et al., 1993), as well as the MMSE (Folstein et al., 1975), and the Clock-Drawing Test (Goodglass & Kaplan, 1972), was administered throughout the first three sessions. Testing in the first three sessions also included measures of sensorimotor functioning, assessment of mobility (Lawton & Brody, 1996; Tinetti, 1986), and objective measures of visual and auditory acuity.

Training in N-Back (Session 1 to 3)

Session 1 included a demonstration of the balance and N-Back tasks. This session lasted about 60 minutes. After a demonstration of the tasks, written informed consent was obtained. Participants were then trained in N-Back (0-Back, 1-Back, 2-Back), consisting of two blocks of each four trials per task per session for up to three sessions. The training ended when perfection (i.e., 10 out of 10 correct in two consecutive blocks of four trials per task) was reached, or after a maximum training of six blocks of four trials per task.

The amount of training needed to reach perfection and the ability to reach perfection differed across the three groups. All younger adults reached perfection in the three tasks, while only 3 of the older adults and none of the Alzheimer's patients reached perfection in 2-Back. Differences were only marginal in the number of training blocks in 0-Back ($F(2,27) = 2.87$, $MSe = 0.41$, $p = .05$), but significant in 1-Back and 2-Back in the three groups (for 1-Back: $F(2,27) = 42.54$, $MSe = 0.69$, $p < .001$; for 2-Back: $F(2, 27) = 48.91$, $MSe = 0.40$, $p < .001$). Post-hoc analyses showed that the differences were statistically reliable for 2-Back between young and older adults ($F(2,27) = 45.34$, $MSe = 0.58$, $p < .001$), and for 1-Back between healthy older adults and Alzheimer's patients ($F(2,27) = 41.04$, $MSe = 1.04$, $p < .001$). The mean number of training blocks and the amount of participants in a group who reached perfection are given in Table 3.

Table 3

Number of Training Blocks and Number of Participants Reaching Perfection in Healthy Young and Older Adults, and Alzheimer's patients in N-Back

	0-Back	1-Back	2-Back
Young	2.1 ± 0.32 (10)	2.0 ± 0.00 (10)	3.4 ± 0.84 (10)
Older	2.0 ± 0.00 (10)	2.1 ± 0.32 (10)	5.7 ± 0.67 (3)
Alzheimer	2.7 ± 1.06 (10)	5.1 ± 1.45 (5)	6.0 ± 0.00 (1)

Table 3. Data represent means ± standard deviations for training blocks. Number of participants reaching perfection in parentheses.

Dual-Task Testing

Session 4 consisted of a baseline assessment of balance on the stable and the moving platform. Each 1 block of four trials standing on the stable and the moving platform were followed by five blocks of each four trials of N-Back (0-Back, 1-Back, 2-Back), on the stable platform.

In session 5, participants were given five blocks of each four trials of N-Back (0-Back, 1-Back, 2-Back) on the moving platform.

In session 6, in order to assess the functional stability boundary on the stable platform, participants were asked to a) move as far in the anterior-posterior axis as they can without falling; b) move as far in the lateral axis as they can without falling; c) move as far in two diagonal axes as they can without falling. Each four trials were given for each of the four axes with and without continuous feedback. Before and after that procedure, continuous feedback was varied (with/without continuous feedback) for each four trials on a stable and a moving platform in order to train participants in the balance task.

In session 7, participants were given five blocks of each four trials of N-Back (0-Back, 1-Back, 2-Back) on the moving platform.

In session 8, participants were given five blocks of each four trials of N-Back (0-Back, 1-Back, 2-Back) on the stable platform. After that, post-test assessment took place. Each 1 block of four trials standing on a stable and a moving platform was followed by five blocks of each four trials of single-task N-Back (1-Back and 2-Back).

Data Analysis

The predictions regarding performance in balance and cognition (*Predicitions 1 and 2)* under dual-task conditions were tested for both raw performance as well as relative dual-task costs. Performance decrements from single- to dual-task were analyzed as a function of group (young versus older adults; older adults versus Alzheimer's patients), working memory task (0-Back versus 1-Back versus 2-Back), and balance task (easy versus difficult). Dual-task costs were computed as relative dual-task costs (i.e., as the percentage of loss in performance under easy and difficult platform conditions relative to performance under seated conditions for the cognitive task; and as the percentage of loss in performance while performing 1- and 2-Back relative to 0-Back, which served a s a control condition for verbalization in the balance task). Dual-task costs were analyzed computing two separate group (young versus older adults; older adults versus Alzheimer's patients) by balance task (easy versus difficult) within-subject multivariate analyses of variance (MANOVAs).

The predictions regarding the pattern of dual-task cost (*Predictions 3*) were analyzed using dual-task costs in balance and in working memory as dependent variables. Two separate group (young versus older adults; older adults versus Alzheimer's patients) by balance task (easy versus difficult) by domain (dual-task costs in balance versus dual-task costs in memory) within-subject MANOVAs were computed.

General Characteristics of the Measurement Space

The N-Back task, as well as the balance task under easy and difficult conditions, was, although the paradigm is not completely novel, a variation of tasks used in the literature. General characteristics, including the validity of the intended experimental manipulation and the reliability of performance levels under both single and dual-task conditions are presented.

Figure 9

Performance in N-Back under Increasing Difficulty across Groups

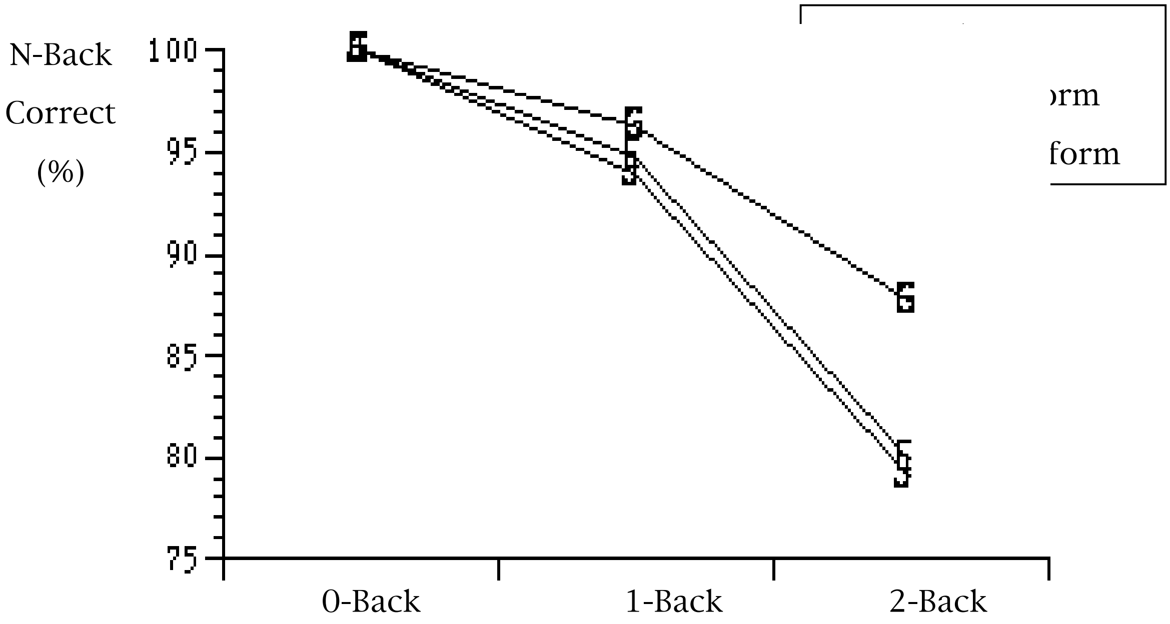

Figure 9. Accuracy in N-Back decreases as a function of complexity (0-Back versus 1-Back versus 2-Back) while seated (open squares), and under stable (open circles) and moving (solid circles) platform conditions.

In the working memory task, difficulty was manipulated using a task testing monitoring and sustained attention only (0-Back), a task testing the scheduled retrieval of items (1-Back), and a task involving working memory functions (2-Back). Due to training, all participants operated at the level of perfection in O-Back (i.e., the overall average was not different from 10; t(1, 479) = 1.42, p = .16). To investigate whether different tasks (0-Back, 1-Back, 2-Back) reflected different levels of complexity, mean accuracy (percentage correct) was collapsed across all groups. In a MANOVA with task condition (0-Back versus 1-Back versus 2-Back) and platform condition (stable versus moving platform) as factors, a significant main effect was found for task condition (F(3,2282) = 41.99, MSe = 725.45, p < .001), indicating that different conditions of the task indeed reflect different levels of complexity. Furthermore, a marginally significant effect for platform condition was found (F(2,2282) = 2.27, MSe = 725.45, p = .09).

