EXPERIMENT 2

Overview

In Experiment 1, a specific pattern of prioritization in dual-task performance was found in patients with Alzheimer's disease, as compared to healthy older adults. Patients with Alzheimer's disease showed overproportional dual-task performance decrements in cognition when the balance task was made more difficult. In the balance task, however, performance decrements decreased from stable to moving platform conditions, indicating an effect of adaptive processes on dual-task performance in Alzheimer's diseases.

However, the fact that older adults tested in experiment 1 had a high level of education points at the potential influence of cognitive resources on the results. Following the notion of a continuum in the pathological changes from aging to Alzheimer's disease (MRC CFAS, 2001), and behavioral concepts of Alzheimer's disease as accelerated aging (Horan & Pendleton, 1995), the question remains whether the effect found in Experiment 1 is indeed specific to Alzheimer's disease, or rather reflects a function of the amount of cognitive resources available. Following general resource models of dual-task performance (Craik & Salthouse, 2000), one could argue that the effects found in Experiment 1 reflect low cognitive resources in patients with Alzheimer's disease, rather than a specific pattern of resource allocation.

In order to differentiate between dementia status and the amount of cognitive resources, the aim of the second experiment was to compare older adults, older adults low on cognitive performance, and patients suffering from Alzheimer's disease. A highly sensitive marker of general intelligence is the Digit Symbol Substitution task (Wechsler, 1955), The task was designed as a measure of perceptual and cognitive speed. Numerous studies have shown an age-related increase in this task (e.g., Salthouse, 1978; Salthouse 1985). Within the two-component model of intelligence, the Digit Symbol Substitution task is considered a test of fluid intelligence, or the cognitive mechanics component, reflecting biological changes across the life-span (compare *Ability Structures in Normal Aging and Alzheimer's Disease*, this study; Lindenberger et al., 1993). This task was employed to define participants low on cognitive resources.

Participants low on cognitive resources were selected from a larger screening sample. The exact same procedure as in Experiment 1 was applied in order to enable a comparison to the older adults and Alzheimer's patients tested in Experiment 1. Two main questions emerged. First, whether the pattern of dual-task costs differs between older adults low on cognitive resources and Alzheimer's patients. Second, whether the amount of dual-task performance decrements is related to cognitive status alone, or whether dementia status alone adds to explain the amount of dual-task costs found in this study. As stated in the predictions section (*Predictions 4*), the first question referred to the comparative analysis of dual-task performance in cognition and balance, now in older adults, older adults low on cognitive resources, and patients with Alzheimer's disease. Specifically, it was investigated whether the prioritization of balance shown by patients suffering from Alzheimer's disease is specific, or a function of cognitive resources. Arguing for a specific effect in Alzheimer's disease patients, it was expected that older adults low on cognitive performance differ from Alzheimer's patients with respect to the prioritization of balance. A main effect of dementia status, a main effect of platform condition, and an interaction thereof was expected. The fifth set of predictions referred to the correlational analysis of dual-task performance as a function of cognitive status and dementia status. On a correlational level, dual-task performance was predicted to be dependent upon single-task performance in both normal and pathological cognitive aging. Additional variance was predicted to be explained by the presence or absence of dementia beyond the level of cognitive performance.

Method

Participants

Recruitment

In Experiment 2, the primary goal was to select a group of older adults low on cognitive resources that matches Alzheimer's patients' cognitive status as closely as possible. Participants were recruited via advertisements in three local newspapers assumed to address readerships from different educational backgrounds ("Tagesspiegel" (high educational background): N = 38; "Berliner Morgenpost" (medium educational background): N = 36; "BZ" (low educational background): N = 35). 99 older adults (65 women and 34 men aged 60 to 89 years, mean age = 70.03 years) from different educational backgrounds (Volksschule: N = 17; Mittlere Reife: N = 29; Abitur: N = 35; University degree: N = 18) were tested with a paper and pencil version of the cognitive battery used in the Berlin Aging Study (compare Lindenberger et al., 1993).

In order to match healthy older adults to Alzheimer's patients, the following rationale was applied: The distinction between fluid (cognitive mechanics) and crystallized (cognitive pragmatics) intelligence implies a distinction between biological and cultural effects on intelligence (compare Horn, 1989; P. Baltes et al., 1999). Since Alzheimer's disease is a pathological, biological process, tasks from the cognitive mechanics domain should provide reasonable indicators of differential brain aging. The Digit Symbol Substitution task is a classical example of an indicator of the cognitive mechanics (compare Lindenberger et al., 1993). It was employed in this study for three reasons. First, because it is widely used in the literature (e.g., Salthouse, 1978; Salthouse 1985), second, because it permits reference to the representative sample from the Berlin Aging Study (BASE, P. Baltes & Mayer, 1999), and third, it optimally discriminates between healthy older adults and Alzheimer's patients already tested in Experiment 1 (see Figure 16).[13]

Figure 16

Performance on the Digit-Symbol-Substitution Task in Young and Older Adults, Older Adults Low on Cognitive Resources and Alzheimer's Patients

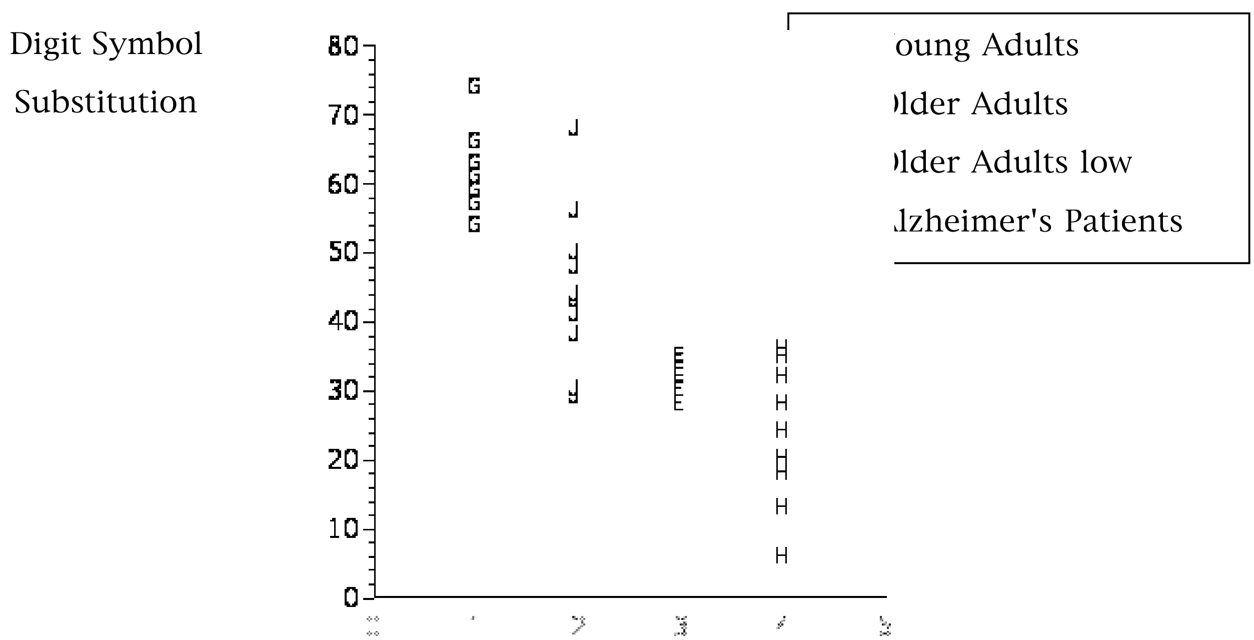

Figure 16. Performance on the Digit Symbol Substitution task in young adults (open squares), healthy older adults (solid circles), older adults low on cognitive resources (open circles), and patients with Alzheimer's disease (solid triangles).

