

5. RESULTS

The presentation of results is divided into three major parts. The first part provides the information on the general statistical procedures used in the present study. The goal of the second part is to present findings with respect to the question ‘How do individuals allocate resources in the dual-task situation that involves simultaneous performance of the RT and the balance task?’ (Predictions 1a – 1b). The first section provides information on the single-task baseline performance. The next two sections deal with the issues of the domain-specific asymmetry and corresponding age-related differences. The goal of the third part of this chapter was to investigate whether the resource allocation in the dual-task situation is under individuals’ control (Predictions 2a – 2b). For this purpose, the dual-task performance under differential emphasis instructions was analyzed. Performance trade-offs in response to task-priority instructions were examined by plotting POCs (as a visual aid) and by quantitative analyses. The interactive effects of difficulty on the performance trade-offs were analyzed first. In the next step, I investigated whether the influence of the instruction and difficulty manipulations on the dual-task performance was larger in younger than in older adults.

5.1 General Statistical Procedures

The research hypotheses were tested using a repeated-measures analysis of variance (ANOVA)¹³. Prior to statistical analyses, I checked the distributions of all variables for the existence of univariate and multivariate outliers¹⁴ using SPSS EXPLORE and REGRESSION, because outliers lead to both Type I and Type II errors and to results that do not generalize. Although outliers influence error term for ANOVA, Stevens (2002) recommends against dropping outliers, rather he proposes to report two analyses (one including outliers and the other excluding them). I followed his recommendations. Presenting the results, I focused on the data of the whole sample. The analyses without outliers were presented only in case there were discrepancies in the results.

¹³ Statistical analyses were conducted using SPSS for Windows 10.0 (SPSS Inc., 1999).

¹⁴ Univariate outliers are those individuals who have z scores > 3 in absolute value if the variable is approximately normally distributed. This rule can be extended to $z > 4$ if the variable has any other type of distribution (Stevens, 2002). Multivariate outliers are cases that have an unusual pattern of scores and, thus, are discrepant from the rest in their combinations of scores (Tabachnick & Fidell, 1996). The criterion for multivariate outliers is Mahalanobis distance at $p < .001$.

In the next step, I checked all variables for possible violations of the basic repeated-measures analysis of variance assumptions because they could have effects on Type I error and power. The assumption of the independence of observation was not violated due to study design. The normality and sphericity assumptions were dealt with. As the sample size and especially the subsamples were small, the normality assumption could hardly be met in several cases. On the other hand, the analysis of variance is known to be fairly robust against violation of univariate and multivariate normality with respect to Type I error and especially if the groups are equal (see Bortz, 1999; Stevens, 2002 for reviews). Thus, no transformations to normalize the data distributions were used¹⁵. Nevertheless, I always provided descriptions of variables important for the normality assumption, that is, the combination of skewness and kurtosis coefficients and the Shapiro-Wilk test¹⁶ in the Appendices. The third assumption for a repeated-measures ANOVA is that of homogeneity of covariance matrices which can be tested using Box's (1950) M test. As this test is sensitive to nonnormality and it is difficult to satisfy the sphericity assumption when there are more than two levels of the within-subject (W-S) variable (see Weinfurt, 2000), the degree of sphericity ($\epsilon = 1/(k - 1)$), which indicates the worst possible violation, was assessed. In cases where data departed significantly from sphericity (e.g., $\epsilon = .50$ for three levels of the W-S variable), I applied the conservative Greenhouse-Geisser (1959) correction to the tests of significance and reported the corrected significance level. If the Greenhouse-Geisser correction did not alter the significance level, I referred to the conservative F-Test according to Wilks' Lambda as recommended by Bortz (1999).

Finally, in order to check whether the experimental tasks yielded reliable measures, the stability (i.e., test-retest) coefficients were computed for all variables. Appendix B provides the detailed information on stability coefficients for all variables that were used in the following analyses. In sum, the experimental tasks provided quite reliable measures of the single- and dual-task performances. The more difficult the task was (two-choice RT versus one-choice RT; difficult versus easy balance task; dual- versus single-task condition), the higher the observed reliability was.

Data analyses were carried out on two levels: (a) the level of raw scores and (b) the level of dual-task costs. On the level of raw scores, the dependent variables in the two-

¹⁵ I used the square-root transformation for the balance data (area of COP [sqr. mm]) because of the geometrical nature of the variable.

¹⁶ Based on the findings by Wilk, Shapiro, and Chen (1968) the combination of skewness and kurtosis coefficients and the Shapiro-Wilk test were the most powerful in detecting departures from normality.

component tasks were the reaction times for correct responses and the square-root transformed area of COP. Additional analyses were carried out on the accuracy data with the percentage of committed errors being the dependent variable. On the level of DTCs, the dependent variables were the proportional dual-task costs in each component task. I reported the results of the analyses as “significant” if the alpha error was ≤ 0.5 , and discussed the findings in terms of trends if tests were significant at the level from .06 to .07. For the reader to fully understand the importance of the findings, I routinely provided the numbers of the effect size estimate (η^2). In order to show whether the present study had sufficient power to detect predicted effects, I reported the power estimate ($1 - \beta$) for all effects that did not reach significance¹⁷.

5.2 How Do Individuals Allocate Resources in Dual-Task Situations?

In order to find out how individuals allocate resources in the dual-task situation, the single-task performance in each component task was examined first. These analyses should provide the first insights into the question of how demanding the RT and the balance task were for young and older adults depending on the difficulty level of the tasks. Moreover, the examination of the single-task performance is important because it enables: (a) to find out whether the task-difficulty manipulation worked in the single-task condition and (b) to check whether there are age-group differences in the single-task baseline performance. If the two age groups differ in the baseline performance, this finding must be taken into consideration while investigating the amount of dual-task interference, that is, while selecting a metric for dual-task costs.

5.2.1 Single-Task Baseline Performance

Table 7 presents the descriptive data on the single-task baseline performance: the mean RTs (in ms), errors (in %), and areas of COP (in mm) as well as standard deviations (SD) for the two age groups and the total sample in two difficulty conditions. It can be seen that young and older adults differed in their single-task baseline performance and that there was a decrease in performance under the difficult condition. These observations were confirmed by an Age Group (2) x Difficulty (2) repeated-measures ANOVA, which was

¹⁷ Conducting a study with small group sizes ($n \leq 20$), it is imperative to be very sensitive to the possibility of poor power (Salthouse, 2000; Stevens, 2002).

carried out within each modality. The dependent variables are described in Appendix C (see Table C1). For the reaction times¹⁸, both main effects and the interaction were significant: the effect of difficulty, $F(1, 34) = 491.65$, $MSE = 667.11$, $p < .001$, $\eta^2 = .94$; the effect of age group, $F(1, 34) = 49.81$, $MSE = 1813.82$, $p < .001$, $\eta^2 = .59$; the Age Group x Difficulty interaction, $F(1, 34) = 24.39$, $MSE = 667.11$, $p < .001$, $\eta^2 = .42$.

Table 7. *Single-Task Baseline Performance as a Function of Task, Sample, and Difficulty*

Task	Young		Old		Total	
	Easy	Difficult	Easy	Difficult	Easy	Difficult
Reaction Time (ms)						
<i>M</i>	214.95	319.88	255.73	420.78	235.34	370.33
<i>SD</i>	13.70	18.69	21.51	62.95	27.27	68.65
Errors (%)						
<i>M</i>	2.51	7.37	1.26	9.52	1.88	8.44
<i>SD</i>	3.30	4.59	1.23	7.87	2.54	6.45
Balance (mm)						
<i>M</i>	17.12	22.06	24.74	31.30	20.93	26.68
<i>SD</i>	2.28	3.06	4.23	4.92	5.11	6.18

Because individuals have capability to tradeoff accuracy for speed, it is not enough to compare the reaction times obtained in two different conditions and conclude that the condition with the slower reaction time was “harder” than the condition with the faster reaction time, unless the error level in the slower condition was greater than the error level in the faster condition (Wickelgren, 1977). To rule out the possibility of speed-accuracy trade-off, I conducted the analysis described before, however, with the percentage of errors

¹⁸ There were neither univariate nor multivariate outliers. Evaluations of assumptions of normality, homogeneity of variance-covariance matrices, and sphericity were acceptable for both the RT and the balance data. I reported the results according to Wilks’ Lambda.

as a dependent variable (see Appendix C; Table C1, for the description of variables)¹⁹. The main effect of difficulty was highly reliable, $F(1, 34) = 53.47$, $MSE = 14.48$, $p < .0001$, $\eta^2 = .61$. Whereas the effect of age group was not significant, ($F < 1.0$, $1 - \beta = .06$), the Age Group \times Difficulty interaction was marginally significant, $F(1, 34) = 3.59$, $MSE = 14.48$, $p = .067$, $\eta^2 = .10$, $1 - \beta = .45$ ²⁰.

In the balance task, there were significant effects of difficulty, $F(1, 34) = 197.84$, $MSE = 3.01$, $p < .0001$, $\eta^2 = .85$, age group, $F(1, 34) = 50.58$, $MSE = 25.29$, $p < .0001$, $\eta^2 = .60$, and a marginally significant Age Group \times Difficulty interaction, $F(1, 34) = 3.96$, $MSE = 3.01$, $p = .055$, $\eta^2 = .10$, $1 - \beta = .49$.

The results from the single-task baseline performance confirmed that, for both the reaction-time and the balance task, the participants performed worse under the difficult than under the easy condition. Thus, the experimental manipulation of difficulty worked. In terms of RTs and the areas of COP, the baseline single-task performance of older adults was on the lower level than the performance of their younger counterparts. This difference was more pronounced after the task-difficulty manipulation. Moreover, the low RT performance in the older adults was not due to the speed-accuracy trade-off. In general, both age groups made a comparable amount of errors. There was a trend in the performance of older participants to commit more errors in the difficult condition. This finding indicates that the two-choice RT task was generally more demanding for older than for younger adults.

In sum, these results are in line with numerous findings from the cognitive (see Salthouse 1991, 1996, for reviews) and the sensorimotor aging literature (see Woollacott, 2000; Woollacott & Shumway-Cook, 1990, for reviews) and demonstrate that the older subsample of the present study was “normal” with respect to age-related decline in processing speed, accuracy, and sensorimotor functioning. Moreover, the results from the baseline level analyses imply that resource limitations are more pronounced in demanding situations, and in old age. Because of these limitations, dual tasks have been argued to be even more challenging than single tasks especially in the difficult condition and in older adults. But how do individuals allocate their limited resources in the dual-task situation

¹⁹ There were two univariate but no multivariate outliers. The normality assumption was violated. The evaluation of homogeneity of variance-covariance matrices and sphericity were acceptable. I reported the results according to Wilks' Lambda.

²⁰ The analysis without outliers yielded similar results. The Age Group \times Difficulty interaction, however, did not reach significance, ($F = 2.51$, $1 - \beta = .34$).

that involves the RT and the balance task? Based on the assumption that the balance task has higher ecological relevance than the RT task, one of the main hypotheses in the present study was that performance of the balance task should be on a higher level as compared to the performance of the RT task. In other words, I expected a domain-specific asymmetry in resource allocation. The focus of the next section is on the investigation of this prediction.