Post hoc analyses revealed that performance in 0-Back was, on overall average, better than performance in 1-Back (t(2,2282) = 3.98, p < .001), and performance in 1-Back was, on overall average, better than performance in 2-Back (t(2,2282) = 2.39, p < .05). With regard to platform condition, seated performance was better than performance on a stable platform (t(2,2282) = 2.09, p < .05), and performance on a stable platform was better than performance on a moving platform (t(2,2282) = 2.07, p < .05). None of the interaction terms, however, reached statistical significance (all ps > .10). The mean performance in each task under stable and moving platform conditions, collapsed across all groups, is given in Figure 9.

In order to analyze the reliability of the assessment, cronbach`s was computed within groups for means and dual-task costs in all conditions. Likewise, within group correlations were computed for each task. Reliabilities and within group correlations in the complexity conditions (1-Back, 2-Back) for each group under both stable and moving platform conditions are given in Appendix B.

Figure 10

Performance in Balance under Increasing Difficulty across Groups

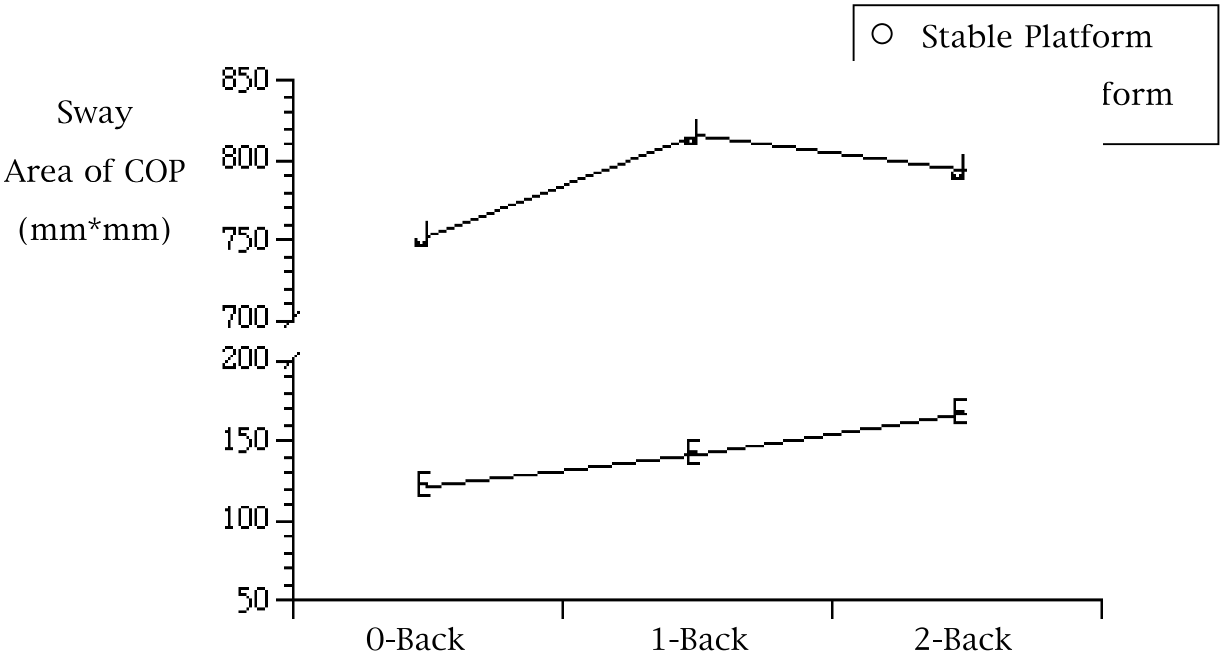

Figure 10. Sway increases from stable (open circles) to moving (solid circles) platform conditions and as a function of complexity in N-Back (0-Back versus 1-Back versus 2-Back).

In the balance task, the easy condition consisted of maintaining balance on a stable platform, while the difficult condition consisted of maintaining balance on a moving platform. Collapsing the area of Center of Pressure (COP Area) data across all groups, a platform (stable versus moving) by N-Back condition (0-Back versus 1-Back versus 2-Back) ANOVA was performed. There was a significant effect of platform condition (stable versus moving) (*F*(1,2184) =

3242.96, $MSe = 71076.09$, $p < .001$). The effect for N-Back condition, however, was only marginally significant ($F(3,2184) = 2.02$, $MSe = 71076.09$, $p = .09$). None of the interaction terms reached statistical significance (all $ps > .10$).

Post hoc analyses revealed that balance performance together with 0-Back was, on overall average, better than balance performance together with 1-Back ($t(2,3242) = 2.63$, $p < .01$). Balance performance together with 1-Back was, however, on overall average, not reliably different from balance performance together with 2-Back ($t(2,3242) = 1.20$, $p = .22$). Thus, despite a significant effect of single (balance together with 0-Back) versus dual-task, differences within dual-task were not reliable across all groups. However, since differential effects were predicted between groups for dual-task effects (an effect that is proven valid), the general validity of the manipulation can be considered satisfactory. The mean balance performance in each task under stable and moving platform conditions, collapsed across all groups, is given in Figure 10.

In order to analyze the reliability of the assessment, cronbach`s ▯ was computed within groups for means and dual-task costs in all conditions. Likewise, within group correlations were computed for each task. Within group correlations and reliabilities in the two conditions (stable versus moving platform), are given in Appendix B.

Overall, these results indicated that the complexity manipulation in both the working memory and the balance task provided valid results. Specifically, accuracy decreased with increasing complexity in the N-Back tasks, whereas sway increased when the balance task was made more difficult. Furthermore, in both task domains, sufficient reliabilities and within group correlations emerged (compare Appendix B). Thus, there was evidence for satisfactory validity for the assessment of balance performance and working memory performance under different complexity manipulations.

Results

Outline

The results section mainly followed the structure of the prediction section. First, however, single-task performance and training effects were described for the N-Back and balance tasks under different conditions (*Single-Task Performance and Training Effects*). Second, performance decrements in cognition when adding a balance task were analyzed both on the level of raw performance data and proportional dual-task costs (*Predictions 1; Dual-Task Performance in Cognition*). Third, performance decrements in balance when adding a cognitive task were analyzed in analogy (*Predictions 2; Dual-Task Performance in Balance*). Fourth, the differences in dual-task costs between domains (balance versus cognition) was analyzed (*Predictions 3; Comparison of Dual-Task Costs*).

Single-Task Performance and Training Effects

N-Back

During single-task training, all participants of this study completed eight consecutive trials of 0-Back without producing any mistake. In both the first and the last training block, there were significant effects that showed that younger adults scored better than older adults and older adults scored better than Alzheimer's patients did. Specifically, in the first training block, young adults outperformed older adults in 2-Back ($F(1,19) = 33.81$, $MSe = 72.23$, $p < .001$). Older adults, however, did not differ from Alzheimer's patients in 2-Back ($F(1,18) = 33.81$, $MSe = 72.2$, $p < .001$). In 1-Back, young adults did not differ from older adults ($F(1,19) = 1.26$, $MSe = 1.12$, $p = .27$), while Alzheimer's patients performed worse than older adults ($F(1,18) = 6.05$, $MSe = 37.21$, $p < .05$). In the last training block, there was a marginally significant difference in 2-Back between young and older adults ($F(1,19) = 3.27$, $MSe = 0.05$, $p = .08$). However, older adults performed better than Alzheimer's patients in 1-Back

(*F*(1,18) = 4.46, *MSe* = 12.29, $p < .05$) and 2-Back (*F*(1,18) = 12.41, *MSe* = 51.23, $p < .01$). All other effects were not statistically reliable (all ps > .33).

Differential training effects in 2-Back between groups were assessed for both young versus older adults, and older adults versus Alzheimer's patients, respectively.

Young versus older adults. The 2 (group) x 3 (training blocks: each the first block of sessions 1, 2, and 3) data pattern violated homogeneity assumptions (Box's *M* = 626.53, $p < .001$). The data were then analyzed after transforming individual scores into probit scores ([1/1-P]). This transformation produces a measure of each individual's performance calibrated to perfect performance (i.e., the probability that an individual score is perfect; compare Verhaeghen et al., 2002). The transformed data pattern was more consistent with homogeneity assumptions (Box's *M* = 75.48, $p < .01$). Young adults performed better than older adults did (*F*(1,18) = 40.41, *MSe* = 15.92, $p < .001$). Both groups improved over training (*F*(2,36) = 36.77, *MSe* = 10.89, $p < .001$), while the training gains (see Figure 11) were larger in older adults than in younger adults (*F*(2,36) = 8.89, *MSe* = 2.66, $p < .01$). A similar pattern emerged when the analysis was re-run using raw scores.