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[13] In line with this rationale, Alzheimer's patients (N = 9) and healthy older adults (N = 10) already tested in Experiment 1 do not differ in performance on the spot-a-word task from the pragmatic domain ($t(18) = 1.66$, $p = .11$). However, performance on the Digit Symbol Substitution task was significantly different between Alzheimer's patients and healthy older adults ($t(18) = 4.03$, $p = .001$).

The screening sample of 99 participants contained a sufficient number of individuals matching the Alzheimer's group in age. Applying the Alzheimer's patients' maximum Digit Symbol Substitution task score of 35 as a cut-off value, 13 individuals who were within the same age range (60 to 79 years) as the Alzheimer's patients were identified. Performance on the Digit Symbol Substitution task (M = 31.39, SD = 4.09) did not differ from Alzheimer's patients' performance (t(20) = 1.68, p = .15). Scatterplots of Digit Symbol Substitution task performances for the tested groups and the group of older adults low on cognitive resources are shown in Figure 16. In BASE, the mean performance on the Digit Symbol Substitution task for older adults aged 70 to 80 was 32.06 (SD = 9.00). The Alzheimer's patients tested in Experiment 1 were, on average (M = 24.40, SD = 10.02), located around the 25th percentile in BASE. The healthy older adults tested in Experiment 1 were, on average (M = 43.63, SD = 11.65), located around the 80th percentile in BASE. The group of older adults low on cognitive resources was, on average (M = 31.39, SD = 4.09), located around the 45th percentile in BASE. It has to be noted that the Alzheimer's patients and healthy older adults tested in Experiment 1 were, on average, younger than the youngest BASE participant was. In reference tables for the HAWIE, the normative Digit Symbol Substitution task score is 42 for persons aged 55-64 and 36 for persons aged 65-69 (Sattler, 1982). This suggests that the groups already tested were above average. Together with the group of older adults low on cognitive resources, however, there was one group above and one group below average performance in Digit Symbol Substitution task in a representative sample.[14]

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[14] In the BASE sample, test-retest reliability over three months for the Digit Symbol Substitution task was .92. In addition, this test showed considerable directional stability in extreme groups. When assessing change over three months in the group below the 20th and above the 80th percentile in BASE, both groups showed slight improvement in the task, which however, was not different in the low versus the high

In order to account for regression to the mean effects, we used Bayesian estimators (Efron & Morris, 1977) to correct for sampling bias. The Bayesian estimator calibrates each individual performance dependent upon the mean of the sample (For the Digit Symbol Substitution Task, in our sample, $M = 42.8$) and the test-retest reliability (in BASE, $r = .92$) following equation (1):

$$E = □ + □ * (DSS_i - □) \quad (1),$$

where E is the Bayesian estimator, □ is the sample mean, □ is the test-retest reliability, and DSS_i reflects an individual score on the Digit Symbol Substitution Task.

In order to exclude patients with dementia from the group of older adults low on cognitive resources, a rather strict inclusion criterion of an MMSE of above 25 points was applied in this experiment (compare Folstein et al., 1975). 1 participant was excluded due to this criterion and referred to a cognitive clinic for further management.

Description of Older Adults low on Cognitive Resources in Comparison to the Older Adults and Alzheimer's patients tested in Experiment 1

Of the 13 older adults low on cognitive resources recruited, 2 had to be excluded due to exclusion criteria applied in Experiment 1[15]. Thus, the final sample consisted of 11 participants (6 female, 5 male; aged 60-78, mean age 66.63 years, $SD = 5.22$ years). The educational status was lower in the older adults low on cognitive resources as compared to older adults and Alzheimer's patients

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performers (for the retest effect: $F(1,205) = 303.79$, $MSe = 536.18$, $p < .001$, $□^2 = .60$; for the group by retest interaction: $F(2,205) = 2.01$, $MSe = 3.54$, $p = .14$).

15 1 participant suffered from severe depression as revealed by history taking. He was referred for continuing therapy to his primary care psychiatrist. 1 participant suffered from chronic alcohol addiction, currently in abstinence. He participated in a short protocol of the experiment. Data are not reported here.

tested in Experiment 1 ($F(2,28) = 6.01$, $MSe = 48.75$, $p < .01$). While the older adults had, on average, 14.0 years of education (*SD* = 3.39 years, *range* 9 to 17 years), the older adults low on cognitive resources had, on average, 9.8 years of education (*SD* = 1.25 years, *range* 8 to 13 years), and the Alzheimer's patients, on average, 12.8 years of education (*SD* = 3.52 years, *range* 8 to 17 years).

The same cognitive battery as in Experiment 1 was used to describe older adults low on cognitive resources. An overview is given in Table 5.

Significant differences between older adults and older adults low on cognitive resources were found for Forward Digit Span ($t(19) = 3.25$, $p < .01$), Digit Symbol Substitution ($t(19) = 3.38$, $p < .01$), Reitan Trailmaking A ($t(19) = 2.16$, $p < .05$), and Clock Drawing ($t(19) = 2.71$, $p < .05$).

Applying Bayesian estimators to older adults', older adults' low on cognitive resources, performance on the Digit Symbol Substitution Task, the difference between older adults and older adults low on cognitive resources remained statistically reliable ($t(17) = 3.86$, $p < .01$).

Due to exclusion of two participants who scored very low on the Digit Symbol Substitution task (see footnote 13), the difference between older adults low on cognitive resources and Alzheimer's patients increased to marginally significant ($t(18) = 2.11$, $p = .07$). For Forward Digit Span and the Spot-a-Word test, however, no significant difference was found (*ps* > .27). A significant difference was further found for Reitan Trailmaking ($t(18) = 2.54$, $p < .05$), Clock Drawing ($t(18) = 5.03$, $p < .001$), and the MMSE ($t(18) = 6.61$, $p < .001$). In all cases, the older adults low on cognitive resources scored better than the Alzheimer's patients.

On the sensorimotor variables, differences between older adults and older adults low on cognitive resources were not statistically reliable (all *ps* > .10) except for shoe size ($t(19) = 2.46$, $p < .05$), which was larger in older adults. Between older adults low on cognitive resources and Alzheimer's patients no statistically reliable difference was found (all *ps* > .13).