5.2.2 Domain-Specific Asymmetry in Resource Allocation

In order to examine the domain-specific asymmetry in resources allocation, the dual-task performance under the instruction “Equal Emphasis” was analyzed because this instruction represents a standard of comparison with other published studies. The first analyses should clarify whether there was dual-task interference in the simultaneous performance of the RT and the balance task and whether this interference was more pronounced particularly in the resource-demanding (i.e., difficult) condition. Specifically, the following hypotheses were formulated: Performance of each component task in the dual-task context should be on the lower level (i.e., slower RTs, more errors, larger areas of COP) than the single-task performance (Hypothesis 1a-1). The deterioration in performance should be especially pronounced in the difficult condition (Hypothesis 1a-2). The performance decrement in the dual-task situation should be larger in the difficult than in the easy condition (Hypothesis 1a-3). First, the data on the level of raw scores were analyzed.

5.2.2.1 Analyses of Raw Scores

In order to test these hypotheses, the reaction-time and the balance task data were analyzed separately with an Age Group (2) x Task (2) x Difficulty (2) mixed-model analysis of variance. The dependent variables are described in Appendix C (see Table C1 and C2)²¹. Presenting the results with regard to the predictions on dual-task interference under the experimental manipulation of difficulty, I refer to the within-subjects phase of each analysis.

With respect to the cognitive domain, the analysis revealed highly significant main effects of task, $F(1, 34) = 71.42$, $MSE = 313.36$, $p < .0001$, $\eta^2 = .68$, and difficulty, $F(1, 34) = 461.79$, $MSE = 1290.48$, $p < .0001$, $\eta^2 = .93$. The main effects were qualified by a reliable Task x Difficulty interaction, $F(1, 34) = 5.87$, $MSE = 245.57$, $p < .05$, $\eta^2 = .15$.

²¹ In the data on the RTs and the areas of COP, there were neither univariate nor multivariate outliers. Evaluations of the assumptions of normality, homogeneity of variance-covariance matrices, and sphericity were acceptable. I reported the results according to Wilks' Lambda.

The left panel of Figure 9 shows that, as expected, the RTs increased from the single- to dual-task condition, and that individuals reacted slower under the difficult than under the easy condition. However, the task difficulty increment did not amplify the deterioration of performance in the dual-task as compared to the single-task situation, that is, the direction of the expected interaction was contrary to the prediction.

To control for a possible speed-accuracy trade-off, I conducted the analysis described before, however, with the percentage of errors as a dependent variable (see Appendix C; Table C1 and C2, for the description of the variables)²². The pattern of results was similar to that obtained for the reaction times. The main within-subjects effects were significant for task, $F(1, 34) = 20.85$, $MSE = 8.27$, $p < .0001$, $\eta^2 = .38$, and for difficulty, $F(1, 34) = 44.83$, $MSE = 33.06$, $p < .0001$, $\eta^2 = .57$. The interaction involving the task and difficulty factors was not statistically reliable, ($F < 1.0$, $1 - \beta = .06$)²³. Both age groups made more errors in the dual- than in the single-task condition ($M = 7.35$, $SD = 6.00$; $M = 5.16$, $SD = 4.03$, respectively). Similarly, participants were less accurate in the difficult than in the easy condition ($M = 9.47$, $SD = 7.55$; $M = 3.05$, $SD = 2.73$, respectively). Therefore, it is reasonably safe to conclude that, in the cognitive domain, the dual-task was more demanding than the single-task situation, and that the difficult task was more challenging than the easy task.

Table 8. Means (SD) in Errors (%) and Correlations among RTs (ms) and Errors (%) as a Function of Difficulty and Task

	Easy		Difficult	
	ST	DT	ST	DT
Means (SD)	1.88 (2.54)	4.21 (3.59)	8.44 (6.45)	10.49 (9.30)
Correlations	-.44**	.37*	.26	.30

Note. * $p < .05$, ** $p < .01$. ST = single task; DT = dual task

²² There were two univariate but no multivariate outliers in the data on the percentage of committed errors. The normality assumption was violated. Evaluations of the assumptions of homogeneity of variance-covariance matrices and sphericity were acceptable. I reported the results according to Wilks' Lambda.

²³ The analysis without outliers revealed similar pattern of results, but for the Task x Difficulty interaction ($F = 2.51$, $1 - \beta = .34$).

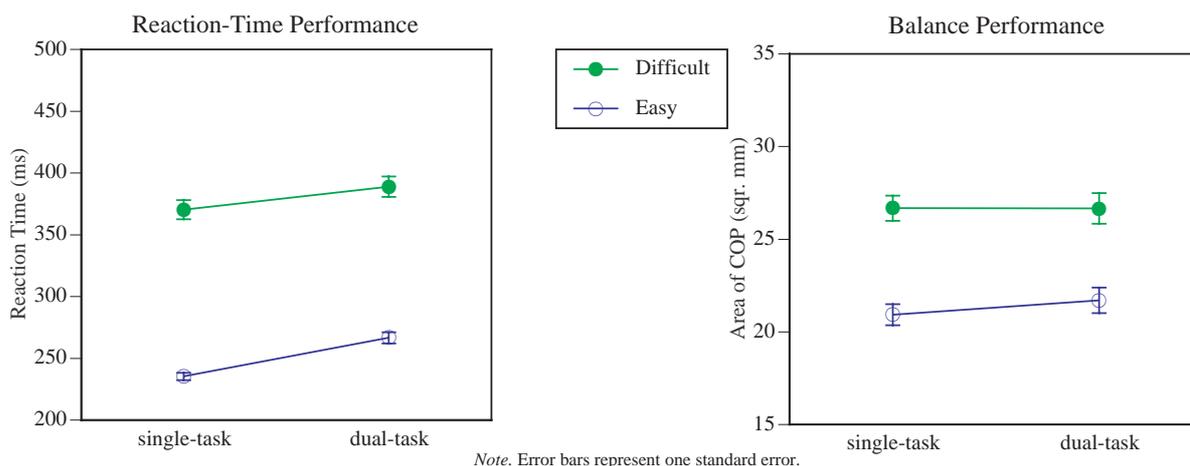


Figure 9. Reaction-time and balance performance as a function of task and difficulty

Correlational analyses confirmed that, in the total sample, the reaction times and errors generally went in the same direction, but for one exception (see Table 8). Generally, faster responses in the single-task condition did not occur at the expense of increased errors.

The analysis of the balance performance revealed only a significant effect of difficulty, $F(1, 34) = 212.87$, $MSE = 4.86$, $p < .0001$, $\eta^2 = .86$. Neither the main effect of task, ($F < 1.0$, $1 - \beta = .15$), nor the interaction involving task and difficulty reached significance, ($F = 2.27$). Note that the power to detect this interaction was not large ($1 - \beta = .31$). As the right panel of Figure 9 shows, participants swayed more under the difficult condition than under the easy condition. This finding is in line with my prediction. However, the hypothesis that the study participants perform at a lower level in the dual- than in the single-task situation and particularly when the tasks are difficult was not confirmed. A tendency to perform worse when the tasks were combined than in the balance task performed alone was present only in the easy condition, $F(1, 34) = 3.96$, $MSE = 2.70$, $p = .055$, $\eta^2 = .10$, $1 - \beta = .49$.

The results from the analyses of the RT and balance performances lead to the conclusion that, in line with the Hypothesis 1a-1, there was clear evidence that performing the RT task in the dual-task context was more challenging than performing it alone. In the sensorimotor domain, however, the dual-task impaired the performance only in the easy condition. The difficulty manipulation influenced both the ability to react as quickly and as accurately as possible and to keep the area of COP as small as possible. This result is consistent with the Hypothesis 1a-2. The interplay of both experimental manipulations (i.e., task and difficulty) resulted in decrement of performance in the cognitive but not in

the sensorimotor domain. However, the difference between the single- and the dual-task performance under the difficult condition was not as pronounced as under the easy condition. These findings are contrary to the Hypothesis 1a-3.

The finding that the dual-task context led to the decrement of the performance in the cognitive but not in the balance task might have two implications. First, the dual-task interference was larger in the cognitive than in the balance domain. Second, compared to the performance of the RT task, the balance performance was better because keeping stability was more relevant for the study participants than reacting quickly and accurately. However, this conclusion is premature because the performance measures on the two tasks were expressed in totally different units. The question arises then whether a domain-specific asymmetry can be found when both measurement scales have the same metric. For this purpose, the dual-task costs were computed.

5.2.2.2 *Computation of Dual-Task Costs*

There are various ways to compute dual-task costs. The absolute DTCs for a given task is simply the amount by which the performance deteriorates from single- to dual-task conditions. However, it is possible that the absolute DTCs give a misleading picture of age-group differences because differences in baseline performance between two groups exist. Accordingly, Somberg and Salthouse (1982) suggested relative DTCs to be the more appropriate measure. The relative costs are calculated by expressing the absolute DTCs as a proportion of single-task performance. For example, the relative dual-task costs for the balance task were computed according to:

$$[(\text{dual-task balance} - \text{single-task balance}) / \text{single-task balance}] \times 100\%.$$

For the RT task the formula was:

$$[(\text{dual-task RT} - \text{single-task RT}) / \text{single-task RT}] \times 100\%.$$

As differences in baseline performance (single-task) between two age groups were found, I computed only the relative DTCs for each component task. Because some participants made no errors in single-task conditions, the computation of the proportional DTCs for the percentage of errors was not possible. Therefore, the proportional DTCs for the percentage of correct responses were computed.

5.2.2.3 Analyses of Dual-Task Costs

Based on the rationale that keeping body's equilibrium is the prerequisite for almost all other activities (i.e., it is an ecologically relevant task) one of the central hypotheses of the present study was that individuals should bias the balance task in the dual-task situation, that is, dual-task costs should be larger in the cognitive than in the balance domain (Hypothesis 1a-4). This domain-specific asymmetry should be more pronounced in the difficult condition (Hypothesis 1a-5), that is when the “survival issue” becomes of particular relevance.

In order to test these hypotheses, the DTCs were analyzed with an Age Group (2), Domain (2), and Difficulty (2) repeated-measures ANOVA. While reporting the results, I refer to the within-subjects phase of this analysis. The dependent variables are described in Appendix D, Table D1²⁴. The analysis revealed significant within-subjects effects of domain, $F(1, 34) = 9.85$, $MSE = 205.56$, $p < .01$, $\eta^2 = .23$, and difficulty, $F(1, 34) = 25.55$, $MSE = 57.39$, $p < .0001$, $\eta^2 = .43$. The Domain x Difficulty interaction did not reach significance, ($F = 2.05$, $1 - \beta = .29$). The Hypothesis 1a-4 was confirmed: The relative costs of both age groups were larger in the cognitive than in the balance domain (see Figure 10).