Older adults versus Alzheimer's patients. Due to homogeneity violations (Box's *M* = 43.25, $p < .001$), a 2 (group) x 3 (training blocks: each the first block of sessions 1, 2, and 3) ANOVA was performed on probit scores (Box's *M* = 18.42, $p < .05$). Older adults performed better than Alzheimer's patients did (*F*(1,17) = 8.15, *MSe* = 18.28, $p < .05$). Both groups improved over training (*F*(2,34) = 35.44, *MSe* = 10.64, $p < .001$), but this improvement was smaller in Alzheimer's patients (*F*(2,34) = 8.90, *MSe* = 2.67, $p < .01$). A similar pattern emerged when the analysis was re-run using raw scores.

As can be seen in Figure 11, scores for 2-Back were higher for young than for older adults than for Alzheimer's patients. In both tasks, younger adults reached ceiling after four to six sessions.

Figure 11

Training Gains in 2-Back

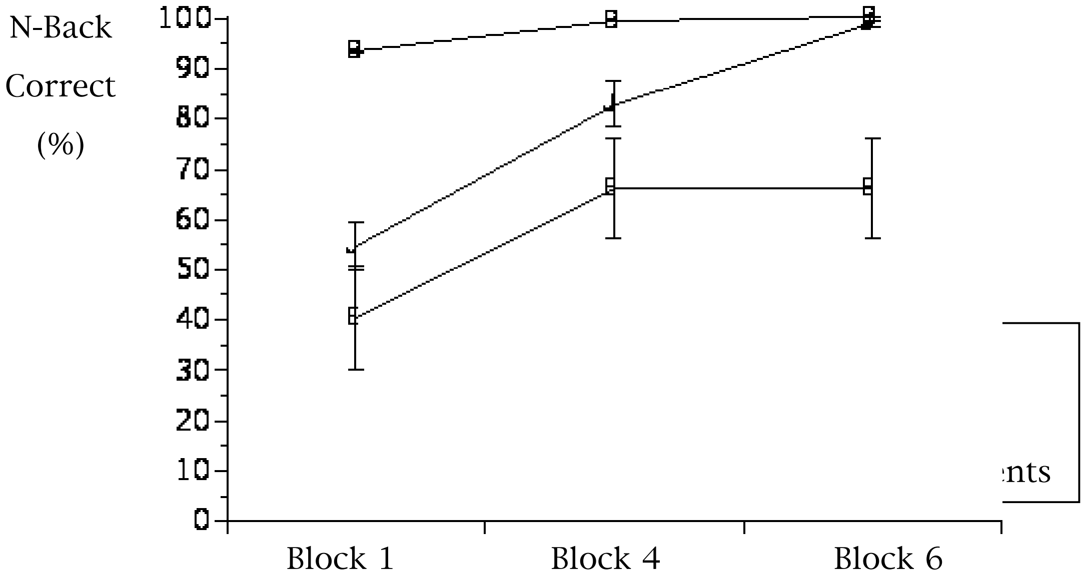

Figure 11. Training gains in 2-Back in younger adults (solid squares), older adults (solid circles), and Alzheimer's patients (open circles). Error bars reflect standard error of the mean.

In order to further explore differential effects of training in older adults and Alzheimer's patients, the amount of training gains from the first to the final training block was computed in each individual as a difference score:

$$\text{Gain} = M_{\text{Block 1}} - M_{\text{Block 6}} \quad (1).$$

Further analysis showed that the training gains were only marginally larger for older adults as compared to Alzheimer's patients in 2-Back ($t(18) = 1.89$, $p = .08$).

In summary, with respect to 2-Back, training gains were found in older adults and Alzheimer's patients. These training effects were only marginally larger in older adults as compared to Alzheimer's patients. In young adults, training effects were small, but younger adults reached perfection after a short period of training.

Balance Performance

Since balance performance is considered a task that has been learned over a lifelong period, balance performance was not trained prior to dual-task testing. However, each four trials of single-task balance performance on a stable and a moving platform were assessed prior to training. In the next section, differences in balance performance between young and older adults, and between older adults and Alzheimer's patients were analyzed.

Young versus older adults. Differences in single-task performance were analyzed with a 2 (group) x 2 (stable versus moving Platform) ANOVA. The data pattern met homogeneity assumptions (Box's $M = 2.41$, $p = .55$). Overall, younger adults showed less sway than older adults did ($F(1,18) = 6.82$, $MSe = 146904.07$, $p < .05$). Balance performance decreased in both groups from stable to moving platform conditions ($F(1,18) = 191.92$, $MSe = 3177156.5$, $p < .001$). The two-way interaction was statistically reliable ($F(1,18) = 6.37$, $MSe = 105413.78$, $p < .05$). Post hoc tests revealed that balance performance on the stable platform did not differ between young and older adults ($t(18) = 0.60$, $p = .55$), while performance on the moving platform ($t(18) = 2.74$, $p < .05$) was better in young, as compared to older adults.

Older adults versus Alzheimer's patients. The 2 (group) x 2 (stable versus moving Platform) data pattern met homogeneity assumptions (Box's $M = 5.98$, $p = .15$). Overall, older adults' balance performance was marginally better than Alzheimer's patients' ($F(1,17) = 4.36$, $MSe = 181797.38$, $p = .05$). Balance performance decreased in both groups from stable to moving platform conditions ($F(1,17) = 207.30$, $MSe = 6217490.7$, $p < .001$). The two-way interaction was statistically reliable ($F(1,17) = 6.53$, $MSe = 195856.80$, $p < .05$). Post hoc tests revealed that balance performance on the stable platform did not differ between older adults and Alzheimer's patients ($t(17) = 0.16$, $p = .87$), while performance on the moving platform ($t(17) = 2.38$, $p < .05$) was better in older adults, as compared to Alzheimer's patients.

Figure 12

Sway on a Stable and a Moving Platform in the three Groups

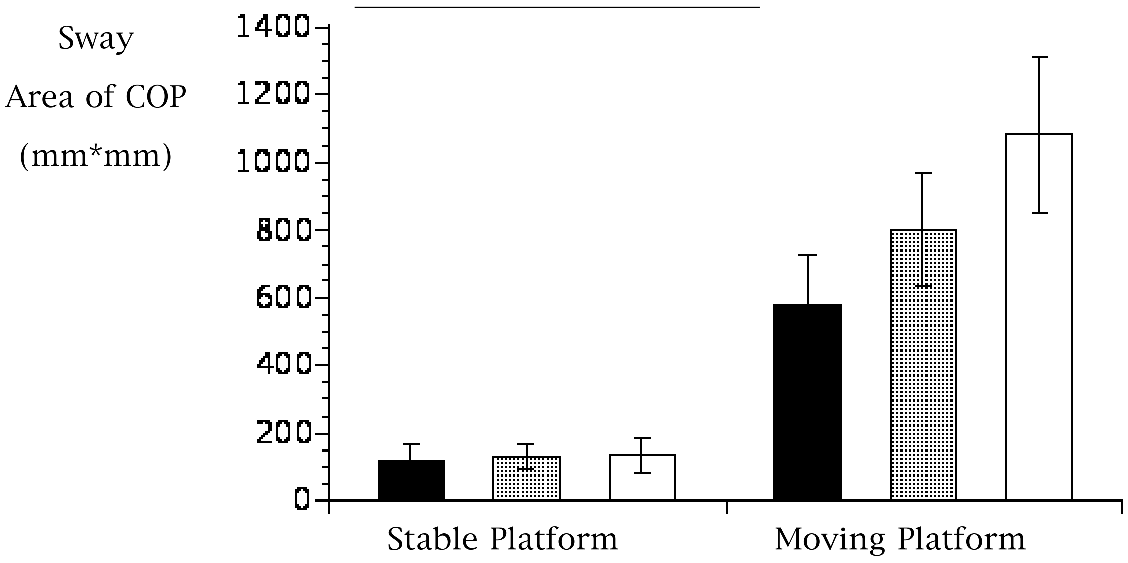

Figure 12. Area of COP movement on a stable (left) and a moving platform (right) in the three groups. Younger adults are depicted in black, older adults in gray, and Alzheimer's patients in white bars. Error bars reflect standard deviations.

The mean balance performance in each group on a stable and a moving platform is plotted in Figure 12.

Training Effects through Dual-Task Assessment

Differential training gains for both the N-Back and the balance task during dual-task assessment were analyzed between young and older adults and between older adults and Alzheimer's patients.