Table 5

Description of Older Adults, Older Adults low on Cognitive Resources, and Alzheimer's Patients

Variable	Older (*N*=10)	Older Low (*N*=11)	Alzheimer (*N*=9)
Age (years)	69.40 ± 5.56	66.63 ± 5.22	70.22 ± 6.09
Education (years)	14.00 ± 3.39	09.81 ± 1.25	12.78 ± 3.52
MMSE	29.44 ± 0.73	29.00 ± 0.89	21.11 ± 3.85
Digit Span	06.70 ± 0.67	05.63 ± 0.81	05.44 ± 1.13
Digit Symbol	44.70 ±11.71	32.45 ± 2.65	24.66 ± 10.82
Clock-Drawing	06.25 ± 0.88	05.09 ± 0.94	03.50 ± 1.43
Reitan Trail A (s)	19.57 ± 4.86	24.09 ± 4.72	39.50 ± 17.69
Spot-a-Word	28.50 ± 1.94	27.63 ± 2.33	26.80 ± 1.87
Tinetti (s)	07.63 ± 1.18	07.18 ± 1.17	08.20 ± 2.15
Grip Strength (kp)	10.93 ± 3.77	13.49 ± 3.75	10.23 ± 1.53
Leg Strength (kp)	20.03 ± 5.85	16.51 ± 7.06	16.30 ± 7.49
Hearing Threshold (dB)	34.20 ± 7.53	30.37 ± 5.61	33.98 ± 8.21
Visual Acuity	00.97 ± 0.05	00.98 ± 0.06	00.94 ± 0.08

Table 5. 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%).

Apparatus, Tasks and Stimuli, Procedure

The exact same apparatus, task, stimuli and procedure were used as in Experiment 1.

During training in the N-Back task, all older adults low on cognitive resources reached perfection in 0-Back after 2 blocks of training. In 1-Back, older adults low on cognitive resources needed, on average, 3.27 training blocks (*SD* = 1.56), and in 2-Back, 5.63 (*SD* = 0.81), respectively. While 9 out of 11 participants reached perfection in 1-Back, only 6 older adults low on cognitive resources reached perfection in 2-Back. The amount of training needed to reach perfection and the ability to reach perfection differed compared to the older adults and the Alzheimer's patients. The number of training blocks in 1-Back differed between older adults and older adults low on cognitive resources (those low on cognitive resources needed more training; ($t(19) = 2.34$, $p < .05$), and between older adults low on cognitive resources and Alzheimer's patients ($t(18) = 2.71$, $p < .05$). For the 2-Back task, however, no significant differences emerged (all *ps* > .19).

Data Analysis

Data were analyzed in analogy to experiment 1. The predictions regarding the pattern of dual-task cost (*Predictions 4*) were analyzed using dual-task costs in balance and in working memory. A group (older versus older adults low on cognitive resources 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 MANOVA was computed.

In addition, correlational analyses were used to determine associations between cognitive status variables and dual-task performance. In order to test the influence of the amount of cognitive resources, as operationalized with the Digit Symbol Substitution Task, a regression analytic approach was chosen to test the prediction that the amount and pattern of dual-task costs is dependent upon cognitive resources and the presence or absence of pathological aging, in this case Alzheimer's disease (*Predictions 5*). Reliabilities and stabilities, as well as mean performance levels are given in Appendix B.

Results

Outline

The results section mainly follows the structure of the prediction section. First, however, single-task performance and training effects will be described for the N-Back and balance tasks under different conditions (*Single-Task Performance and Training Effects*). Second, the differences in dual-task costs between domains (balance versus cognition) will be analyzed (*Predictions 4; Comparison of Dual-Task Costs*). Third, the correlational analyses will be presented (*Predictions 5; Dual-Task Performance as a Function of Cognitive Resources and Dementia Status*)

Single-Task Performance and Training Effects in Older Adults low on Cognitive Resources

N-Back

It was shown in the method section that all older adults low on cognitive resources reached perfection in the 0-Back task. In both the first and the last training block, there were significant effects that showed that older adults scored better than older adults low on cognitive resources and that older adults low on cognitive resources scored better than Alzheimer's patients. In the first and the last training block, older adults did not differ from older adults low on cognitive resources in 1-Back (all ps > .10). In 2-Back, however, a marginally significant difference remained with older adults low on cognitive resources scoring lower ($F(1,20) = 3.59$, $MSe = 4.83$, $p = .07$). Older adults low on cognitive resources differed from Alzheimer's patients in 1-Back ($F(1,19) = 7.54$, $MSe = 39.09$, $p < .05$) and 2-Back ($F(1,19) = 5.83$, $MSe = 34.69$, $p < .05$) in the first training block, but not in the last block (all ps > .13).

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

Older adults versus older adults low on cognitive resources. The 2 (group) x 3 (training blocks: each the first block of sessions 1, 2, and 3) data pattern violated homogeneity assumptions (Box's $M = 32.87$, $p < .001$). The data were then analyzed after transforming individual scores into probit scores ([1/1-P]). The transformed data pattern was consistent with homogeneity assumptions (Box's $M = 9.11$, $p = .27$). Overall, both groups were comparable in performance ($F(1,19) = 0.11$, $MSe = 0.11$, $p = .75$). Both groups improved over training ($F(2,40) = 51.38$, $MSe = 15.41$, $p < .001$), while the training gains (see Figure 17) were larger in older adults than in older adults low on cognitive resources ($F(2,40) = 6.21$, $MSe = 1.86$, $p < .01$). A similar pattern emerged when the analysis was re-run using raw scores.

Older adults low on cognitive resources versus Alzheimer's patients. The 2 (group) x 3 (training blocks: each the first block of sessions 1, 2, and 3) ANOVA met homogeneity assumptions (Box's $M = 12.76$, $p = .11$). Older adults low on cognitive resources performed slightly better than Alzheimer's patients ($F(1,19) = 4.55$, $MSe = 14.70$, $p < .05$). Both groups improved over training ($F(2,38) = 40.00$, $MSe = 44.37$, $p < .001$), but this effect did not interact with group ($F(2,38) = 1.16$, $MSe = 1.29$, $p = .32$).

As can be seen in Figure 17, scores for 2-Back were higher for older adults low on cognitive resources than for Alzheimer's patients. However, the pattern of the training curve is strikingly similar, and different to the older adults tested in Experiment 1.

In order to account for 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:

$$\text{Gain} = M_{\text{Block 1}} - M_{\text{Block 6}}. \qquad (2)$$

Further analysis showed that the training gains were larger for older adults as compared to older adults low on cognitive resources ($t(20) = 3.23$, $p < .01$), but did not differ between older adults low on cognitive resources and Alzheimer's patients in 2-Back ($t(19) = 1.38$, $p = .18$).