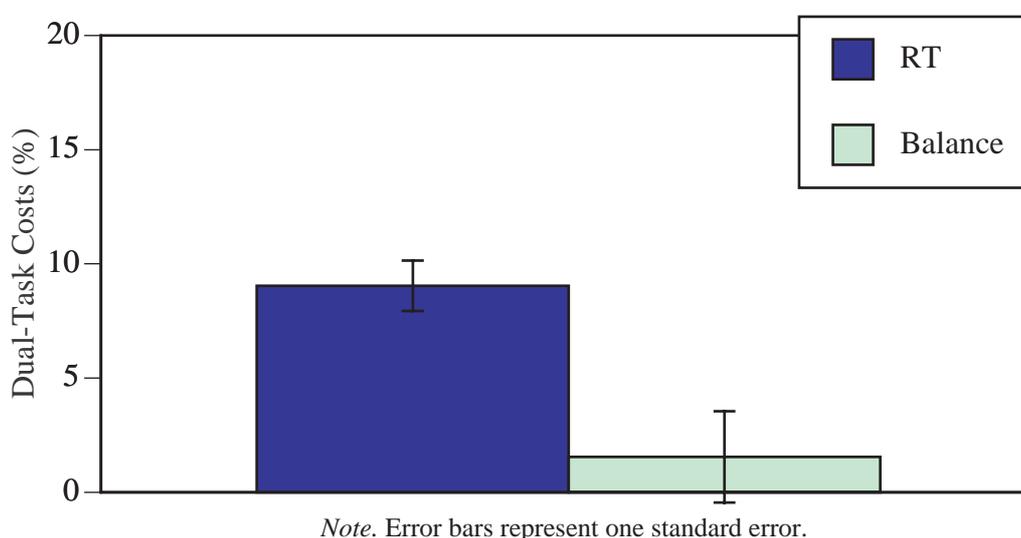


Figure 10. Dual-task costs are higher in the cognitive than in the balance domain

²⁴ There were three univariate but no multivariate outliers. The normality assumption was partially violated. Evaluations of the assumptions of homogeneity of variance-covariance matrices and sphericity were acceptable. I reported the results according to Wilks' Lambda. The analysis without outliers did not change the pattern of results.

However, the results did not support the prediction on the more pronounced domain-specific asymmetry in the difficult condition (Hypothesis 1a-5), most probably, because the DTCs were smaller under the difficult than under the easy condition in both domains (see Appendix D, Table D1). Thus, were the expected interaction statistically reliable, its direction would be contrary to my prediction.

Taken together, the analyses of the raw scores and the dual-task costs revealed that when the RT task is performed concurrently with the balance task under the instruction “Equal Emphasis”, there is dual-task interference and it is larger in the cognitive than in the balance domain (Hypothesis 1a-4). This finding suggests that due to resource limitations individuals cannot perform two simultaneous tasks equally well. They appear to select the most relevant task for them, that is, balance. However, the performance of young and older adults might be differently impaired by the demands of the dual tasks. As a result of this difference, one could assume a non-identical pattern of resource allocation in young and old age. Thus, the question I address next is “Do young and older adults allocate their resources differently in the dual-task situation that involves a simultaneous performance of the RT and the balance task?”

5.2.3 Age-Related Differences

Because older adults possess less resources than their younger counterparts and because these resource limitations are assumed to be especially pronounced in challenging situations, the following predictions with respect to age-related differences were made: In the RT and the balance task, the performance of older adults should be at a lower overall level than the performance of younger adults (Hypothesis 1b-1). The difference in the performance of younger and older individuals should be especially pronounced in the difficult (Hypothesis 1b-2) as well as in the dual-task condition (Hypothesis 1b-3), and in the dual-task condition in which both tasks are made more difficult (Hypothesis 1b-4). Similar to the analyses on the domain-specific asymmetry, the age-group differences were examined on the level of raw scores and dual-task costs.

5.2.3.1 Analyses of Raw Scores

The raw scores in the RT and the balance task were analyzed separately with two Age Group (2) × Task (2) × Difficulty (2) mixed-model ANOVAs. The dependent variables are

described in Appendix C (see Table C1 and C2)²⁵. While presenting the results, I refer to the between-subjects phase of these analyses.

The expected age-group differences in RTs were confirmed by a highly significant main effect of age group, $F(1, 34) = 62.42$, $MSE = 3790$, $p < .0001$, $\eta^2 = .65$. This effect was qualified by two significant interactions involving age group and task, $F(1, 34) = 12.01$, $MSE = 313.36$, $p < .001$, $\eta^2 = .26$, and age group and difficulty, $F(1, 34) = 30.33$, $MSE = 1290$, $p < .0001$, $\eta^2 = .47$. Figure 11 shows the results. In line with my predictions, older individuals were in general slower than young individuals, the deterioration in performance was greater for older than for younger individuals in the dual-task condition, and older adults were penalized more under the difficult condition. The expected higher-order Age Group \times Task \times Difficulty interaction was not reliable, ($F = 1.24$), most probably because of lack of power ($1 - \beta = .19$).

In order to examine whether the interpretability of results based on reaction times could be limited by age-differential speed-accuracy trade-offs, an Age Group (2) \times Task (2) \times Difficulty (2) mixed-model ANOVA was carried out on the percentage of errors as a dependent variable. The dependent variables are described in Appendix C (see Table C1

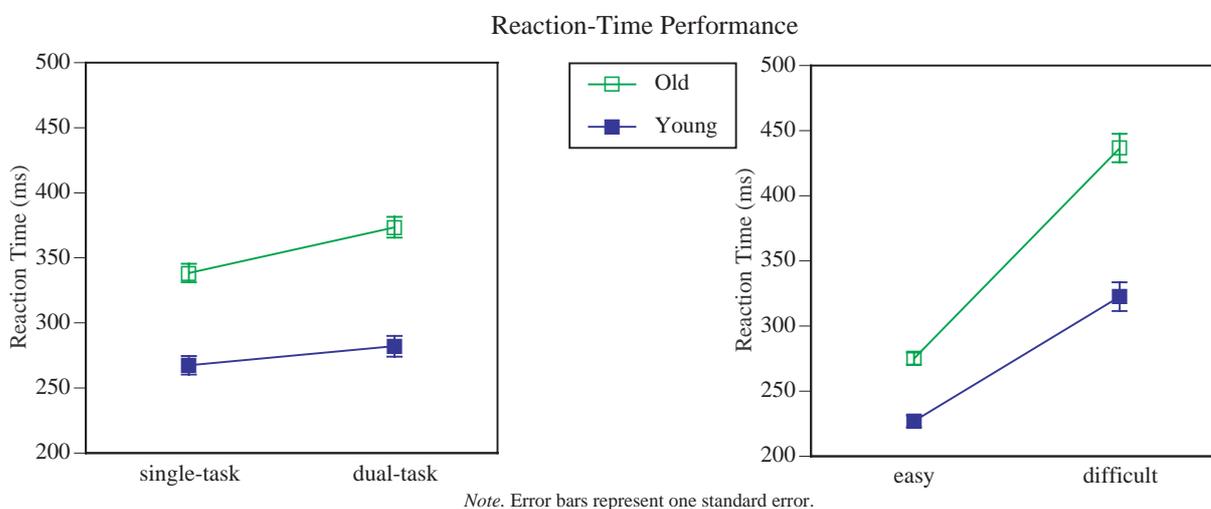


Figure 11. Reaction-time performance as a function of age group, task, and difficulty

²⁵ In the data on the RTs and the areas of COP, there were neither univariate nor multivariate outliers. Evaluations of the assumptions of normality, homogeneity of variance-covariance matrices, and sphericity were acceptable. I reported the results according to Wilks' Lambda.

and C2)²⁶. The pattern of results was similar to the one found for the RTs, but for some exceptions. There was no main effect of age group, ($F = 1.10$, $1 - \beta = .17$), indicating that overall older adults did not make more errors than their younger counterparts. However, the analysis revealed a significant interaction involving the age-group and task factors, $F(1, 34) = 6.70$, $MSE = 8.27$, $p < .05$, $\eta^2 = .17$ ²⁷. That is, although generally young and older adults made a comparable amount of errors ($M = 5.41$, $SD = 4.66$; $M = 7.10$, $SD = 5.06$, respectively), older individuals were more penalized in the dual-task condition ($M = 5.88$, $SD = 5.76$; $M = 8.81$, $SD = 6.02$, respectively). Inspection of data (see Table 9) shows that in particular older adults committed more errors in the difficult than in the easy condition. However, neither the Age Group \times Difficulty, ($F = 2.23$, $1 - \beta = .31$), nor the higher-order Age Group \times Task \times Difficulty interaction, ($F < 1.00$, $1 - \beta = .08$), reached significance.

Table 9. Means (SD) in Errors (%) as a Function of Sample, Difficulty, and Task

Sample	Easy		Difficult	
	ST	DT	ST	DT
Young	2.51 (3.30)	3.33 (3.22)	7.37 (4.59)	8.44 (9.47)
Old	1.26 (1.23)	5.10 (3.81)	9.52 (7.87)	12.54 (8.91)

Note. ST = single task; DT = dual task

Thus, the data on the percentage of errors made in the reaction-time task confirmed the results yielded for the speed of responses with respect to the dual-task condition that was more demanding for older participants. Although perhaps less sensitive, the correlational analysis supported the evidence that older adults did not tradeoff accuracy for speed in the dual-task situation. Table 10 shows that, in older adults, correlations between the RTs and percentage of errors are positive under almost all experimental conditions. Opposite pattern was found, however, for the younger group of participants. All

²⁶ There were two univariate but no multivariate outliers. The normality assumption was violated. The evaluation of homogeneity of variance-covariance matrices and sphericity were acceptable. I reported the results according to Wilks' Lambda.

²⁷ The analysis without outliers yielded similar results: for the main effect of age group, ($F = 1.97$, $1 - \beta = .28$), for the Age Group \times Task interaction, $F(1, 32) = 12.35$, $MSE = 4.95$, $p = .001$, $\eta^2 = .28$.

correlations were negative (see Table 10), indicating that, despite the instruction to give correct and quick responses, young individuals had a tendency to prefer speed to accuracy.

Table 10. *Correlations among RTs (ms) and Errors (%) as a Function of Sample, Difficulty, and Task*

Sample	Easy		Difficult	
	ST	DT	ST	DT
<i>Young</i>	-.78**	-.48*	-.46	-.38
<i>Old</i>	-.02	.67**	.32	.44

Note. * $p < .05$, ** $p < .01$. ST = single task; DT = dual task

The results obtained from the analyses of the reaction-time task performance imply that the dual-task situation, which involved a simultaneous performance of the RT and the balance task, was more demanding for older than for younger adults. One could argue that this pattern of findings emerged because older adults protected their resources for the more relevant balance task. If this is the case, the group of older participants might have a tendency to omit the RT task stimuli more often than the group of young individuals, that is, to commit more “Time-Out” errors. This possibility was confirmed by an ANOVA on “Time-Out” errors in single versus dual task in young and older adults. The main effects of age group and task were significant, $F(1, 34) = 43.94$, $MSE = 498.49$, $p < .0001$, $\eta^2 = .56$; $F(1, 34) = 6.80$, $MSE = 288.81$, $p < .05$, $\eta^2 = .17$, respectively. The Age Group \times Task interaction did not reach significance, ($F = 1.70$, $1 - \beta = .24$). Numerically, however, the amount of “Time-Out” errors committed in the single- versus dual-task situation was different for the two age groups (for young adults, $M = 3.66$, $SD = 4.33$, $M = 8.88$, $SD = 19.71$, respectively; for older adults, $M = 33.32$, $SD = 22.88$, $M = 48.99$, $SD = 25.38$, respectively).