Young versus older adults. Analysis of change in single-task performance in the N-Back tasks before and after dual-task assessment (comparing session 3 to session 8) was done using a 2 (group) x 2 (1-Back versus 2-Back) x 2 (Session 3 versus Session 8) repeated measures ANOVA. The data pattern violated homogeneity assumptions (Box's $M = 63.01$, $p < .001$). The data were again analyzed after transforming individual scores into probit scores ([1/1-P]). The data pattern was more consistent with homogeneity assumptions (Box's $M = 42.08$, $p < .05$). Overall, older adults performed worse than younger adults did ($F(1,18) = 11.15$, $MSe = 0.09$, $p < .01$). Performance in 1-Back was better than performance in 2-Back ($F(1,18) = 11.15$, $MSe = 0.09$, $p < .01$). The effect for task condition interacted with group ($F(1,18) = 11.15$, $MSe = 0.09$, $p < .01$). None of the other effects or interactions was statistically reliable (all *ps* > .10).

For the balance task, the 2 (group) x 2 (stable versus moving platform) x 2 (Pretest 2 versus Posttest) data pattern met homogeneity assumptions (Box's $M = 23.94$, $p = .06$). Younger adults' sway was smaller than older adults' ($F(1,18) = 8.15$, $MSe = 263610.91$, $p < .05$). Overall, performance on the stable platform was better than performance on the moving platform ($F(1,18) = 232.88$, $MSe = 4852400.1$, $p < .001$). This effect interacted with group ($F(1,18) = 10.76$, $MSe = 224184.53$, $p < .01$). In addition, a significant training effect emerged ($F(1,18) = 18.85$, $MSe = 104076.87$, $p < .001$), which interacted with platform condition ($F(1,18) = 14.62$, $MSe = 6239.26$, $p < .01$), indicating that training effects were larger on the moving platform as compared to the stable platform ($t(18) = 3.13$, $p < .001$). This training effect, however, did not interact with group ($p > .71$).

Older adults versus Alzheimer's patients. Analysis of change in single-task performance in the N-Back tasks before and after dual-task assessment (comparing session 3 to session 8) was done using a 2 (group) x 2 (1-Back versus 2-Back) x 2 (Session 3 versus Session 8) repeated measures ANOVA. The data pattern violated homogeneity assumptions (Box's $M = 72.06$, $p < .001$). The data were again analyzed after transforming individual scores into probit scores ([1/1-P]). The data pattern was more consistent with homogeneity assumptions (Box's $M = 37.14$, $p < .05$). Older adults outperformed Alzheimer's patients ($F(1,17) = 7.64$, $MSe = 1.32$, $p < .05$), and overall, performance was better in 1-Back as compared with 2-Back ($F(1,17) = 12.12$, $MSe = 0.63$, $p < .01$). None of the interactions with training was statistically reliable (all $ps > .14$).

For the balance task, a 2 (group) x 2 (stable versus moving platform) x 2 (Pretest 2 versus Posttest) ANOVA was performed. The data pattern met homogeneity assumptions (Box's $M = 19.14$, $p = .17$). Alzheimer's patients' sway was larger than older adults' ($F(1,17) = 6.87$, $MSe = 545360.72$, $p < .05$), and performance was better on the stable as compared to the moving platform ($F(1,17) = 207.88$, $MSe = 11466517$, $p < .001$). This effect was larger in the Alzheimer's patients (1,17) = 11.07, $MSe = 610441.80$, $p < .01$). In addition, a significant training effect emerged ($F(1,17) = 9.31$, $MSe = 42582.33$, $p < .01$). This training effect, however, did not interact with group ($p > .08$). However, there was a significant interaction between group, platform condition, and training ($F(1,17) = 4.64$, $MSe = 24160.81$, $p < .05$). As can be seen in Table 4, this interaction was mainly due to the fact that older adults' performance on the moving platform improved, whereas it did not in Alzheimer's patients.

Summary

Single-task performance in N-Back differed between young adults, older adults and Alzheimer's patients. Specifically, in 1-Back and 2-Back, young adults outperformed older adults who in turn outperformed Alzheimer's patients. In the Balance task, single-task performance did not differ between the three groups on the stable platform. However, on the moving platform, young adults performed better than older adults who in performed better than Alzheimer's patients.

Table 4

Mean Performance Before and After Dual-Task Assessment

	Single-Task Balance	
	Pretest 2	Posttest
Young Adults (N = 10)		
Stable Platform	114.32 (50.18)	122.88 (44.60)
Moving Platform***	575.31 (153.53)	435.27 (160.81)
Older Adults (N = 10)		
Stable Platform	132.86 (38.35)	122.22 (41.66)
Moving Platform***	799.19 (168.03)	652.76 (165.44)
Alzheimer's Patients (N = 9)		
Stable Platform	127.60 (51.14)	107.80 (62.48)
Moving Platform	1081.50 (230.85)	1068.74(225.24)

	Single-Task N-Back	
	Pretest 2	Posttest
Young Adults (N = 10)		
1-Back	100.00 (0.00)	100.00 (0.00)
2-Back	100.00 (0.00)	100.00 (0.00)
Older Adults (N = 10)		
1-Back	100.00 (0.00)	100.00 (0.00)
2-Back	98.89 (16.13)	91.67 (14.24)
Alzheimer's Patients (N = 9)		
1-Back	90.55 (16.00)	90.33 (16.42)
2-Back	73.61 (24.14)	74.52 (27.01)

Table 4. Significant differences between Pretest 2 (before) and Posttest (after dual-task assessment): *p < .05; ** p < .01; *** p < .001. Values in parentheses represent standard deviations.

With respect to Training in N-Back prior to the dual-task assessment, significant training gains were found in both older adults and in Alzheimer's patients. These training effects were only marginally larger in older adults as compared to Alzheimer's patients. In young adults, training effects were small, but younger adults reached perfection after a short period of training.

With regards to training effects through dual-task assessment, significant training effects were found for both the N-Back and the Balance tasks. However, these effects were not differential for age or disease status, indicating a general effect of assessment. For the following analyses of dual-task performance, we thus averaged across the first (Sessions 4 and 5) and the second (Sessions 7 and 8) part of dual-task assessment. Mean performance before and after dual-task assessment in each group is given in Table 4.

Dual-Task Performance in Cognition[9]

In the following analyses, we included only those trials in which participants scored at least 4 correct in N-Back in order to ascertain that participants did actually perform the task rather than drop it completely in the dual-task context. The number of trials excluded for that reason differed between groups. While zero trials were below 4 correct in young adults, there were 13 trials (5.41%) in older adults, and 30 trials (13.88%) in Alzheimer's patients. In general, results for 1-Back were in line with the results in 2-Back. Thus, for the analysis of Predictions 1 through 3, only data in 2-Back were analyzed. The data analysis for 1-Back can be found in Appendix C.

In *Predictions 1*, differential dual-task costs in working memory when adding a balance task were expected in the three groups. Specifically, a main effect for age, a main effect for dementia, a main effect for platform condition, and an interaction between dementia status and platform condition were

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[9] Mean performance levels in single- and dual-task conditions in each group are given in Appendix B.

expected. The dual-task costs in the 2-Back task for stable and moving platform conditions in young adults, older adults and Alzheimer's patients are depicted in Figure 13.

Young versus older adults. To test the prediction of a differential decrease in 2-Back performance when adding a balance task between young and older adults under different complexity conditions, a 2 (group) x 3 (seated versus stable versus moving platform condition) ANOVA was performed.

Performance in 2-Back was better in young as compared to older adults ($F(1,18) = 7.79$, $MSe = 34.40$, $p < .05$, $\square^2 = .30$). A main effect for platform condition ($F(2,36) = 7.37$, $MSe = 4.27$, $p < .01$, $\square^2 = .29$) emerged, which interacted with group ($F(2,36) = 5.96$, $MSe = 3.64$, $p < .01$, $\square^2 = .24$).

Post hoc tests showed that, in younger adults, 2-Back performance did not differ between sitting and standing on a stable platform nor between standing on a stable and a moving platform (t-tests; $ps > .17$). In older adults, however, performance in 2-Back was significantly better while sitting as compared to standing on a stable ($t(9) = 2.50$, $p < .05$) and as compared to standing on a moving platform ($t(9) = 2.78$, $p < .05$).