Figure 17

Training Gains in 2-Back

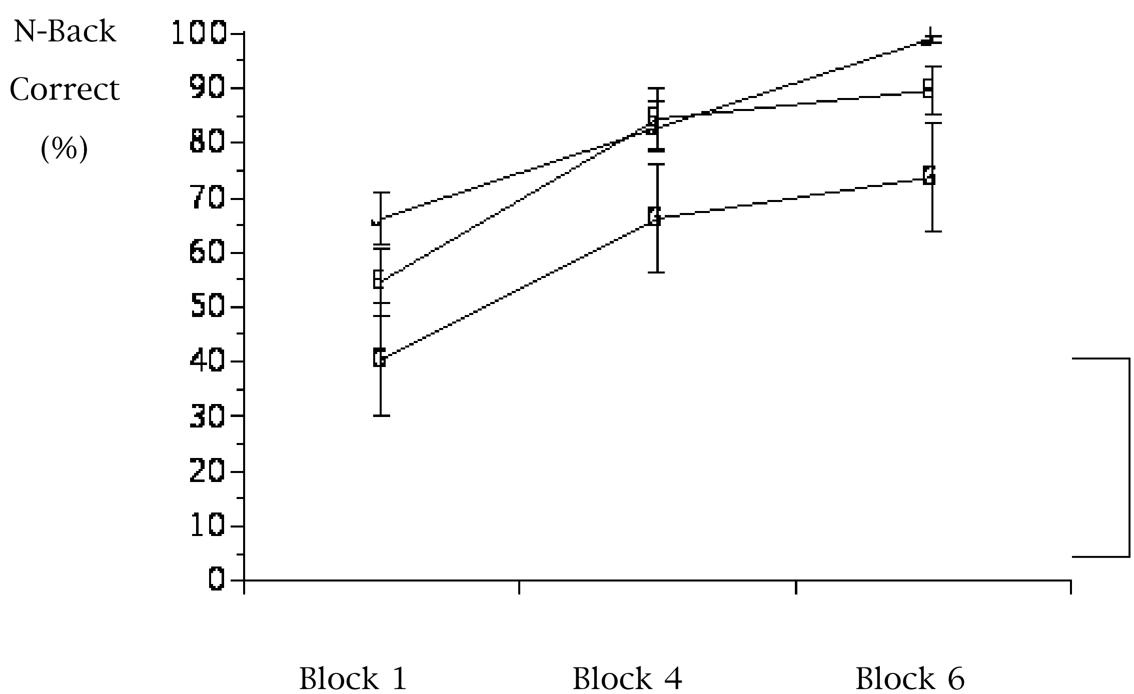

Figure 17. Training gains in 2-Back in adults (solid circles), older adults low on cognitive resources (open circles) and Alzheimer's patients (open squares). Error bars reflect standard error of the mean.

In summary, training gains were similar in older adults low on cognitive resources and Alzheimer's patients, but smaller than in older adults.

Differences in Single-Task Balance Performance

Older adults versus older adults low on cognitive resources. 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 $M = 8.73$, $p = .05$). Overall, older adults low on cognitive resources performed the balance task marginally better than the older adults did ($F(1,19) = 3.61$, $MSe = 74537.36$, $p = .07$). Balance performance decreased in both groups from stable to moving platform conditions ($F(1,19) = 284.29$, $MSe = 4291645.0$, $p < .001$). The two-way interaction was not statistically reliable ($p = .31$).

Older adults low on cognitive resources versus Alzheimer's patients. The 2 (group) x 2 (stable versus moving Platform) data pattern met homogeneity assumptions (Box's $M = 4.42$, $p = .27$). Overall, balance performance was better in older adults low on cognitive resources ($F(1,18) = 13.66$, $MSe = 503212.67$, $p < .01$). Balance performance decreased in both groups from stable to moving platform conditions ($F(1,18) = 241.11$, $MSe = 6114257.8$, $p < .001$). The two-way interaction was statistically reliable ($F(1,18) = 13.57$, $MSe = 344085.68$, $p < .01$). Post hoc tests revealed that balance performance on the stable platform differed only marginally between older adults low on cognitive resources and Alzheimer's patients ($t(18) = 1.93$, $p = .08$), while performance on the moving platform ($t(18) = 3.73$, $p < .01$) was better in older adults low on cognitive resources, as compared to Alzheimer's patients. The mean balance performance in each group on a stable and a moving platform is plotted in Figure 18.

In summary, on the stable platform, balance performance did not differ in the three groups. However, on the moving platform, older adults low on cognitive resources showed less sway than older adults and Alzheimer's patients.

Figure 18

Sway on a Stable and a Moving Platform in Older Adults low on Cognitive Resources compared to Older Adults and Alzheimer's Patients

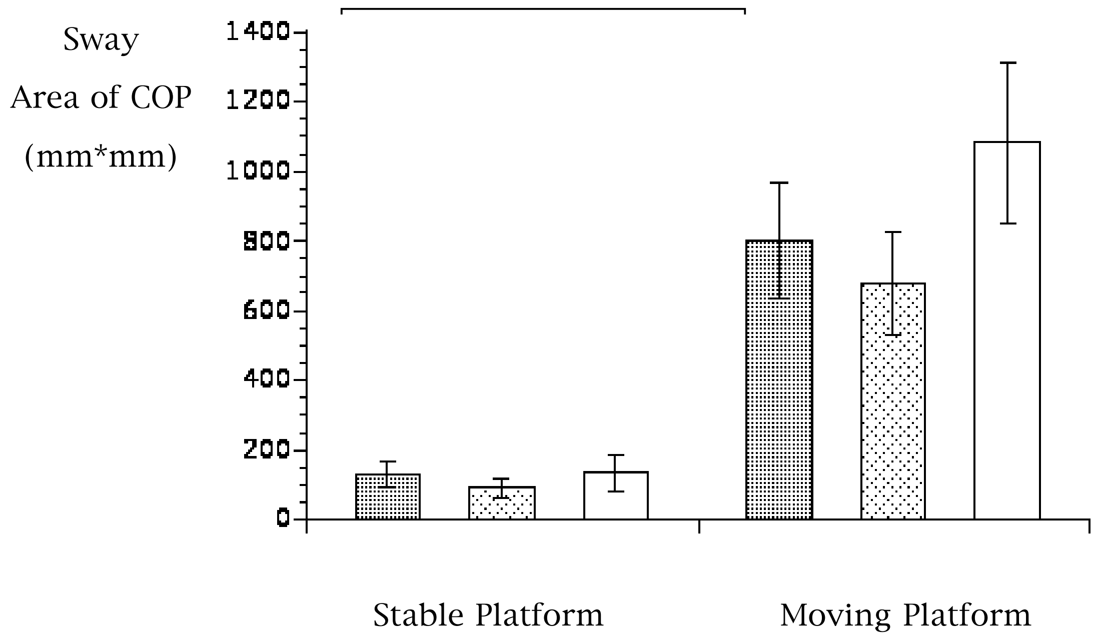

Figure 18. Area of COP movement on a stable (left) and a moving platform (right). Older adults are depicted in black, older adults low on cognitive resources in gray, and Alzheimer's patients in white bars. Error bars reflect one standard deviation.