The results obtained for the balance task were similar to those found for the RTs. There was a significant effect of age group, $F(1, 34) = 56.86$, $MSE = 57.25$, $p < .0001$, $\eta^2 = .63$, which was qualified by two higher-order interactions: the Age Group \times Task, $F(1, 34) = 7.28$, $MSE = 5.76$, $p < .05$, $\eta^2 = .18$, and the Age Group \times Difficulty interaction, $F(1, 34) = 9.60$, $MSE = 4.86$, $p < .01$, $\eta^2 = .22$. The results are shown in Figure 12.

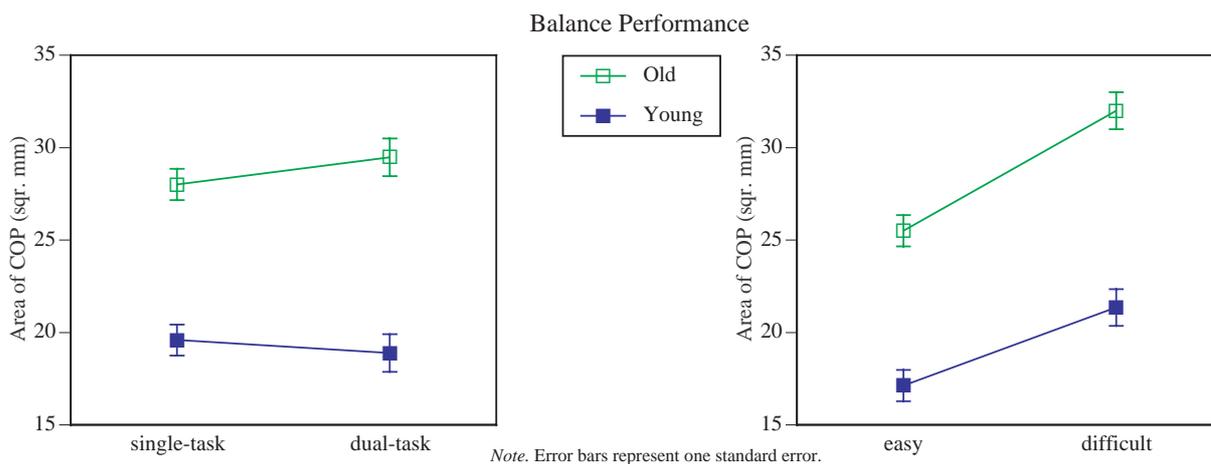


Figure 12. Balance performance as a function of age group, task, and difficulty

Compared to younger adults, older individuals performed at a lower overall level as indicated by the larger areas of COP. The deterioration of the balance performance in the dual-task condition was greater for older than for younger individuals. Additionally, older adults were penalized more under the difficult condition. Although the mean COP areas in older adults were larger than in young individuals in all experimental conditions (see Appendix C, Table C1 – C2), the expected three-way interaction between the age-group, task (single versus dual), and difficulty (easy versus difficult) factors did not reach significance, ($F = 1.56$). Thus, the influence of the difficulty manipulation on the dual-task balance performance of younger and older adults seems to be comparable. Note that the power to detect this interaction was not large ($1 - \beta = .23$).

Taken together, in support of my prediction was that older adults were penalized more than their younger counterparts in both the RT and the balance task (Hypothesis 1b-1). That is, they reacted slower and were less stable in each experimental condition. In line with the Hypothesis 1b-2, the age-related difference was exacerbated as the component tasks increased in difficulty. As hypothesized, the requirement of divided attention was more detrimental to the performance of older adults than to that of young adults (Hypothesis 1b-3). However, the Hypothesis 1b-4 was not confirmed. Neither the ability to react quickly and accurately nor the balance performance suffered in older participants more than in younger individuals when the component tasks were combined and the tasks difficulty was manipulated.

In general, the findings on age-related differences in dual-task interference demonstrated that the disruption in performance was larger for older than for younger

adults. However, this difference might be attributed to differences in the single-task baseline performance. That is why the numerical interpretation of the found Age Group \times Task (single versus dual) interaction in both domains is difficult. Therefore, I decided to further address the issue of differential pattern of resource allocation in young and older adults by expressing individuals' dual-task performance relative to their single-task performance, that is, based on the relative dual-task costs (see Section 5.2.2.2, for description of the computational procedure).

5.2.3.2 Analyses of Dual-Task Costs

If the age-related deficit in dual-task performances is beyond the general decline, older adults, as compared to their younger counterparts, should have larger overall dual-task costs (Hypothesis 1b-5). Because the consequences of falls are more dramatic in old than in young age, in particular older adults should perform better in the balance than in the cognitive domain and especially under the resource demanding condition. In other words, the age-related difference in the amount of DTCs should be more pronounced in the cognitive than in the balance domain (Hypothesis 1b-6) and particularly in the difficult condition (Hypothesis 1b-7).

The age-specific pattern in DTCs was analyzed with an Age Group (2), Domain (2), and Difficulty (2) repeated-measures ANOVA. While reporting the results, I refer to the between-subjects phase of this analysis. The dependent variables are described in Appendix D, Table D1²⁸. The analysis revealed a highly significant between-subjects effect of age group, $F(1, 34) = 10.26$, $MSE = 169.44$, $p < .01$, $\eta^2 = .23$, indicating that older adults had higher dual-task costs than their younger counterparts (see Figure 13). This main effect, however, was not qualified by any interaction: the Age Group \times Domain, ($F < 1.0$, $1 - \beta = .11$), the Age Group \times Difficulty, ($F = 1.42$, $1 - \beta = .21$), the Age Group \times Domain \times Difficulty, ($F < 1.0$, $1 - \beta = .07$).

The analysis of dual-task costs in the percentage of correct responses yielded a significant main effect of age group, $F(1, 34) = 5.34$, $MSE = 21.92$, $p < .05$, $\eta^2 = .14$, such that older adults, in comparison to their younger counterparts, had higher costs in the

²⁸ There were three univariate but no multivariate outliers. The normality assumption was partially violated. Evaluations of the assumptions of homogeneity of variance-covariance matrices and sphericity were acceptable. I reported the results according to Wilks' Lambda. The analysis without outliers did not change the pattern of results.

number of correct responses in the dual-task situation²⁹. Thus, the group of older individuals had not only higher DTCs in the reaction times and balance, but also in the amount of errors they committed in the dual-task blocks.

Taken together, one of the central hypotheses of the present study was confirmed: The DTCs were larger in older than in younger adults (Hypothesis 1b-5). The expected interactions, however, did not reach significance. The findings were contrary to the prediction that the age-group differences in DTCs should be especially pronounced in the cognitive domain (Hypothesis 1b-6) and particularly after the task-difficulty manipulation (Hypothesis 1b-7). Thus, although the overall costs in older individuals were larger than in younger adults, the lack of the predicted interactive effects might suggest that the two age groups showed a similar pattern of domain-specific asymmetry in resource allocation and that this pattern was not altered in a more challenging situation. However, closer examination of the data provides some hints into the possibility that this pattern of results might rest on different reasons for young and older adults.

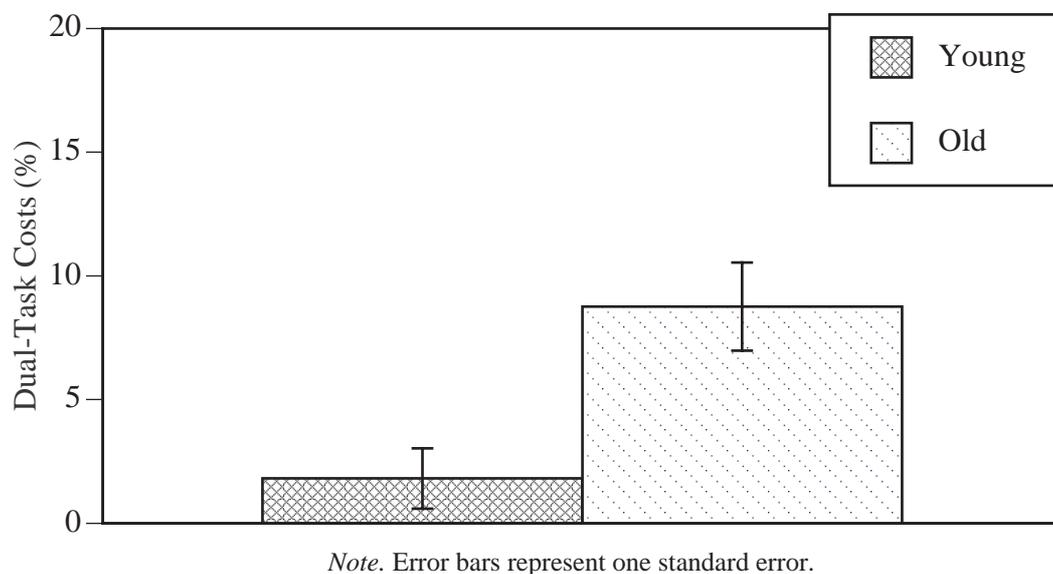


Figure 13. Dual-task costs are higher in older than in younger adults

²⁹ There was one outlier in the younger group. The analysis without the outlier revealed that the age-group difference in the DTCs for the percentage of correct responses was even more pronounced, $F(1, 33) = 12.44$, $MSE = 14.49$, $p < .001$, $\eta^2 = .27$.

Two one-sample t tests revealed that the dual-task costs were reliably greater than zero only in the group of older adults: for older adults, $t(17) = 4.91, p = .000$, for young adults, $t(17) = 1.47, p = .160$. Most probably, this finding appeared because the group of younger participants had zero or negative costs in the balance domain and almost no DTCs in the cognitive domain under the difficult condition (see Appendix D, Table D1). Note, that these are the results from the test phase of the study. Thus, it is conceivable that young participants got rid of DTCs in balance due to training and reduced them almost to zero in the cognitive domain. This assumption is supported by the data on the DTCs from the 1st and 2nd assessment, which are presented in Figure 14 and 15. I provided the detailed analyses of the training effects in Appendix E. The inspection of Figure 14 reveals that although the DTCs in balance decreased in both age groups, the dual-task interference disappeared only in the group of younger adults, particularly in the easy condition. Figure 15 shows that, in terms of dual-task costs, only younger adults improved their performance in the cognitive domain. Based on these findings, one might argue that generally both age groups invest more resources into the balance than into the cognitive performance. Whereas this pattern of resource allocation was typical for older adults in both assessments, young adults appeared to do so only in a novel dual-task situation³⁰. After practice, the balance task was not resource demanding in younger participants.