A numerical interpretation of the results proved difficult for two reasons. First, the data pattern massively violated homogeneity assumptions (Box's $M = 81.61$, $p < .001$). Second, the two groups differed in single-task performance in the 2-Back task prior to dual-task testing. In order to attain variance homogeneity and to control for baseline performance, relative dual-task costs were computed to assess the magnitude of dual-task performance decrements in each group. Performance decrements under dual-task conditions were expressed as a percentage of single-task performance:

$$DTC = [(NC_{seated} - NC_{balance}) / NC_{seated}] * 100 \quad (1),$$

for both the stable and the moving platform condition (DTC = dual-task costs; NC = average number of correct items per block).

A 2 (group) x 2 (stable versus moving platform) ANOVA showed that dual-task costs were larger in older as compared to younger adults ($F(1,18) = 6.35$, $MSe = 1120.62$, $p < .05$, $\square^2 = .26$)[10]. Statistical trends further indicated a main effect of platform condition ($F(1,18) = 3.56$, $MSe = 41.34$, $p = .08$, $\square^2 = .17$), which marginally interacted with group ($F(1,18) = 3.14$, $MSe = 36.42$, $p = .09$, $\square^2 = .15$). None of the other effects or higher interactions was statistically reliable (all *ps* > .10).

Post hoc tests showed that in younger adults, dual-task costs were not significantly different from zero on a stable, nor on a moving platform (t-tests; *ps* > .17). In older adults, however, significant dual-task costs emerged on a stable ($t(9) = 2.46$, $p < .05$), and on a moving platform ($t(9) = 2.71$, $p < .05$). In older adults, dual-task costs on a moving platform were marginally higher as compared to dual-task costs on a stable platform ($t(9) = 1.86$, $p = .09$).

Older adults versus Alzheimer's patients. Analogous analyses were performed to test the prediction of a differential decrease in 2-Back performance when adding a balance task at different levels of complexity between older adults and Alzheimer's patients.

The 2 (group) x 3 (seated versus stable versus moving platform condition) data pattern violated homogeneity assumptions (Box's $M = 65.86$, $p < .05$). Overall, 2-Back performance was better in older adults as compared to Alzheimer's patients ($F(1,17) = 12.08$, $MSe = 169.60$, $p < .01$, $\square^2 = .43$). A main effect for platform condition ($F(2,34) = 35.56$, $MSe = 43.24$, $p < .001$, $\square^2 = .69$) emerged, which interacted with group ($F(2,34) = 6.92$, $MSe = 8.41$, $p < .01$, $\square^2 = .30$).

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[10] After dual-task cost transformation, the data pattern was only slightly more consistent with homogeneity assumptions (Box's $M = 49.67$, $p < .01$).

Figure 13

Dual-Task Costs in Cognition in Young Adults, Older Adults, and Alzheimer's Patients

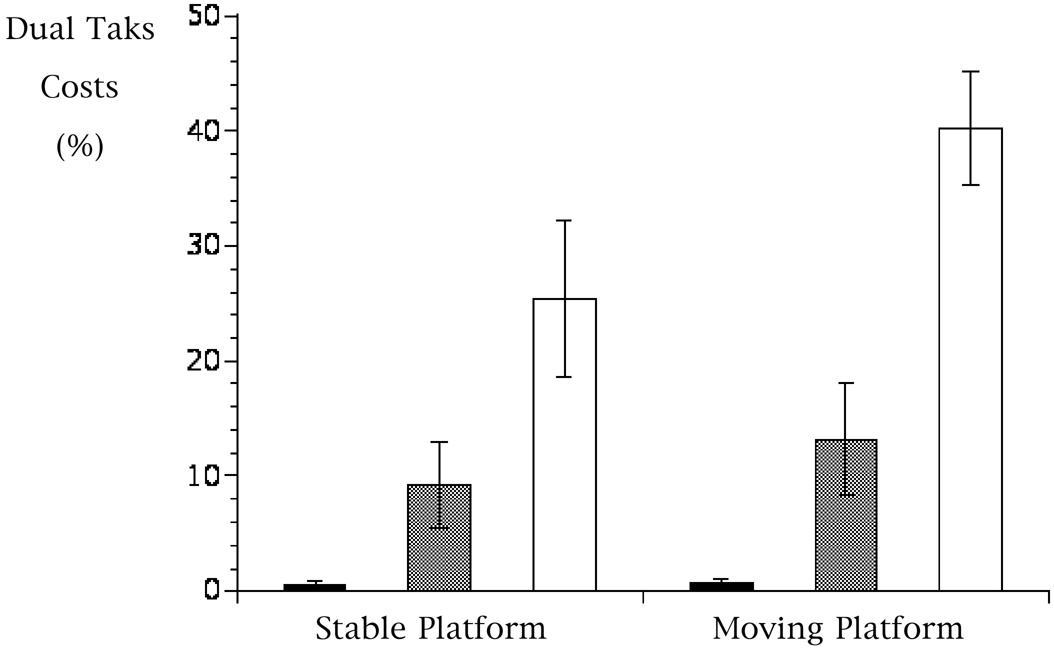

Figure 13. Relative dual-task costs (%) in 2-Back, under stable and moving platform conditions, in young adults (depicted in black bars), older adults (gray bars), and Alzheimer's patients (white bars). Error bars reflect one standard error of the mean.

Post hoc tests showed that, in older adults, performance in 2-Back was significantly better while sitting, as compared to standing on a stable ($t(9) = 2.50$, $p < .05$) and as compared to standing on a moving platform ($t(9) = 2.78$, $p < .05$). The same pattern emerged for Alzheimer's patients on a stable ($t(8) = 2.40$, $p < .05$), and on a moving platform ($t(8) = 4.18$, $p < .01$). The performance decrement in 2-Back from standing on a stable to standing on a moving platform, however, was larger in Alzheimer's patients, as compared to older adults ($F(1,17) = 15.04$, $MSe = 220.47$, $p < .001$, $\eta^2 = .47$). Again, a numerical interpretation of the results proved difficult, since older adults and Alzheimer's patients differed in single-task performance in the N-Back tasks prior to dual-task testing.

Thus, relative dual-task costs were again computed in order to assess the magnitude of dual-task performance decrements in each group. The 2 (group) x 2 (stable versus moving platform) data pattern was more consistent with homogeneity assumptions (Box's $M = 10.40$, $p < .05$). Overall, dual-task costs were larger in Alzheimer's patients, as compared to older adults ($F(1,17) = 13.70$, $MSe = 5724.14$, $p < .01$, $\eta^2 = .45$). Furthermore, dual-task costs were larger on the moving, as compared to the stable platform ($F(1,17) = 13.54$, $MSe = 860.07$, $p < .01$, $\eta^2 = .44$), and this effect was more pronounced in the Alzheimer's patients, as compared to the older adults ($F(1,18) = 4.66$, $MSe = 295.76$, $p < .05$, $\eta^2 = .22$).

In summary, 2-Back was not affected by standing on a stable or moving platform in young adults, while in older adults, significant dual-task costs emerged. In Alzheimer's patients, dual-task costs emerged that were larger than older adults', and increased disproportionally from stable to moving platform conditions.

Dual-Task Costs in Balance[11]

Analogous analyses were performed for balance performance. In *Predictions 2*, differential dual-task costs in balance were expected when adding a working memory task. Specifically, a main effect of age, a main effect of dementia, a main effect of platform condition, and an interaction between dementia status and platform condition were expected. However, given the assumption that standing on a moving platform is a task critical to survival in older adults and patients

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[11] Mean balance performance levels in single and dual-task conditions in each group are given in Appendix B.

with Alzheimer's disease, a decrease in dual-task costs (i.e., an increase in dual-task performance) was expected from stable to moving platform conditions. The dual-task costs in balance on the stable and moving platform when adding the 2-Back task in young adults, older adults and Alzheimer's patients are depicted in Figure 14.

Young versus older adults. To test the prediction of a differential decrease in balance performance when adding the 2-Back task between young and older adults under different complexity conditions, a 2 (group) x 2 (baseline versus 2-Back) x 2 (stable versus moving platform condition) ANOVA was performed.

The data pattern violated homogeneity assumptions (Box's $M = 141.19$, $p < .001$). Performance in balance was better in young as compared to older adults ($F(1,18) = 9.59$, $MSe = 845419.24$, $p < .01$, $\eta^2 = .35$). A main effect for platform condition ($F(1,18) = 201.49$, $MSe = 11328023$, $p < .001$, $\eta^2 = .92$) emerged, which interacted with group ($F(1,18) = 10.84$, $MSe = 609703.91$, $p < .01$, $\eta^2 = .38$). Furthermore, a main effect for dual-task condition ($F(1,18) = 11.11$, $MSe = 182975.02$, $p < .01$, $\eta^2 = .38$) emerged, which interacted with platform condition at marginal significance ($F(1,18) = 3.66$, $MSe = 62730.23$, $p = .07$, $\eta^2 = .17$). None of the other effects was statistically significant (all $ps > .10$).