Training Effects through Dual-Task Assessment

Older adults versus older adults low on cognitive resources. 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 $M = 83.21$, $p < .001$). 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* = 32.48, $p < .05$). Performance in 1-Back was better than performance in 2-Back ($F(1,20) = 29.17$, $MSe = 0.87$, $p < .001$). 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* = 21.73, $p = .08$). Older adults' sway was comparable to sway in older adults low on cognitive resources ($p = .12$). Overall, performance on the stable platform was better than performance on the moving platform ($F(1,20) = 321.37$, $MSe = 7259361.7$, $p < .001$). In addition, a significant training effect emerged ($F(1,20) = 19.92$, $MSe = 78224.16$, $p < .001$), which interacted with platform condition ($F(1,20) = 11.14$, $MSe = 55415.50$, $p < .01$), indicating that training effects were larger on the moving platform as compared to the stable platform. This training effect, however, did not interact with group ($p > .18$).

Older adults low on cognitive resources 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* = 65.41, $p < .001$). 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* = 38.78, $p < .05$). Older adults low on cognitive resources outperformed Alzheimer's patients ($F(1,18) = 5.74$, $MSe = 0.97$, $p < .05$), and overall, performance was better in 1-Back as compared with 2-Back ($F(1,18) = 17.26$, $MSe = 1.13$, $p < .01$). None of the interactions with training was statistically reliable (all ps > .43).

Table 6

Mean Performance before and after Dual-Task Assessment in Single-Task Balance and the N-Back Tasks

	Single-Task Balance	
	Pretest 2	Posttest
Older Adults (N = 10)		
Stable Platform	132.86 (38.35)	122.22 (41.66)
Moving Platform***	799.19 (168.03)	652.76(165.44)
Older Adults low (N = 11)		
Stable Platform	89.31 (28.22)	80.99 (48.04)
Moving Platform***	677.41 (149.62)	603.29(134.07)
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
Older Adults (N = 10)		
1-Back	100.00 (0.00)	100.00 (0.00)
2-Back	98.89 (16.13)	91.67 (14.24)
Older Adults low (N = 11)		
1-Back	100.00 (0.00)	100.00 (0.00)
2-Back	89.58 (14.49)	88.43 (13.68)
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 6. Significant differences between Pretest2 (before) and Posttest (after dual-task assessment): *$p < .05$; ** $p < .01$; *** $p < .001$. Values in parentheses represent standard deviations.

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 $M = 19.49$, $p = .14$). Alzheimer's patients' sway was larger than older adults' ($F(1,18) = 17.87$, $MSe = 1123108.1$, $p < .001$), and performance was better on the stable as compared to the moving platform ($F(1,18) = 286.00$, $MSe = 11767036$, $p < .001$). This effect was larger in the Alzheimer's patients $(1,18) = 20.22$, $MSe = 832032.09$, $p < .001$). In addition, a marginally significant training effect emerged ($F(1,18) = 3.51$, $MSe = 3199.08$, $p = .08$). This training effect, however, did not interact with group ($p > .43$).

Summary

Single-Task performance in N-Back differed between older adults, older adults low on cognitive resources and Alzheimer's patients. Specifically, in 1-Back and 2-Back, older adults outperformed older adults low on cognitive resources 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, older adults low on cognitive resources performed better than Alzheimer's patients.

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 low on cognitive resources as compared to Alzheimer's patients.

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 group membership, 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 6.

Comparison of Dual-task Costs[16]

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 there were 13 trials (5.41%) in older adults, there were 17 trials (7.12%) in older adults low on cognitive resources, and 30 trials (13.88%) in Alzheimer's patients. Only data in 2-Back were analyzed. To test the prediction that the pattern of dual-task costs is dependent upon cognitive resources and disease status, dual-task costs for both domains in 2-Back were compared in analogy to Experiment 1 (*Predictions 4*).

Older adults versus older adults low on cognitive resources versus Alzheimer's patients. The 3 (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 $M = 33.92$, $p = .15$). There was a main effect for group ($F(2,27) = 3.51$, $MSe = 5091.90$, $p < .05$, $\eta^2 = .21$). Overall, dual-task costs in balance were larger than dual-task costs in cognition ($F(1,27) = 6.09$, $MSe = 7031.85$, $p < .05$, $\eta^2 = .19$). There was a main effect of platform condition ($F(1,27) = 6.14$, $MSe = 4971.90$, $p < .05$, $\eta^2 = .19$), which was found to interact with domain (balance versus cognition) ($F(1,27) = 15.47$, $MSe = 15859.59$, $p < .001$, $\eta^2 = .36$). The three way interaction between group, platform condition, and domain (balance versus cognition) was also significant ($F(2,27) = 3.53$, $MSe = 3444.97$, $p < .05$, $\eta^2 = .20$).

Post hoc tests showed that the average dual-task costs were comparable between older adults and older adults low on cognitive resources ($p < .67$), but larger in Alzheimer's patients ($F(1,27) = 5.49$, $MSe = 9211.53$, $p < .05$, $\eta^2 = .23$).

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

Figure 19

Dual-Task Costs in Balance and Cognition in Older Adults,

Older Adults low on Cognitive Resources, and Alzheimer's Patients

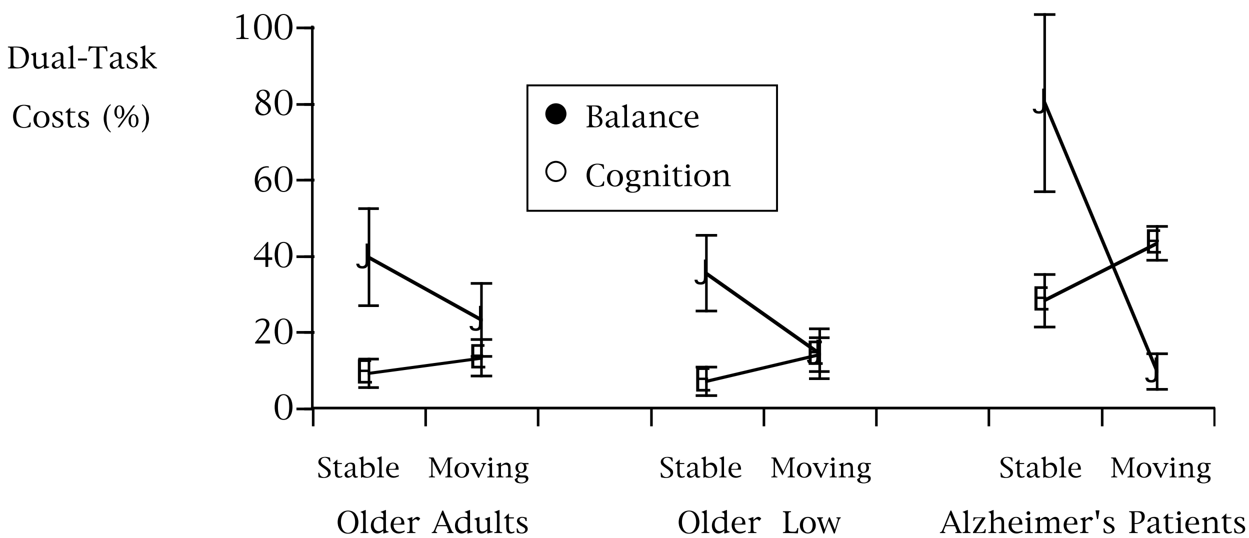

Figure 19. Relative dual-task costs (%) in 2-Back (left) and Balance (right) under stable and moving platform conditions in older adults (dark gray bars), older adults low on cognitive resources (light gray bars), and Alzheimer's patients (white bars). Error bars reflect one standard error of the mean.