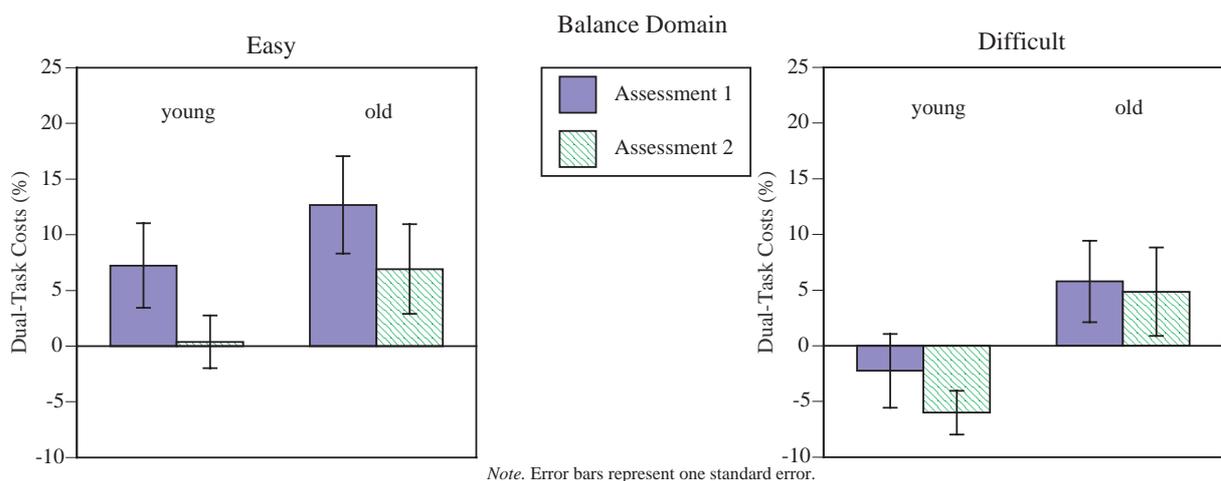


Figure 14. Balance domain: Decrement in dual-task costs through training

³⁰ In the difficult condition, the DTCs in the balance domain were negative in both assessments. I address the possible reasons for this pattern of results in the “Discussion” chapter.

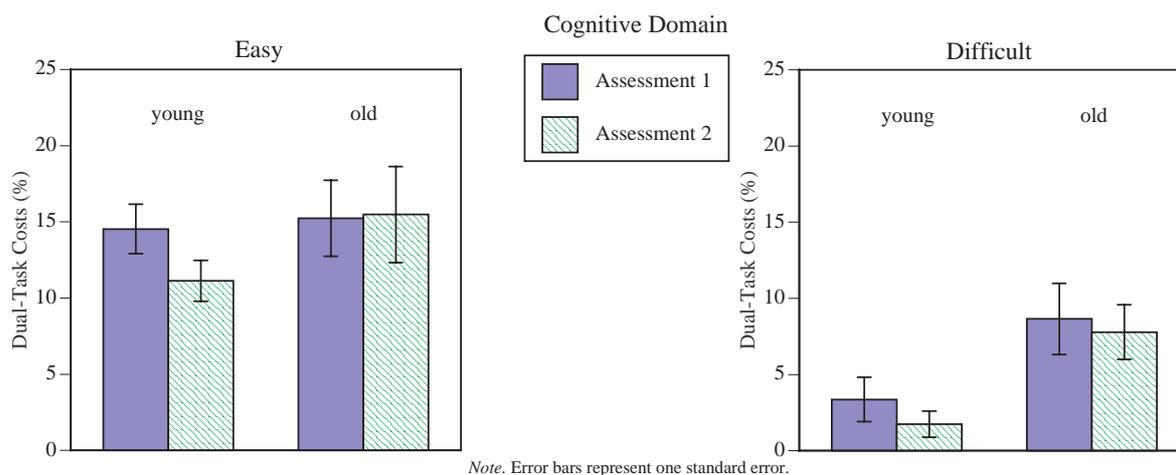


Figure 15. Cognitive domain: Decrement in dual-task costs through training

The following section summarizes the main findings that provide answer to the question “How do young and older adults allocate resources in the dual-task situation that involves a simultaneous performance of the RT and the balance task?”

5.2.4 Summary: Domain-Specific Asymmetry and Age-Related Differences

In the dual-task situation that involves a simultaneous performance of the RT and the balance task, individuals allocate more resources to the performance of the balance task. The domain-specific asymmetry in resource allocation was found on the level of raw scores and confirmed by the analyses of the dual-task costs. This finding is in line with one of the main predictions of the present study (Hypothesis 1a-4). Contrary to the Hypothesis 1a-5, however, was the result that the found asymmetry was not more pronounced in the challenging (i.e., difficult) condition. Although I made no specific predictions about the influence of task-difficulty manipulation on the amount of dual-task costs, the pattern of smaller DTCs in the difficult than in the easy condition seems to be counterintuitive and is addressed in the “Discussion” chapter.

With respect to age-related differences, the results revealed the predicted effects: Older adults performed worse than their younger counterparts regardless of experimental conditions. In more detail, the older subsample reacted slower, was less stable, was more sensitive to difficulty manipulation, and to dual-task situation (Hypotheses 1b-1 – 1b-3). However, the Hypothesis 1b-4 on the negative influence of the dual-task in combination with the difficulty condition on the performance of older adults was not confirmed. With

regard to age-related differences in the domain-specific asymmetry, the analyses yielded support to the Hypothesis 1b-5 that the experimental requirement to simultaneously perform the RT and the balance task under the instruction “Equal Emphasis” should lead to larger dual-task interference (i.e., DTCs) in older than in younger adults. Unexpectedly, however, the age-group differences were not more pronounced in the cognitive domain (Hypothesis 1b-6) and particularly in the difficult condition (Hypothesis 1b-7). The lack of significant interactions involving the age-group factor might suggest that the pattern of resource allocation is comparable in older and younger participants in both domains and under both difficulty conditions. However, the balance data yielded a different picture for young and older participants. Whereas young adults had either no or negative DTCs, older participants had substantial dual-task costs in both difficulty conditions. The findings from the training phase of the study helped to find out that, particularly in the easy condition, the younger subsample got rid of dual-task interference in balance through practice. Despite these differences, the results of the statistical analyses conducted so far suggest that there is an affirmative answer to the question “Does the pattern of resource allocation differ by domain?” and a negative answer to the question “Does the pattern of resource allocation differ by age group?” Before accepting these answers, I examine whether young and older individuals are able to change their selected priorities (i.e., deliberately control their resource allocation) when given instructions not only to perform both tasks equally well, but either to focus on the sensorimotor or the cognitive component of the dual task. The third part of this chapter addresses this issue.

5.3 Can Individuals Deliberately Control Resource Allocation?

5.3.1 Deliberate Control is Limited in Challenging Situations and in the Balance Domain

Based on the assumption that human resources are controllable and divisible and that organisms have the capability to employ available resources in ways that produce desired developmental outcomes while minimizing undesired outcomes, the present study predicted that adults can deliberately control their resource allocation. That is why, the poorest performance was expected in the task from which resource (e.g., attention, effort) was distracted, better performance was expected if resources were allocated equally to both tasks, and the best performance was expected in the task to which resources were primarily shifted (Hypothesis 2a-1). However, this flexible resource allocation or perfect control

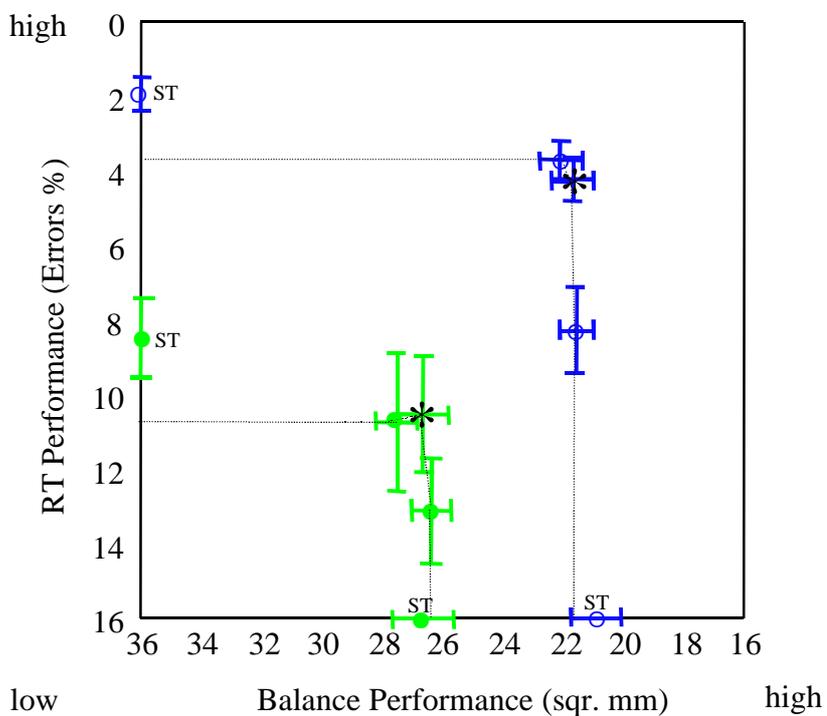
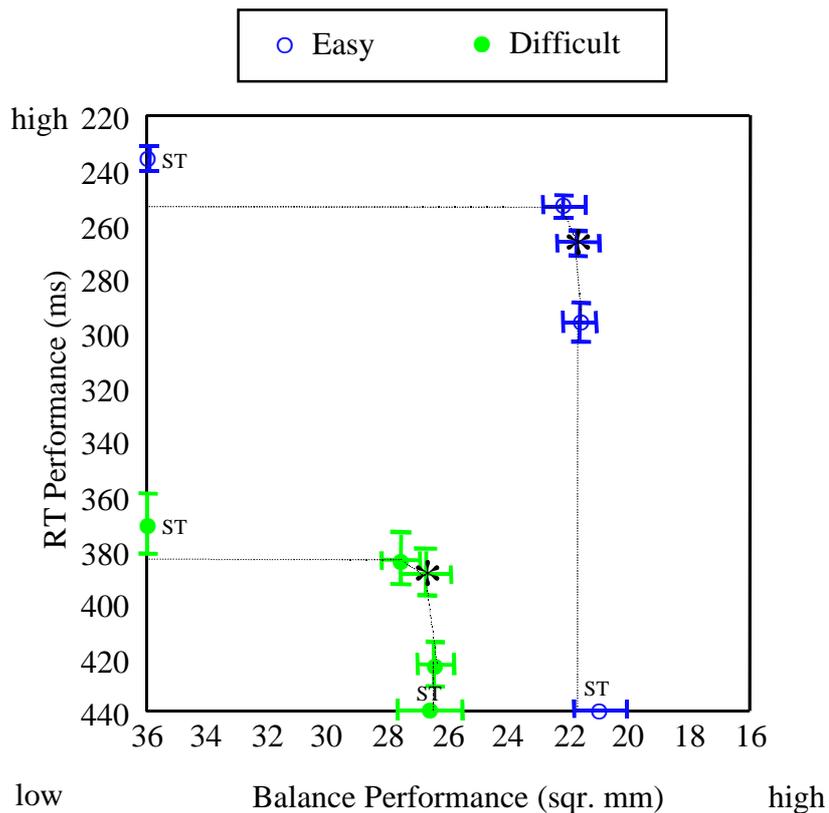
should be reduced in more challenging situations because more difficult tasks demand more resources, which are limited. Thus, a reduction in the ability to deliberately control resource allocation was expected in the difficult condition (Hypothesis 2a-2). Although cognitive system is strongly involved in the sensorimotor functioning, balance belongs to the processes that are only partially accessible on the mental level. Consequently, I expected a reduced ability to deliberately control resource allocation in the balance domain (Hypothesis 2a-3). To test these hypotheses, the dual-task performance under three task-priority instructions (“Focus on RT”, “Equal Emphasis”, and “Focus on Balance”) was analyzed on the level of raw scores and DTCs. In the first step, performance trade-offs in response to changing task priorities were examined graphically by plotting the joint dual-task performance on POCs.