Post hoc tests showed that, in younger adults, Balance performance did not differ between baseline and 2-Back neither on the stable platform nor between baseline and 2-Back on the moving platform (t-tests; $ps > .10$). In older adults, however, performance in balance was significantly better at baseline, as compared to 2-Back on the stable platform ($t(9) = 3.29$, $p < .01$). On the moving platform, however, the difference was only marginally significant ($t(9) = 2.14$, $p = .06$).

Relative dual-task costs were computed. The 2 (group) x 2 (stable versus moving platform) data pattern of relative dual-task costs met homogeneity assumptions (Box's $M = 7.38$, $p = .10$). Dual-task costs were larger in older as compared to younger adults ($F(1,18) = 4.35$, $MSe = 3547.15$, $p < .05$, $\square^2 = .20$). The ANOVA revealed no other effects or higher interactions of statistical reliability (all $ps > .27$).

Post hoc tests showed that in younger adults, dual-task costs were only marginally different from zero on the moving platform ($t(9) = 2.18$, $p = .06$), and did not differ from zero on the stable platform ($t(9) = 1.80$, $p = .11$). In the older adults, dual-task costs were significantly different from zero (stable platform: $t(9) = 3.12$, $p < .05$; moving platform: $t(9) = 2.42$, $p < .05$). However, there was no significant difference between dual-task costs on the stable and the moving platform ($t(9) = 1.07$, $p = .31$).

Older adults versus Alzheimer's patients. Analogous analyses were performed between older adults and Alzheimer's patients.

The 2 (group) x 2 (baseline versus 2-Back) x 2 (stable versus moving platform condition) data pattern met homogeneity assumptions (Box's $M = 72.54$, $p = .57$). Performance in balance was better in older adults as compared to Alzheimer's patients ($F(1,17) = 5.87$, $MSe = 988985.61$, $p < .05$, $\square^2 = .25$). A main effect for platform condition ($F(1,17) = 202.35$, $MSe = 24644096$, $p < .001$, $\square^2 = .92$) emerged, which interacted with group ($F(1,17) = 7.08$, $MSe = 861793.40$, $p < .05$, $\square^2 = .29$). Furthermore, there was a main effect of dual-task condition ($F(1,17) = 13.69$, $MSe = 307644.85$, $p < .01$, $\square^2 = .45$).

Post hoc tests showed that, in older adults, performance in balance on the stable platform was significantly better at baseline as compared to 2-Back ($t(9) = 3.29$, $p < .01$). On the moving platform, however, the difference was only marginally significant ($t(9) = 2.14$, $p = .06$). In Alzheimer's patients, too, only the difference between baseline and 2-Back on the stable platform was statistically reliable ($t(8) = 3.76$, $p < .01$).

Relative dual-task costs were computed. The 2 (group) x 2 (stable versus moving platform) data pattern of relative dual-task costs met homogeneity assumptions (Box's $M = 7.07$, $p = .10$). The ANOVA revealed a significant effect of platform condition, indicating that dual-task costs were larger on the stable as compared to the moving platform (*F*(1,17) = 10.02, *MSe* = 17899.55, $p < .01$, $\square^2$ = .37). This effect marginally interacted with group (*F*(1,17) = 3.90, *MSe* = 6958.52, $p = .06$, $\square^2$ = .19).

Figure 14

Dual-Task Costs in Balance in Young Adults, Older Adults,
and Alzheimer's Patients

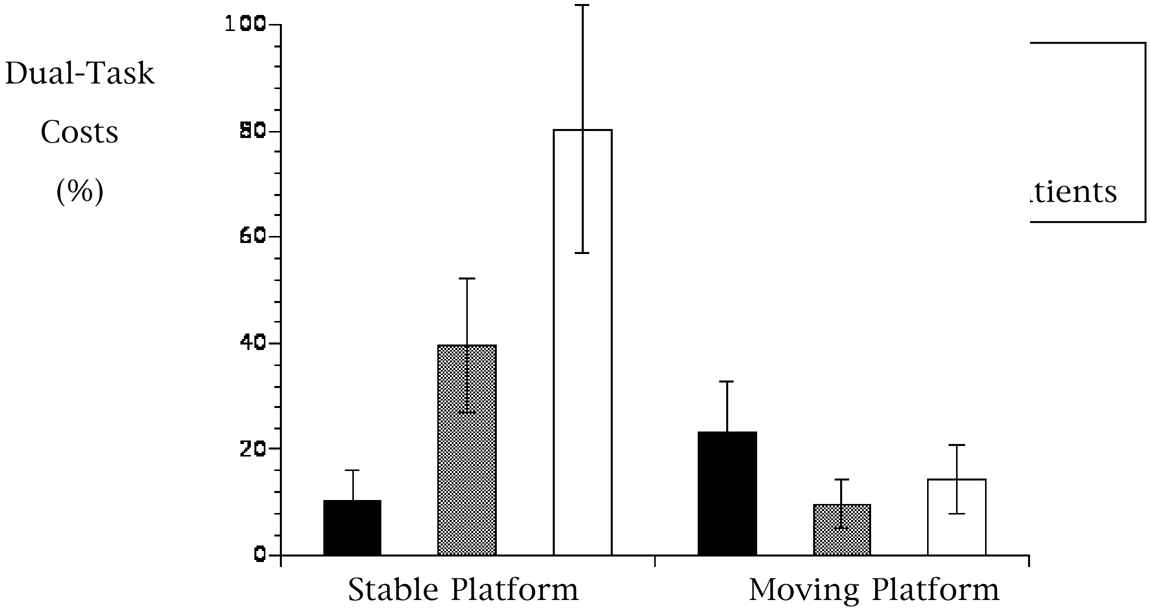

Figure 14. Relative dual-task costs (%) in 2-Back, under stable and moving platform conditions, in young adults (depicted in black bars), older adults (gray bars), and Alzheimer's patients (white bars). Error bars reflect one standard error of the mean.

In the older adults, dual-task costs were significantly different from zero (stable platform: $t(9) = 3.12$, $p < .05$; moving platform: $t(9) = 2.42$, $p < .05$). There was no significant difference between dual-task costs on the stable and the moving platform ($t(9) = 1.07$, $p = .31$). In the Alzheimer's patients, too, dual-task costs were significant in both platform conditions (stable platform: $t(8) = 3.43$, $p < .01$; moving platform: $t(8) = 2.43$, $p < .05$). However, in the Alzheimer's patients, a significant difference emerged between platform conditions, indicating that dual-task costs were actually larger on the stable as compared to the moving platform ($t(9) = 3.00$, $p < .05$).

In summary, dual-task costs increased from young adults to older adults to Alzheimer's patients. While young and older adults' costs did not differ between stable and moving platform conditions, dual-task costs in Alzheimer's patients were larger on the stable as compared to the moving platform.

Comparison of Dual-Task Costs

In order to test the prediction of differential prioritization (Predictions 3), dual-task costs in balance performance and in N-Back performance were compared. The prediction states an increase in the dual-task costs in cognition together with a decrease of dual-task costs in balance from stable to moving platform conditions in older adults, and more so in Alzheimer's patients. To that end, only dual-task costs in 2-Back were examined.

Young versus older adults. The 2 (group) by 2 (dual-task costs in balance versus dual-task costs in cognition) by 2 (stable versus moving platform) data pattern violated homogeneity assumptions (Box's $M = 67.46$, $p < .001$). Overall, dual-task costs were larger in older adults as compared to younger adults ($F(1,18) = 7.58$, $MSe = 4327.63$, $p < .05$, $\square^2 = .30$). Furthermore, dual-task costs were larger for balance than for cognition in both groups ($F(1,18) = 12.39$, $MSe = 5221.90$, $p < .01$, $\square^2 = .41$). None of the other main effects or interactions was statistically reliable (all $ps > .20$).

Older adults versus Alzheimer's patients. The 2 (group) by 2 (dual-task costs in balance versus dual-task costs in cognition) by 2 (stable versus moving platform) data pattern met homogeneity assumptions (Box's $M = 24.71$, $p = .05$).

Overall, dual-task costs were larger in Alzheimer's patients as compared to older adults ($F(1,17) = 6.09$, $MSe = 6853.41$, $p < .05$, $\square^2 = .26$).