In older adults ($t(9) = 1.86$, $p = .10$) dual-task costs for cognition were of equal amount on the moving as compared to the stable platform. In older adults low on cognitive resources, the cognitive dual-task costs were marginally larger on the on the moving as compared to the stable platform ($t(10) = 1.99$, $p = .07$). In Alzheimer's patients, however, dual-task costs for cognition were larger on the moving as compared to the stable platform ($t(8) = 3.06$, $p < .05$).

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 ($t(9) = 1.07$, $p = .31$), and older adults low on cognitive resources ($t(9) = 1.18$, $p = .26$), in Alzheimer's patients, dual-task costs were larger on the stable as compared to the moving platform ($t(9) = 3.00$, $p < .05$). The dual-task costs for both domains on a stable and a moving platform are depicted in Figure 19.

In summary, the pattern of dual-task cost found in Alzheimer's patients was different from the pattern in older adults low on cognitive resources. Specifically, while dual-task costs for cognition increased and dual-task costs for balance decreased from stable to moving platform conditions in Alzheimer's patients, dual-task costs remained comparable in older adults low on cognitive resources when the balance task was made more difficult.

Correlates of Dual-Task Performance

In *Predictions 5*, it was hypothesized that the amount of dual-task cost is independent from sensorimotor and cognitive resources, but dependent upon the presence and severity of dementia. In order to test this prediction, two types of analyses were performed. First, dual-task performance in cognition and balance and their associations to cognitive and sensorimotor variables, respectively, were assessed.[17] The nature of these associations was then further explored with regression analyses. All older participants of Experiment 1 and 2 were included in the analyses (10 older adults, 11 older adults low on cognitive resources, and 9 Alzheimer's patients).

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[17] As cognitive predictor variable, the Digit Symbol Substitution task was used. As sensorimotor variable, a composite of grip and leg strength (□ = .66), was used. For the presence or absence and disease severity of dementia, a dichotomous variable (0 = absence, 1 = presence of dementia) was used.

Table 7

Correlates of Dual-Task Performance in Cognition

	Dual-Task Performance	
	Stable Platform	Moving Platform
Older Adults		
Single-Task Performance	.81**	.70*
Muscular Strength	.06	.25
DSS	.00	.23
MMSE	.08	.33
Age	.56	.37
Older Adults Low		
Single-Task Performance	.79**	.83**
Muscular Strength	.10	.01
DSS	.31	.65*
MMSE	.29	.41
Age	.30	.18
Alzheimer's Patients		
Single-Task Performance	.84**	.83**
Muscular Strength	.06	-.01
DSS	.98**	.86**
MMSE	.79*	.78*
Age	.35	.37

Table 7. *$p < .05$; ** $p < .01$. Correlations were computed within groups (in older adults, $N = 10$, in older adults low, $N = 11$, in Alzheimer's patients, $N = 9$). MMSE = Mini-Mental Status Examination. DSS = Digit Symbol Substitution task.

Dual-Task Performance in Cognition

We applied a model of dual-task performance as a function of single-task performance, age, performance on the Digit Symbol Substitution task, dementia, and interactions thereof in a regression analytic approach. The model was specified as follows:

$$\text{DTP}_{COG} = \beta_0 + \beta_1 \text{STP} + \beta_2 \text{age} + \beta_3 \text{muscle strength} + \beta_4 \text{DSS} + \beta_5 \text{dementia status} + \beta_6 (\text{dementia status} * \text{STP}) \quad (3)$$

where DTP reflects dual-task performance, STP reflects single-task performance, and DSS reflects performance on the Digit Symbol Substitution task.

As can be seen in Table 7, dual-task performance in cognition was associated with cognitive performance in single-task in all groups. The correlation between the Digit Symbol Substitution Task and dual-task performance increased numerically from older adults to older adults low on cognitive resources to Alzheimer's patients. In Alzheimer's patients, dementia status as assessed with the MMSE was strongly associated to dual-task performance. In addition, there were moderate, but nonsignificant correlations with age in all groups.

Stable platform. A single regression line, predicting dual-task performance from single-task performance, fitted the data well (R^2 = .70). Entering terms for chronological age (p = .84), muscular strength (p = .92), and the Digit Symbol Substitution Task (p = .42), and dementia status (p = .38), did not significantly improve fit. However, the interaction between single-task performance and dementia status led to a marginally significant improvement in fit and explained an additional 4% of the variance over and above single-task performance (R^2 = .74; ΔR^2 = .04; F change (1, 23) = 3.60, p = .07). The dual-task performance in cognition on the stable platform as a function of cognitive resources is shown in Figure 20.

Figure 20

Dual-Task Performance in 2-Back on the Stable Platform

as a Function of Cognition

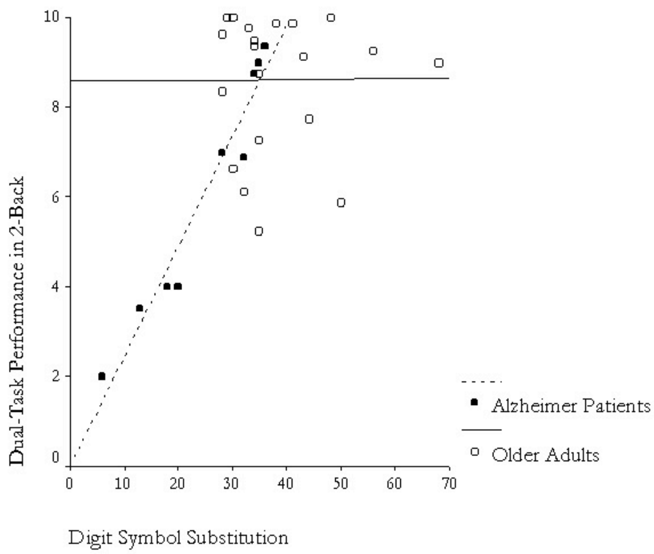

Figure 20. Scatterplot of Dual-Task Performance in 2-Back (number of correct items) on a Stable Platform as a function of Digit Symbol Substitution Scores.