5.3.1.1 POC Evaluation

Figure 16 displays the POCs for the raw scores in the easy and difficult conditions. From left to right, each point on the POCs represents one task-emphasis condition: single-task RT (100%, 0%); dual task with emphasis on the reaction-time task (i.e., “Focus on RT”); dual task with equal emphasis on both tasks (i.e., “Equal Emphasis” which is marked with asterisks); dual task with emphasis on the balance task (i.e., “Focus on Balance”); and single-task balance (0%, 100%). Several characteristics of the POCs are of interest (see Wickens, 1984): cost of concurrence (COC), time-sharing efficiency, degree of a linear exchange, and allocation bias.

The COC is present if the single-task points are higher (better performance) than the dual-task points. The points of intersection of the POCs with the ordinate indicate the cost of concurrence for the RT performance. Figure 16 shows that, in the easy as well as in the difficult condition, the study participants reacted slower and committed more errors under the instruction “Focus on RT” than in the single-task condition. Different picture emerged for the performance of the balance task, which is shown on the abscissa. Whereas the dual-task situation under the instruction “Focus on Balance” altered the participants’ balance in the easy condition, the single- and dual-task points are located approximately on the same level in the difficulty condition.

The degree of time-sharing efficiency is indicated by the distance of the POC curve from the left bottom point of the rectangle (i.e., origin) that represents a low-level performance. The closer the POC curve to the origin, the less efficient is the time-sharing.



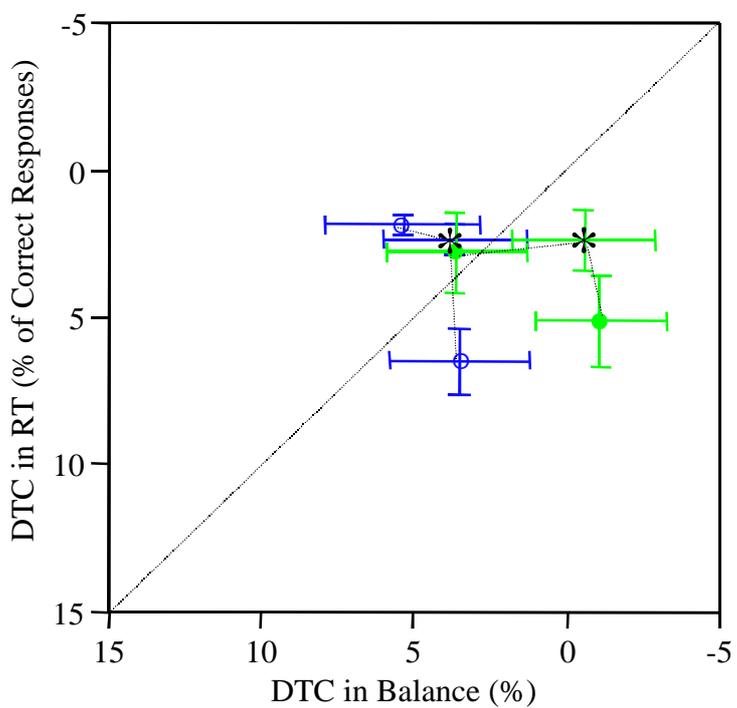
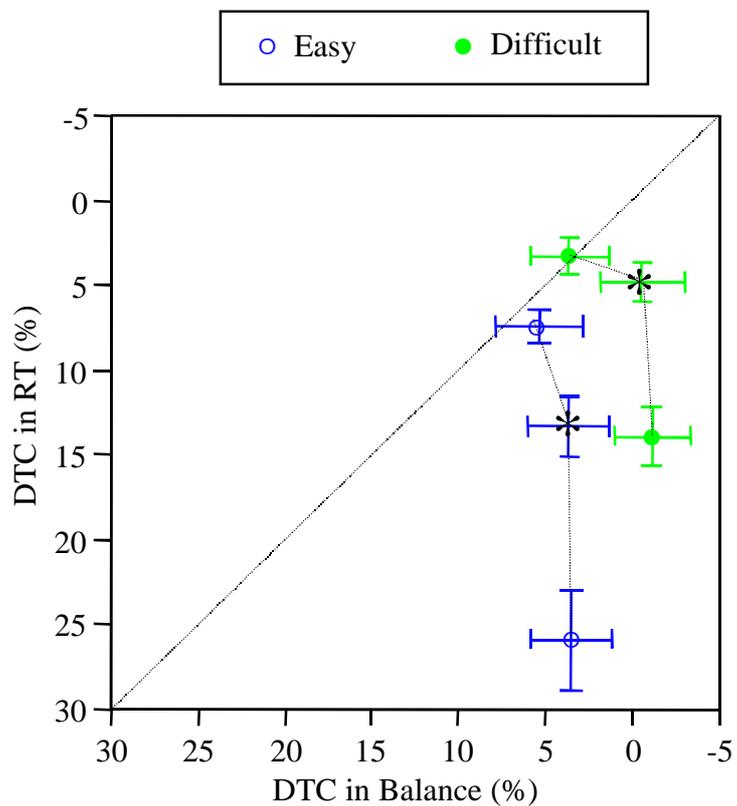
Note. Error bars represent one standard error. ST = single task.

Figure 16. POC for raw scores in reaction-time and balance task under easy and difficult condition

Perfect time-sharing can be inferred by extending the best single-task performance labeled on each axis to the point where they intersect. As can be seen in Figure 16, the POC moved closer to the origin in the difficult condition, showing decreased time-sharing efficiency.

Linear exchange or a considerable performance trade-off between two tasks should be observed if resources are exchangeable between the tasks. In other words, a given number of units of resources removed from one task (thereby decreasing its performance) can be transferred to and utilized by the other task (improving its performance). Figure 16 shows rectangular POCs for both difficulty conditions. This pattern suggests that resources withdrawn from the reaction-time task (thereby decreasing its performance) could not be used to benefit performance on the balance task. The POCs are parallel to the ordinate, that is, the 3 points, which represent the balance performance under the task-priority instructions, lie on the level of the single task. Thus, performance change in the RT task did not occur concurrently with a change in the balance task. However, there is also a clear difference between the POCs for the two difficulty conditions. When performing simultaneously two easy tasks, the study participants adjusted their RT performance to instructions. The RTs were the quickest under the instruction “Focus on RT”, as indicated by the point on the top of the POC, slower under the instruction “Equal Emphasis”, and the slowest under the instruction “Focus on Balance”, as indicated by the lowest point. The POC for the percentage of errors is similar to the POC for reaction times, but for one exception. In terms of committed errors, individuals could hardly differentiate between the instruction “Focus on RT” and “Equal Emphasis”. In the difficult condition, the data points on the POCs for the reaction time and for percentage of errors are less spread out, suggesting that there is almost no difference in the reaction-time task performance under the instructions “Focus on RT” and “Equal Emphasis”.

Allocation bias is indicated by the proximity of a given point on the POC to one axis over the other. As the performance measures on the component tasks are expressed in totally different units (i.e., milliseconds and millimeters), it is difficult to infer about the allocation bias from the POCs that are shown in Figure 16. In dealing with this issue, I plotted the dual-task costs in POC form. The general pattern in Figure 17 is very similar to the one in Figure 16. The most important point for now is that the allocation bias can be seen. Except for the performance in the difficult condition under the instruction “Focus on RT”, all data points are below the diagonal and, thus, near to the abscissa, suggesting that generally the balance task was prioritized. The lower panel in Figure 17 shows the POCs



Note. Error bars represent one standard error. ST = single task.

Figure 17. POC for dual-task costs in reaction-time and balance task under easy and difficult condition

for the dual-task costs in the percentage of correct responses as well as in the balance performance. The pattern of POCs suggests that, regardless of the difficulty condition, the RT performance in terms of correct responses did not differ under the instruction “Focus on RT” and “Equal Emphasis”. As for the allocation bias, the study participants prioritized balance in the easy condition only under the instruction “Focus on Balance” and in the difficult condition under the instructions “Equal Emphasis” and “Focus on Balance”.

In order to quantitatively evaluate the pattern of findings that are shown in Figure 16 and 17, and thus to test the research hypotheses with respect to the role of challenging situations on deliberate resource allocation, the raw scores and the DTCs were analyzed statistically. The RTs, percentage of errors, and areas of COP were submitted to separate Age Group (2) × Instruction (3) × Difficulty (2) repeated-measures ANOVAs, with age group as a between-subjects variable, and instruction and difficulty as within-subjects variables. In order to check whether the DTCs were more sensitive to the experimental manipulation of instruction in the cognitive than in the balance domain, I conducted an Age Group (2) × Instruction (3) × Difficulty (2) × Domain (2) repeated-measures ANOVA. To examine whether performance changed according to instructions, two not orthogonal contrasts were defined for the instruction factor: (a) “Focus on Balance” versus “Equal Emphasis” and (b) “Focus on RT” versus “Equal Emphasis”. Thus, the raw scores and the DTCs under each of the emphasis conditions were compared to the performance under the instruction “Equal Emphasis”. The dependent variables are described in Appendix F, Table F1 – F6. Presenting the results with regard to the experimental manipulations of instruction and difficulty, I refer to the within-subjects phase of the analyses.