Figure 15

Dual-Task Costs in Balance and Cognition in Young Adults,
Older Adults, and Alzheimer's Patients

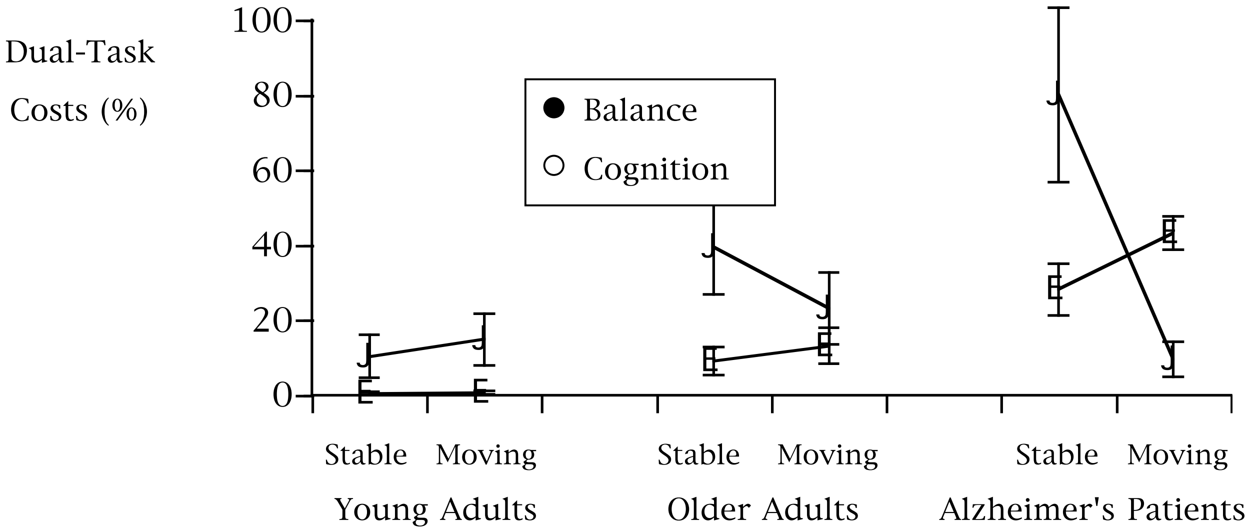

Figure 15. Relative dual-task costs (%) in 2-Back (open circles) and Balance (solid circles) under stable and moving platform conditions in young adults (left), older adults (center), and Alzheimer's patients (right). Error bars reflect one standard error of the mean.

Dual-task costs in balance were marginally larger than dual-task costs in cognition ($F(1,17) = 3.27$, $MSe = 4105.61$, $p = .09$, $\square^2 = .16$). There was a main effect of platform condition ($F(1,17) = 7.48$, $MSe = 5456.18$, $p < .05$, $\square^2 = .31$), which was found to interact with domain (balance versus cognition) ($F(1,17) =$

11.88, $MSe = 13303.44$ $p < .01$, $\square^2 = .41$). The three-way interaction between group, platform condition, and domain (balance versus cognition) was also significant ($F(1,17) = 4.52$, $MSe = 5061.47$, $p < .05$, $\square^2 = .22$).

Post hoc tests showed that the average dual-task costs on the stable platform were larger than on the moving platform ($t(18) = 2.51$, $p < .05$). In older adults, dual-task costs for cognition were of equal amount on the moving as compared to the stable platform ($t(9) = 1.86$, $p = .10$). In Alzheimer's patients, however, dual-task costs for cognition were larger on the moving as compared to the stable platform ($t(8) = 3.06$, $p < .01$). For the dual-task costs in balance, the reverse picture emerged. While dual-task costs in balance were of equal size on the stable and the moving platform in older adults ($t(9) = 1.07$, $p = .31$), in Alzheimer's patients, dual-task costs were larger on the stable as compared to the moving platform ($t(9) = 3.00$, $p < .01$). The dual-task costs for both domains on a stable and a moving platform are depicted in Figure 15.

In summary, while dual-task costs where comparable on the moving and the stable platform in young and older adults, Alzheimer's patients showed an increase in dual-task costs for cognition and a decrease in dual-task costs in balance from stable to moving platform conditions.

Control Analysis

In order to control for individual differences in the ability to tolerate sway, the functional stability boundary (FSB) measure was taken into account. The area covered by the functional stability boundary was larger in young ($M = 27369.13$; $SD = 4640.46$) as compared to older adults ($M = 17948.70$; $SD = 8364.34$; $t(18) = 3.11$, $p < .01$), but did not differ between older adults and Alzheimer's patients ($M = 19212.60$; $SD = 9651.55$; $t(17) = 0.31$, $p = .77$). As a control analysis, the analysis on the comparison of dual-task costs (*Comparison of Dual-Task Costs*) was rerun using the FSB as a covariate for each factor.

Young versus older adults. The 2 (group) by 2 (dual-task costs in balance versus dual-task costs in cognition) by 2 (stable versus moving platform) data pattern violated homogeneity assumptions (Box's $M = 67.46$, $p < .001$). The main effect of group was no longer significant ($F(1,18) = 1.54$, $MSe = 764.76$, $p = .23$, $\square^2 = .08$). Dual-task costs remained larger for balance than for cognition in both groups ($F(1,18) = 12.39$, $MSe = 5221.90$, $p < .01$, $\square^2 = .41$). None of the other main effects or interactions was statistically reliable (all $ps > .20$).

Older adults versus Alzheimer's patients. The 2 (group) by 2 (dual-task costs in balance versus dual-task costs in cognition) by 2 (stable versus moving platform) data pattern met homogeneity assumptions (Box's $M = 23.41$, $p = .07$). Overall, dual-task costs were larger in Alzheimer's patients as compared to older adults ($F(1,17) = 7.91$, $MSe = 9171.66$, $p < .05$, $\square^2 = .33$). Dual-task costs in balance were now significantly larger than dual-task costs in cognition ($F(1,17) = 7.62$, $MSe = 7068.64$, $p < .05$, $\square^2 = .31$). There was a main effect of platform condition ($F(1,17) = 5.17$, $MSe = 7057.97$, $p < .05$, $\square^2 = .23$), which again interacted with domain (balance versus cognition) ($F(1,17) = 13.12$, $MSe = 18104.17$, $p < .01$, $\square^2 = .44$). The three way interaction between group, platform condition, and domain (balance versus cognition) remained clearly significant ($F(1,17) = 5.92$, $MSe = 8164.06$, $p < .05$, $\square^2 = .26$).

In summary, when the analysis was rerun with the FSB, a measure of individual differences in the ability to tolerate sway, as a covariate, a similar pattern emerged between older adults and Alzheimer's patients. Between older and younger adults, however, effects disappeared when controlling for FSB.

Discussion

Overview

The aim of this study was to investigate the simultaneous performance of a cognitive and a balance task in normal and pathological aging. Two main questions guided Experiment 1. First, are there differential amounts of performance decrements while performing a cognitive and a sensorimotor task simultaneously in young adults, older adults, and Alzheimer's patients? Second, are there differential patterns of prioritization of one balance over cognition in young and older adults, and patients suffering from Alzheimer's disease? Specifically, it was investigated whether patients suffering from Alzheimer's disease adaptively prioritize balance performance, which is considered critical to survival in old age, over cognition when the balance task is made more difficult.

On a descriptive level, it was found that performance levels in cognition decreased from young to older adults to older adults low on fluid intelligence to Alzheimer's patients. Balance performance did not differ between young and older adults. However, balance performance on a moving platform was worse in Alzheimer's patients and better in older adults low on fluid intelligence, as compared to older adults, respectively. The amount of training gains in single-task N-Back prior to dual-task assessment was larger in older adults as compared to older adults low on fluid intelligence, and larger in older adults low on fluid intelligence as compared to Alzheimer's patients. Significant improvements were found through dual-task assessment. However, this difference was not related to group status, indicating a general effect of the assessment.

In line with the first set of predictions, differential dual-task decrements were found in cognition when adding a balance task. Decrements were larger in older adults as compared to young adults. Between older adults and Alzheimer's patients, decrements increased in an overadditive manner when the balance task was made more difficult.

In line with the second set of predictions, dual-task decrements in balance when adding a cognitive task increased from young to older adults to Alzheimer's patients on a stable platform. However, but as expected, on a moving platform, dual-task decrements decreased in older adults and more so in Alzheimer's patients, indicating that with increasing difficulty of the balance task, dual-task decrements decreased in older adults and Alzheimer's patients.

In the third set of predictions, it was hypothesized that dual-task costs in cognition increase from stable to moving platform conditions, and at the same time decrease in balance, indicating a prioritization of balance over cognition in older adults and Alzheimer's patients. This prediction was based on the assumption that balance performance is a task critical to survival in older adults. While this prediction was confirmed, it could be shown that the pattern of prioritization was exaggerated in Alzheimer's disease, as revealed by a group by domain by task difficulty interaction.