Moving platform. A single regression line, predicting dual-task performance from single-task performance, fitted the data moderately ($\underline{R}^2$ = .59). Entering terms for chronological age (p = .50), muscular strength (p = .94), and the Digit Symbol Substitution Task (p = .39), did not significantly improve fit. However, dementia status ($\underline{R}^2$ = .69; □$\underline{R}^2$ = .10; $\underline{F}$ change (1, 24) = 8.11, p < .01), as well as the interaction between single-task performance and dementia status ($\underline{R}^2$ = .78; □$\underline{R}^2$ = .09; $\underline{F}$ change (1, 23) = 10.70, p < .01) led to a significant improvement in fit and explained each about an additional 10% of the variance over and above single-task performance. The dual-task performance in cognition on the moving platform as a function of cognitive resources is shown in Figure 21.

Figure 21

Dual-Task Performance in 2-Back on the Moving Platform

as a Function of Cognition

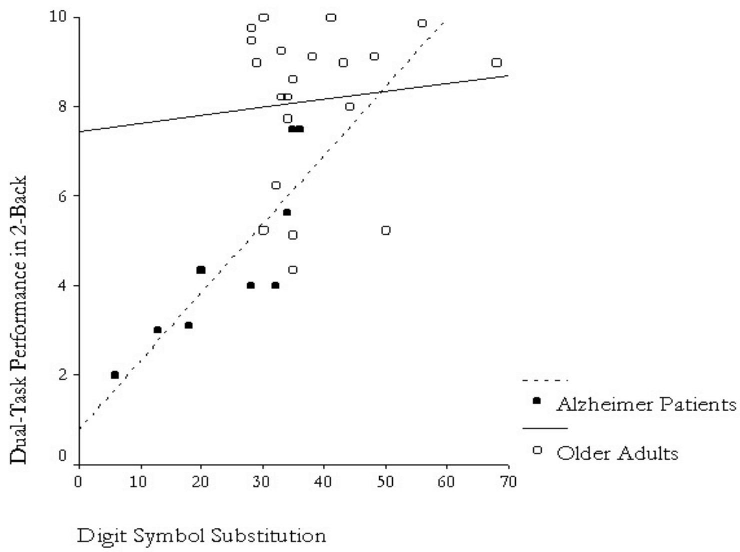

Figure 21. Scatterplot of Dual-Task Performance in Cognition (number of correct items) on a Moving Platform as a function of Digit Symbol Substitution Scores.

Dual-Task Performance in Balance

An analogous model was applied to dual-task performance in balance:

$$\underline{DTC_{BAL}} = \beta_0 + \beta_1 \underline{STP} + \beta_2 \text{age} + \beta_3 \text{muscle strength} + \beta_4 \text{DSS} + \beta_5 \text{dementia status} + \beta_6 (\text{dementia status} * \underline{STP}) \quad (4),$$

where DTP reflects dual-task performance, STP reflects single-task performance, and DSS reflects performance on the Digit Symbol Substitution task.

Table 8

Correlates of Dual-Task Performance in Balance

	Dual-Task Performance	
	Stable Platform	Moving Platform
Older Adults		
Single-Task Performance	-.83**	-.77**
Muscular Strength	-.48	-.74*
DSS	-.27	-.71*
MMSE	-.21	-.15
Age	-.04	-.17
Older Adults Low		
Single-Task Performance	-.59	-.74**
Muscular Strength	-.17	-.47
DSS	-.04	-.48
MMSE	-.39	-.36
Age	-.12	-.36
Alzheimer's Patients		
Single-Task Performance	-.65	-.77**
Muscular Strength	-.38	-.28
DSS	-.76**	-.73**
MMSE	-.38	-.51
Age	-.48	-.17

Table 8. **p* < .05; ** *p* < .01. Correlations were computed within groups (in older adults, *N* = 10, in older adults low, *N* = 11, in Alzheimer's patients, *N* = 9). Correlations are negative since the amount of sway was used as an indicator for balance performance. MMSE = Mini-Mental Status Examination. DSS = Digit Symbol Substitution task.

Stable platform. A single regression line, predicting dual-task performance from single-task performance, fitted the data well (R^2 = .78). Entering terms for chronological age (*p* = .73), muscular strength (*p* = .52), and dementia status (*p* = .52), did not significantly improve fit. The Digit Symbol Substitution Task, however, led to a significant improvement in fit and explained an additional 7% of the variance over and above single-task performance (R^2 =

.85; □R^2 = .07; F change (1, 25) = 5.42, $p < .05$). The dual-task performance in balance on the stable platform as a function of cognitive resources is shown in Figure 22.

Figure 22
Dual-Task Performance in Balance on the Stable Platform
as a Function of Cognition

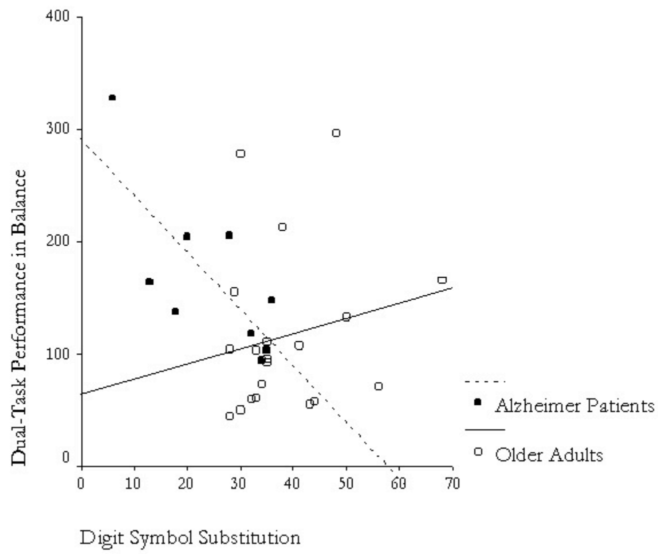

Figure 22. Scatterplot of Dual-Task Performance in Balance (Sway) on a Stable Platform as a function of Digit Symbol Substitution Scores. Correlations are negative since the amount of sway was used as an indicator for balance performance.

Moving platform. A single regression line, predicting dual-task performance from single-task performance, fitted the data well (R^2 = .75). Entering terms for chronological age (p = .46), muscular strength (p = .57), and Digit Symbol Substitution Task (p = .48), did not significantly improve fit. Dementia status, however, led to a significant improvement in fit and explained an additional 4% of the variance over and above single-task performance ($\underline{R}^2$ = .79; $\Delta\underline{R}^2$ = .04; $\underline{F}$ change (1, 24) = 4.39, $p < .05$). The dual-task performance in balance on the stable platform as a function of cognitive resources is shown in Figure 23.