5.3.1.2 Analyses of Raw Scores

The analysis of RTs³¹ revealed significant within-subjects effects and planned contrasts on the factor instruction: effect of instruction, $F(1.51, 51.45) = 51.63$, $MSE = 840.12$, $p < .0001$, $\eta^2 = .60$; effect of difficulty, $F(1, 34) = 399.53$, $MSE = 2162.05$, $p < .0001$, $\eta^2 = .92$;

³¹ There were neither univariate nor multivariate outliers (see Appendix F, F1 – F2). Evaluations of assumptions of normality and homogeneity of variance-covariance matrices were acceptable. The assumption of sphericity was violated: the Mauchly’s test was significant for the effect of instruction and for the interaction involving the instruction and difficulty factors. Moreover, the Greenhouse-Geisser estimates of the degree of sphericity were $\epsilon = .76$ and $\epsilon = .77$, respectively. Thus, I reported Greenhouse-Geisser corrected significance levels for these effects.

contrast (a), $F(1, 34) = 57.07$, $MSE = 1237.92$, $p < .001$, $\eta^2 = .63$; and contrast (b), $F(1, 34) = 9.71$, $MSE = 664.10$, $p < .01$, $\eta^2 = .22$. It is apparent in Figure 18 (left panel) that reaction times did vary with the instructional emphases and were substantially higher in the difficult condition. As expected, the participants responded slower under the instruction “Focus on Balance” than under the instruction “Equal Emphasis”. Adults of both age groups reacted quicker under the instruction “Focus on RT” than under the instruction “Equal Emphasis”. Although the Instruction \times Difficulty interaction was not significant, ($F = 1.10$, $1 - \beta = .21$), the a priori specified contrast (b) on this interaction reached statistical significance, $F(1, 34) = 4.60$, $MSE = 275.76$, $p < .05$, $\eta^2 = .12$. As can be seen in Figure 18, both age groups reacted quicker under the instruction “Focus on RT” in comparison to the instruction “Equal Emphasis” in the easy condition. When both tasks were made more difficult, the performance under the instruction “Focus on RT” did not differ from the performance under the instruction “Equal Emphasis”.

In order to rule out the possibility that the study participants could adjust their reaction-time performance according to instructions due to speed-accuracy trade-offs, I analyzed the percentage of errors under the task-priority instructions in both difficulty conditions. Table 11 provides the descriptive data³². It can be seen that the amount of errors committed in the RT task under three instructions changed in a similar fashion the reaction times did. The analysis of variance yielded significant within-subjects effects of instruction, $F(2, 50.97) = 10.69$, $MSE = 34.31$, $p < .001$, $\eta^2 = .24$, and difficulty, $F(1, 34) = 29.28$, $MSE = 67.20$, $p < .001$, $\eta^2 = .46$, suggesting that the study participants adjusted their performance in the cognitive domain not only in terms of their RTs but also in terms of errors. However, only the a priori defined contrast (a) was statistically reliable, $F(1, 34) = 11.79$, $MSE = 66.69$, $p < .01$, $\eta^2 = .26$, indicating that more errors were made under the instruction “Focus on Balance” than under the instruction “Equal Emphasis”. This pattern was present in both difficulty conditions. Neither the planned contrast (b), nor the Instruction \times Difficulty interaction, nor the contrasts on this interaction were statistically reliable, ($F < 1.0$, $1 - \beta = .00$; $F = 1.68$, $1 - \beta = .33$; $F = 1.45$, $1 - \beta = .04$; $F < 1.0$, $1 - \beta = .01$, respectively). Additionally, I analyzed the relationship between the reaction times and

³² The description of dependent variables is given in Appendix F, Table F3. There was one univariate and one multivariate outlier. The normality assumption was partially violated. Evaluation of assumption of variance-covariance matrices was acceptable. The assumption of sphericity was violated for the factor instruction. The Mauchly’s test of sphericity was significant and the Greenhouse-Geisser estimate of the degree of sphericity was $\epsilon = .75$. Therefore, I reported Greenhouse-Geisser corrected significance levels for this effect.

the percentage of errors under three instructions and two difficulty conditions. Table 11 shows that the correlations of the whole sample were generally positive. This correlational pattern suggests that individuals did not adjust their RT performance according to instructions due to speed-accuracy trade-offs. Thus, the hypothesis that the deliberate control of resource allocation is limited in the difficult condition was supported for the cognitive domain on the level of raw scores.

Table 11. Means and SD in Errors (%) and Correlations among RTs (ms) and Errors (%) as a Function of Difficulty and Instruction

	Easy			Difficult		
	Focus on RT	Equal Emphasis	Focus on Balance	Focus on RT	Equal Emphasis	Focus on Balance
<i>Means</i>	3.70	4.21	8.24	10.69	10.49	13.08
<i>SD</i>	3.12	3.59	7.01	11.10	9.30	10.28
<i>Correlations</i>	-.19	.37*	.58**	.41*	.30	.69**

Note. * $p < .05$, ** $p < .01$.

The analysis of the balance data³³ revealed that a main effect of instruction was marginally significant, $F(2, 33) = 2.91$, $MSE = 6.59$, $p = .069$, $\eta^2 = .15$, $1 - \beta = .53$, and the effect of difficulty was highly significant, $F(1, 34) = 184.06$, $MSE = 7.53$, $p < .0001$, $\eta^2 = .84$. The a priori defined contrast (a) for the instruction factor was not statistically reliable ($F < 1.0$, $1 - \beta = .07$). However, the contrast (b) was marginally significant, $F(1, 34) = 3.73$, $MSE = 8.26$, $p = .062$, $\eta^2 = .10$, $1 - \beta = .47$. Inspection of Figure 18 (right panel) reveals that the study participants had a weak tendency to sway more under the instruction “Focus on RT” than under the instruction “Equal Emphasis” and that in the difficult condition all individuals performed worse than in the easy condition. Neither the Instruction x Difficulty interaction nor the a priori specified contrasts for this interaction reached statistical significance, ($F < 1.0$, $1 - \beta = .14$; $F < 1.0$, $1 - \beta = .06$; $F < 1.0$, $1 - \beta =$

³³ There were neither univariate nor multivariate outliers (see Appendix F, F1 – F2). Evaluations of assumptions of normality and homogeneity of variance-covariance matrices were acceptable. The assumption of sphericity was not violated. Thus, I reported results according to Wilks’ Lambda.

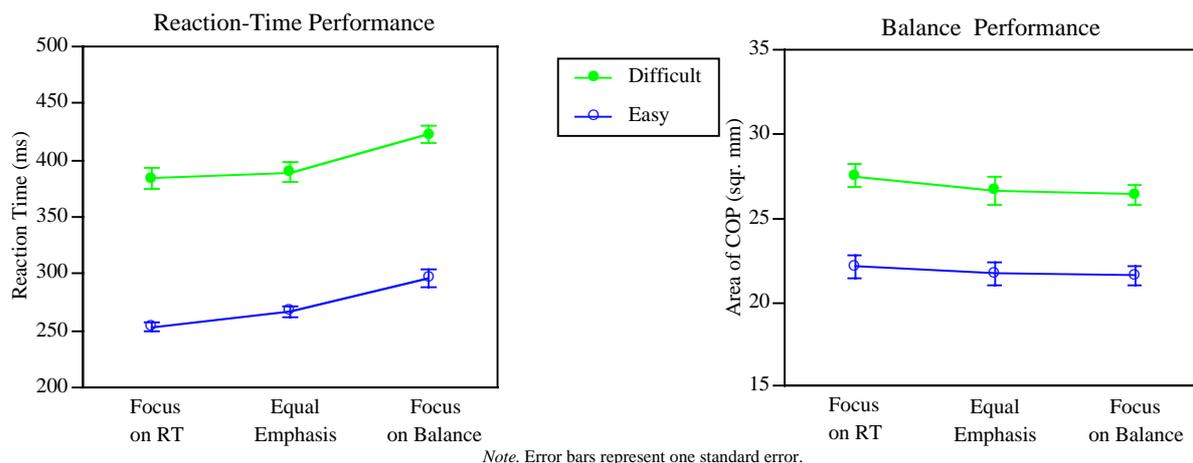


Figure 18. Sensitivity of reaction-time and balance performance to instructional manipulation as a function of difficulty

.13, respectively). Thus, the deliberate control of the balance performance was comparable for both difficulty conditions.

In sum, the findings from the RT performance confirm the Hypotheses 2a-1 and 2a-2. Study participants could adjust their performance according to instructions (i.e., deliberately control) in terms of both the RTs and errors. This ability was, however, reduced in a more demanding situation. In the balance domain, there was a tendency of deliberate resource allocation in both difficulty conditions. This pattern of results is in line with the Hypothesis 2a-1. However, no evidence supporting the Hypothesis 2a-2 was found. That is, the ability to adjust the balance performance according to instructions was not differentially influenced by the manipulation of task-difficulty. These results suggest that, as expected, individuals can better control their cognitive than their balance performance (Hypothesis 2a-3). This conclusion is premature until the performance in both domains has been analyzed using the same metric (e.g., dual-task costs).

5.3.1.3 Analyses of Dual-Task Costs

The analyses presented in this section aimed at answering the question whether DTCs revealed similar pattern of results the raw scores did. Specifically, the main focus here is on the sensitivity of DTCs to the instructional manipulation. Moreover, of interest was whether this sensitivity was more pronounced in the easy than in the difficult condition, and in the cognitive than in the balance domain. The Age Group (2) x Instruction (3) x

Difficulty (2) x Domain (2) repeated-measures ANOVA³⁴ revealed a highly significant main effect of instruction, $F(2, 33) = 20.13$, $MSE = 70.81$, $p < .0001$, $\eta^2 = .55$, but this effect should be considered in light of the two higher-order interactions: the Instruction x Domain, $F(1.55, 52.85) = 26.59$, $MSE = 142.50$, $p < .001$, $\eta^2 = .44$, and the Instruction x Difficulty interactions, $F(1.68, 57.16) = 5.50$, $MSE = 57.06$, $p = .01$, $\eta^2 = .14$. The left panel of Figure 19 shows that the DTCs were more sensitive to the instructional manipulation in the cognitive than in the balance domain. The right panel of Figure 19 demonstrates that the change in the dual-task costs following instructions is more pronounced under the easy than under the difficult condition.