The central finding of the present study is that, when performing a balance and a cognitive task simultaneously, Alzheimer's patients prioritized balance over cognition when the task was made more difficult. The pattern of prioritization was present despite large dual-task performance decrements in Alzheimer's disease patients. This pattern of prioritization implies that effects of adaptive processes have considerable influence on dual-task performance in Alzheimer's disease. In the following, I will discuss possible limitations and qualifications of Experiment 1.

Qualifications and Alternative Interpretations

Validity of Measurement

In Experiment 1, the main finding is based on performance under dual-task conditions, comparing cognition and sensorimotor performance. Three potential threats to the validity of the assessment will be discussed in the following. First, the possibility that Alzheimer's patients completely neglected one task, in the sense that they did not do it at all. Second, differences in training effects between stable and moving platform conditions could have influenced the results. Third, anxiety and fear of falling could have had a differential impact on balance performance and dual-task performance across groups.

A potential threat to the validity of the data can be seen in the possibility that Alzheimer's patients, operating at their limits of performance, could have completely neglected one task while performing two tasks simultaneously. As shown in the results section, there was indeed a number of trials where Alzheimer's patients performed extremely poor in the N-Back task. However, when only trials with a certain level of performance (i.e., performance of more than three items correct, indicating that at least four consecutive digits were successfully stored, scheduled and retrieved within working memory) were considered, both the amount and the pattern of dual-task costs proved statistically reliable.

Second, while standing on a stable platform can be seen as a task that has been overlearned across the lifespan, standing on a moving platform can be seen as a novel task that may show differential training effects, which in turn may have influenced the prioritization pattern as found in this study. However, between consecutive sessions, stabilities for the standing platform were smaller as compared to stabilities on the moving platform. In addition, when training effects over the course of dual-task assessment were assessed, no significant differences could be found between groups.

Third, the influence of anxiety on balance performance needs to be considered. It may well be that differences in fear of falling, which have been described in the literature for older adults, could have affected the present results. In order to control for differences in behavior that may have been due to different levels of anxiety, an individually referenced measure of tolerance of sway was assessed in each participant. The functional stability boundary measure consists of repeated assessments of the maximum amount of self-induced sway a participant is able to tolerate. While age effects were found for this measure (young adults tolerated larger amounts of sway as compared to older adults), there was no significant difference between older adults and Alzheimer's patients. When controlling for differences in the FSB, the main finding (compare *Comparison of Dual-Task Costs*) remained statistically reliable. Thus, while age differences may have been due to different levels of anxiety (which would be one causal factor for the proposed age-saliency of the task), behavioral differences between older adults and Alzheimer's patients can be ruled out.

Representation of Effects in Relative Dual-Task Costs

The main finding of this study is based on the analysis of proportional dual-task costs. However, following different theoretical approaches, different metrics for describing dual-task performance can be found in the literature.

Based upon theories of general resource models of dual-task performance, absolute costs (i.e., difference scores between single and dual-task performance) have been reported in a variety of studies. Reliable age differences have been found for a number of tasks using a difference score metric. However, this method primarily accounts for additive changes in performance from single to dual-task. When combining a balance and a cognitive task, disproportional dual-task costs can be expected for three reasons (compare Lindenberger et al., 2000): the two tasks share stimulus modality (e.g., both tasks share the visual modality), sequencing and coordination between tasks is necessary, and third, one task in itself taxes cognitive control processes to a high degree (which is true for sensorimotor performance with aging (Lindenberger & P. Baltes, 1994). Thus, as discussed at some length in the literature review section, all three criteria for the expectation of disproportional dual-task costs are met in the present study. A second reason for computing dual-task costs in a proportional metric is of relevance. Only rarely have researchers succeeded in equating performance between young adults, older adults and Alzheimer's patients. Potentially, two methodological approaches are possible. First, participants could be equated in performance using a series of extensive training in a testing the limits paradigm (compare Kliegl, Smith, & P. Baltes, 1989). This procedure, however, was beyond the scope of this dissertation. Alternatively, it has been proposed to use simple tasks of working memory in order to equate performance (e.g., Baddeley, 1986). While such a strategy has shown successful results, it does not allow for complexity manipulations, since more complex tasks would lead to differences in baseline performance. Kinsbourne (Kinsbourne, 1987), who suggested controlling for differences of single-task performance by using a proportional metric, has put a relative dual-task metric forth as an alternative.

In sum, a proportional metric of dual-task performance was applied in order to account for specific features of the tasks used in combination (interrelatedness of modalities, demands on cognitive control), and in order to control for differences in baseline performance. The argument upon which the metric is based is thus a theoretical, rather than a statistical one.

Validity and Effects of Sampling

The main finding in Experiment 1 of this research is based upon differences between older adults, as compared to Alzheimer's patients. In the Alzheimer's patients group, and consequently in the older adults group, more male than female participants were recruited. Potential effects of this sampling outcome will be discussed.

In this study, more male than female participants suffering from Alzheimer's disease were willing to participate. This gender bias may hamper the generalizability of the results. In the literature, there is no clear indication of gender differences in working memory functions in old age (Doverspike, Cellar, Douglas, Barrett, & Alexander, 1985). While gender differences have been reported in visuospatial working memory, theses differences seem to affect processing speed rather than accuracy (Long-Meier & Halpern, 1999), which was measured in this study. With regards to balance performance, some studies have argued that women beyond age 80 show poorer balance performance than men

(Wolfson, 1992). However, none of these studies accounted for selectivity effects of gender. Thus, it could well be that selection effects, in the sense that men beyond age 80 are positively selected with regard to their physical functioning influence such findings. In this study, however, participants aged 60 to 80 were tested. Given the lack of theoretical and empirical foundations of gender effects in cognitive and balance performance in this age group, it seems defendable to generalize from a predominantly male sample.

Prioritization of Balance as a Function of Task Complexity or Cognitive Resources

The main finding of this study has some implications for general resource theories on aging and dual-task performance.

Research on dual-task in Alzheimer's disease and normal aging indicates that dual-task costs specific to Alzheimer's disease may emerge independent of cognitive speed alone (Baddeley et al., 2001). Baddeley and colleagues conducted a series of experiments using reaction time tasks, visual letter search, and combinations of memory span and box crossing, as well as visual search and auditory detection in a dual-task paradigm. The results showed age effects in simple reaction time tasks and an interaction of age and dementia status in the dual-task experiments. Baddeley concluded that general slowing did not affect Alzheimer's patients disproportionally, while dual-task did, thus suggesting a specific deficit in dual-task performance in Alzheimer's patients (Baddeley et al., 2001).

Likewise, an interaction between age and dementia status was found in Experiment 1, indicating that there are specific effects of dual-task in Alzheimer's disease. However, older adults (matched to Alzheimer's patients with respect to gender, age, and education) had a quite high level of education. Thus, it could well be that this additional qualification of dual-task performance in a cognitive and a sensorimotor task is dependent upon task the amount of cognitive resources available to an individual. In fact, a prior study by Li and colleagues (Li et al., 2001) showed prioritization of a walking task over a cognitive in healthy older adults at the limits of performance (i.e., after 23 sessions of adaptive single-task training). In this study, older adults were not tested at their limits of resources. Thus, it could well be that a prioritization pattern could be found as a function of the amount of resources available.[12]

Summary

The internal and external validity of the main findings in Experiment 1 was discussed with regards to the validity of measurement, the representation of dual-task performance in proportional dual-task costs, and sampling effects. It seems difficult to interpret the results in terms of measurement errors. Although the sampling procedure proved difficult, overall, the results seem generalizable to patients in initial stages of Alzheimer's disease. With regards to the question whether the effects may be due to the level of cognitive resources, however, the answer remains inconclusive. On the one hand, it could be that the prioritization effect found in Experiment 1 is specific to Alzheimer's disease. However, it could well be that the effect is a function of cognitive resources, rather than dementia status, given that the cognitive resources in Alzheimer's patients were significantly lower as compared to the healthy older adults. The effect of cognitive resources versus dementia status on dual-task performance in a cognitive and a sensorimotor task will be the focus of Experiment 2.

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[12] In an ongoing study, using a complexity manipulation (N-Back 3), older adults from Experiment 1 of this study are adaptively tested at the performance level of Alzheimer's patients, in order to disentangle effects of task complexity and pathological cognitive aging. This study is conducted in the context of the Project SOC Sensorimotor Performance at the Max Planck Institute for Human Development, Berlin.