Figure 23

Dual-Task Performance in Balance on the Moving Platform as a Function of Cognition

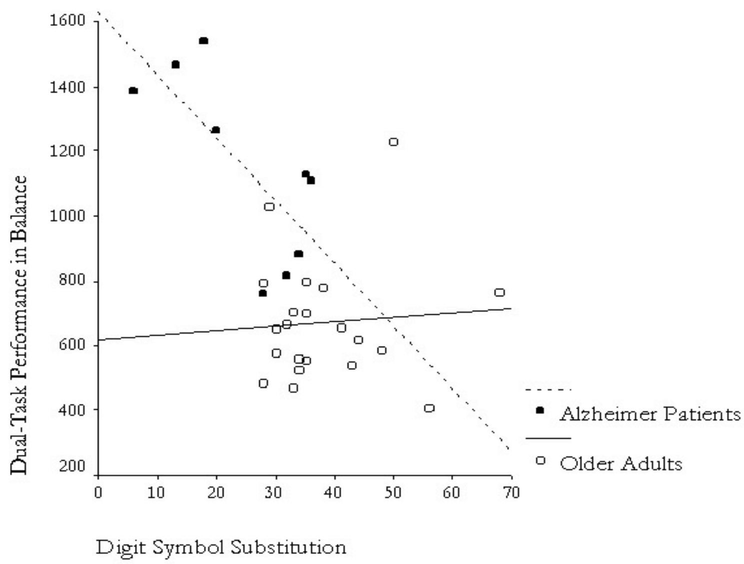

Figure 23. Scatterplot of Dual-Task Performance in Balance (Sway) on a Moving Platform as a function of Digit Symbol Substitution Scores. Correlations are negative since the amount of sway was used as an indicator for balance performance.

Summary of Regression Analyses

Throughout the regression analyses, the models specified could account for sizeable amounts of variance in dual-task performance. With respect to dual-task performance in both domains, both cognitive (as measured with the Digit

Symbol Substitution task) and dementia (i.e., the absence or presence of dementia) status explained a variance over and above single-task performance. However, while cognitive status only added variance to dual-task performance in balance on the stable platform, dementia status or interactions thereof explained additional variance in dual-task performance in cognition on both on the stable and the moving platform, and in dual-task performance in balance on the moving platform.

Discussion

Overview

The aim of the second experiment was to investigate the effect of cognitive resources, as operationalized with the Digit Symbol Substitution task, on resource allocation between balance and cognition in dual-task in aging and Alzheimer's disease. Two main questions guided this experiment. First, whether there is a difference between older adults low on cognitive resources and patients suffering from Alzheimer's disease in dual-task performance in a cognitive and a balance task. The critical question in the second experiment was whether the pattern of prioritization found in Alzheimer's disease also emerges in older adults low on cognitive resources. Second, it was investigated whether dual-task performance decrements are merely related to cognitive resources, or whether they are specific to Alzheimer's disease.

In Experiment 2, it was shown that both the amount and pattern of dual-task decrements did not differ between older adults high and older adults low in performance on a fluid intelligence task, but differed significantly in patients with Alzheimer's disease. The correlational analyses further showed an effect of dementia status on dual-task performance beyond the level of performance in the Digit Symbol Substitution task in both cognition and balance.

Thus, the results of the second experiment suggest a specific pattern of prioritization in Alzheimer's disease despite larger dual-task performance decrements, and independent of cognitive resources. The prioritization of balance over cognition proved to be specific to Alzheimer's disease, indicating an effect of adaptive processes in pathological aging independent of the level of cognitive performance. In the following, possible limitations and qualifications of the second experiment are discussed.

Qualifications and Alternative Interpretations

Validity and Effects of Sampling

The main finding in Experiment 2 of this research is based upon differences between older adults high and older adults low on cognitive resources, as compared to Alzheimer's patients. First, the validity of this sampling procedure needs to be taken into account. Second, 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.

Older adults low on cognitive performance were selected from a larger screening sample. It is a well-known phenomenon in psychometric research that extreme groups tend to show performance over time that approaches the overall group mean (regression to the mean; Galton, 1953). Using Bayesian estimators, which provide a predictor of future observations for which there is no regression to the mean (compare Efron & Morris, 1977), significant differences between the groups remained stable. In addition, in this research, the fluid intelligence test was used for screening purposes only, while performance in the cognitive task used in the dual-task assessment (N-Back) showed statistically reliable differences between older adults high and older adults low on cognitive resources after three sessions of training. In addition, regression to the mean may be a phenomenon that is confounded with retest effects. Several training studies in fluid intelligence tasks in old age have consistently shown retest effects of around 0.3 standard deviations (e.g., Willis, 1990). In a reanalysis of data from the Berlin Aging Study, we studied the retest effect in three groups (one group who scored above the 75th percentile on the first assessment, one group who scored below the 25th percentile, and a third group who scored between the 40th and 60th percentile) in order to disentangle retest effects from regression to the mean effects. A strong impact of regression to the mean would have been reflected in larger retest effects in the group who initially scored low, and smaller retest effects in the group who initially scored high on the fluid intelligence task, both as compared to the group scoring around the grand mean. Results showed that this was not the case. From a developmental perspective, this is consistent with the idea that older adults high on cognitive resources benefit more from training or retest than older adults low on cognitive resources (compare Willis, 1990). Thus, in old age, differential training effects and retest effects on the one hand, and statistical artifacts of regression to the mean on the other, may counteract one another.

A second concern regarding the validity of the sampling procedure stems from biomedical concepts of preclinical dementia. Older adults low on fluid intelligence could represent a group of participants in a preclinical stage towards dementia. In order to classify individuals at the transition to dementia, the concept of mild cognitive impairment (MCI) is widely used in neurology and psychiatry (Reisberg et al., 1982). Several theoretical concepts have been applied to the phenomenon of MCI. While some focus on subjective memory loss (Kral, 1962), others stress the notion of a preclinical state of dementia (Gurland & Cross, 1982; Reisberg et al., 1982), while a third group conceptualizes MCI as cognitive decline comparable to that seen in normal aging (Blackford & LaRue, 1989; Levy, 1994). MCI has been defined as objective loss of cognitive functions in two or more cognitive domains without significant decline in activities of daily living (Zaudig et al., 1991). Operational criteria include a score on the MMSE between 23 and 27 points (or comparable scores on other dementia rating scales) together with an exclusion of dementia and depression as causes of the cognitive impairment seen (Zaudig et al., 1991). Using these criteria, several studies have examined the incidence rate for dementia in persons with MCI. Incidence rates above 50% were found in two studies (Rubin & Kinscherf, 1989; O'Connor, 1991), while other authors reported incidence rates as low as 10% (Zaudig et al., 1991). It could be that the conceptual diversity and the diagnostic validity of the exclusion criteria, especially depression, might have had some impact on the study of MCI. In this study, using the operational criteria as defined by Zaudig (1991), only one of the older adults low on cognitive resources fell into the category of MCI.

Summary

The internal and external validity of the main findings in this study was discussed with regards to sampling effects. With regards to the question whether older adults low on cognitive resources represent a preclinical stage of dementia, follow-up research will be discussed in the following section. The implications for models of dual-task performance in normal and pathological aging will be discussed comparing the results of this study to other studies of dual-task in older adults and patients suffering from Alzheimer's disease.