In order to determine the source of these interactions, I analyzed the DTCs within each domain with an Age Group (2) x Instruction (3) x Difficulty (2) repeated-measures ANOVA. In the cognitive domain, the main effect of instruction as well as the interaction involving the instruction and difficulty factors were highly significant, $F(1.47, 49.97) = 54.82$, $MSE = 102.85$, $p < .0001$, $\eta^2 = .62$; $F(1.36, 46.10) = 7.24$, $MSE = 56.13$, $p < .01$,

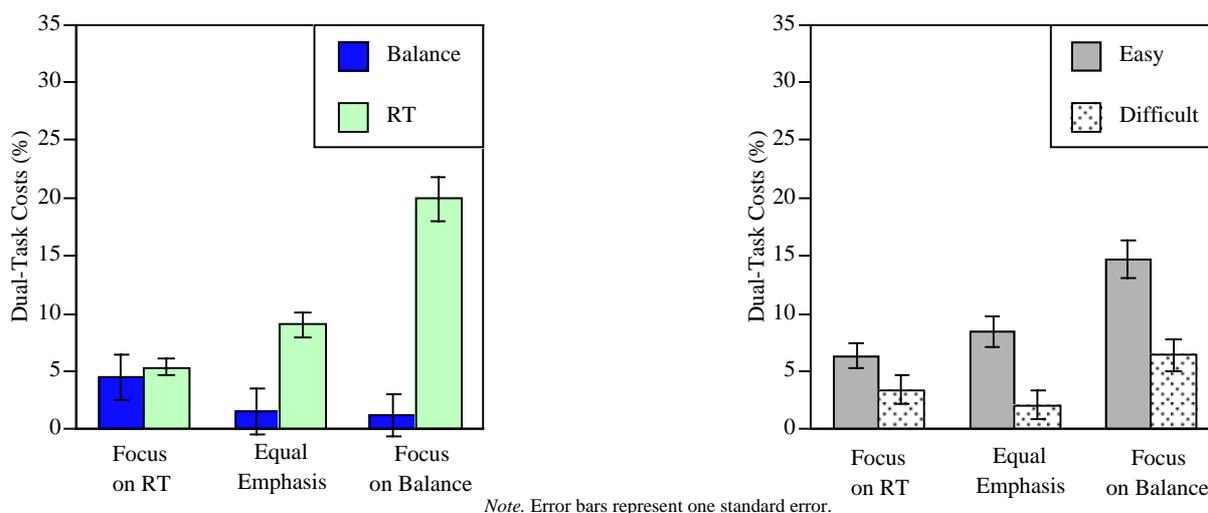


Figure 19. Sensitivity of dual-task costs to instructional manipulation as a function of domain and difficulty

³⁴ The presentation of results is restricted to the effects dealing with purpose of this section. As there were outliers (four univariate but no multivariate), the dual-task costs were analyzed twice: with and without outliers. The analysis without outliers did not alter the pattern of results. The dependent variables are described in Appendix F, Table F4 – F5. Tests of normality, homogeneity of variance-covariance, and sphericity showed that these assumptions were slightly violated. The assumption of sphericity was violated for the Instruction x Domain, Instruction x Difficulty, Instruction x Domain x Difficulty interactions. The Greenhouse-Geisser estimates of the degree of sphericity were $\epsilon = .78$, $\epsilon = .84$, and $\epsilon = .80$, respectively. Thus, I reported Greenhouse-Geisser corrected significance levels for these effects.

$\eta^2 = .18$, respectively. Two a priori specified contrasts on the factor instruction were statistically reliable: for contrast (a), $F(1, 34) = 55.34$, $MSE = 153.93$, $p < .0001$, $\eta^2 = .62$, for contrast (b), $F(1, 34) = 14.00$, $MSE = 71.15$, $p = .001$, $\eta^2 = .29$. However, only the a priori specified contrast (b) on the Instruction \times Difficulty interaction was significant, $F(1, 34) = 13.86$, $MSE = 24.75$, $p = .001$, $\eta^2 = .29$, (for contrast (a) $F = 2.30$, $1 - \beta = .31$). Figure 20 (left panel) shows the DTCs in the cognitive domain under three instructional conditions. In general, the dual-task costs were sensitive to the instructional manipulation. Similar to raw scores, the DTCs in the easy condition were the largest under the instruction “Focus on Balance”, smaller under the instruction “Equal Emphasis”, and the smallest under the instruction “Focus on RT”. By contrast, in the difficult condition no difference was found between the instructions “Focus on RT” and “Equal Emphasis”³⁵.

In the balance domain, neither a main effect of instruction, nor the interaction involving the instruction and difficulty factors were significant, ($F = 2.23$, $1 - \beta = .43$; $F < 1.0$, $1 - \beta = .16$, respectively). The a priori specified contrast (a) on the factor instruction, comparing the DTCs under the instructions “Focus on Balance” and “Equal Emphasis”, was not statistically reliable, ($F < 1.0$, $1 - \beta = .05$). However, the contrast (b), comparing the DTCs under the instructions “Equal Emphasis” and “Focus on RT”, was marginally significant, $F(1, 34) = 3.70$, $MSE = 169.42$, $p = .063$, $\eta^2 = .10$, $1 - \beta = .46$. Neither of the two contrasts specified on the Instruction \times Difficulty interaction was significant, ($F < 1.0$, $1 - \beta = .05$; $F = 1.26$, $1 - \beta = .19$, respectively). Figure 20 (right panel) illustrates that the DTCs in the balance domain were not sensitive to the instructional manipulation in both difficulty conditions. There was a slight tendency of higher costs under the instruction “Focus on RT”, but the instruction “Equal Emphasis” as well as the instruction “Focus on Balance” influenced DTCs in a similar way. This pattern of results is parallel to the findings based on the raw scores.

³⁵ In order to rule out the possibility that the DTCs in the RTs were sensitive to instructions because of speed-accuracy trade-offs, I analyzed the dual-task costs in the percentage of correct responses with an Age Group (2) \times Instruction (3) \times Difficulty (2) repeated-measures ANOVA. The main effect of instruction was significant, $F(1.59, 53.97) = 9.23$, $MSE = 39.09$, $p < .01$, $\eta^2 = .21$. Only the a priori specified contrast (a) on the factor instruction was statistically reliable: for contrast (a), $F(1, 34) = 10.44$, $MSE = 81.21$, $p < .01$, $\eta^2 = .24$, for contrast (b), $F < 1$, $\beta = .05$. Neither the main effect of difficulty nor the Instruction \times Difficulty interaction was significant, $F < 1$, $1 - \beta = .05$, $F = 1.35$, $1 - \beta = .27$, respectively. The two a priori specified contrasts on this interaction were not significant either: for contrast (a), $F < 1$, $1 - \beta = .03$, for contrast (b), $F < 1$, $1 - \beta = .01$. In general, the pattern of results was similar to the one found for the dual-task costs in RTs and almost parallel to the findings based on raw scores. The DTCs in the percentage of correct responses were generally sensitive to instructional manipulation. They were higher under the instruction “Focus on Balance” than under the instruction “Equal Emphasis”.

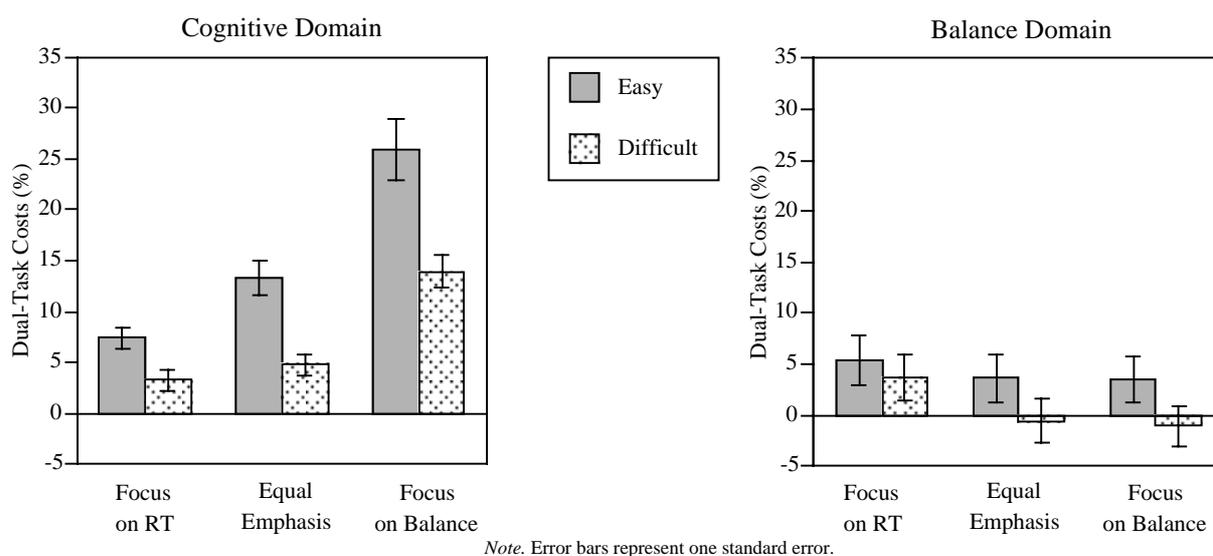


Figure 20. Sensitivity of dual-task costs to instructional manipulation as a function of difficulty

In sum, similar to raw scores, the proportional dual-task costs were sensitive to the experimental manipulation of instruction. As expected, the instructions had larger effects on dual-task costs in the cognitive than in the balance domain, and in the easy than in the difficult condition.

Taken together, the hypotheses with respect to deliberate control of resource allocation were confirmed on the level of raw scores as well as on the level of dual-task costs. In general, individuals were able to adjust their RT and balance performance according to instructions (Hypothesis 2a-1). As expected, this ability was reduced in the difficult condition (Hypothesis 2a-2) and in the balance domain (Hypothesis 2a-3). Taking into account the findings on age-group differences in dual-task costs and assuming that young and older adults differ in the efficiency with which they use their resources, the question arises whether the ability to deliberately control resource allocation is comparable in the two age groups. This issue is addressed in the next section.

5.3.2 Age-Related Differences

With respect to age-group differences in the adjustability of the reaction-time and balance performance according to instructions, three hypotheses were formulated. The ability to adjust ones performance according to instructions was expected to be reduced in older adults (Hypothesis 2b-1) because, in old age, individuals do not only possess less

resources, but are assumed to be less efficient in resource budgeting. This age-related difference was hypothesized particularly for the difficult condition (Hypothesis 2b-2) and for the balance domain (Hypothesis 2b-3) because the limitations in the mental and physical resources should place restrictions on the ability to efficiently allocate resources in old age. Similar to the hypotheses on the deliberate control of resource allocation, first, the age-group differences were examined graphically by plotting the joint dual-task performance on POCs. Following that, I performed the quantitative evaluation of performance trade-offs on the level of raw scores and dual-task costs.

5.3.2.1 POC Evaluation

The POCs of young and older adults (see Figures 21, 22, 23, and 24) were evaluated according to the four characteristics (i.e., cost of concurrence, time-sharing efficiency, degree of linear exchange, and allocation bias).

The inspection of Figure 21 reveals that, in the easy condition, young as well as older adults have COC in the reaction times. As for the balance performance, only older adults performed worse in the dual-task block under the instruction “Focus on Balance” in comparison to the single-task condition. In the difficult condition, the performance of young adults is free of COC in both domains. Older individuals, however, experienced larger cost of concurrence in the reaction-time task than in the balance task. The evaluation of the percentage of errors made under the task-emphasis instructions in comparison to the single task yielded a similar pattern (see Figure 22). Both groups had COC in the percentage of errors. The performance of older participants, however, suffered particularly in the difficult condition.

With respect to the time-sharing ability, marked age-related differences can be seen in Figure 21. The POCs of older individuals moved increasingly closer to the origin, particularly when both component tasks were difficult. Similar picture emerged for both the reaction times and the percentage of committed errors (see Figure 22). The young group’s box-like POCs for errors with limited spread of the data points showed that their time-shared performance was quite close to the optimum.

As for the degree of linear exchange, the performance of both age groups was comparable. In the cognitive domain, the influence of the task-priority instructions, in young as well as older adults, was larger in the easy than in the difficult condition.

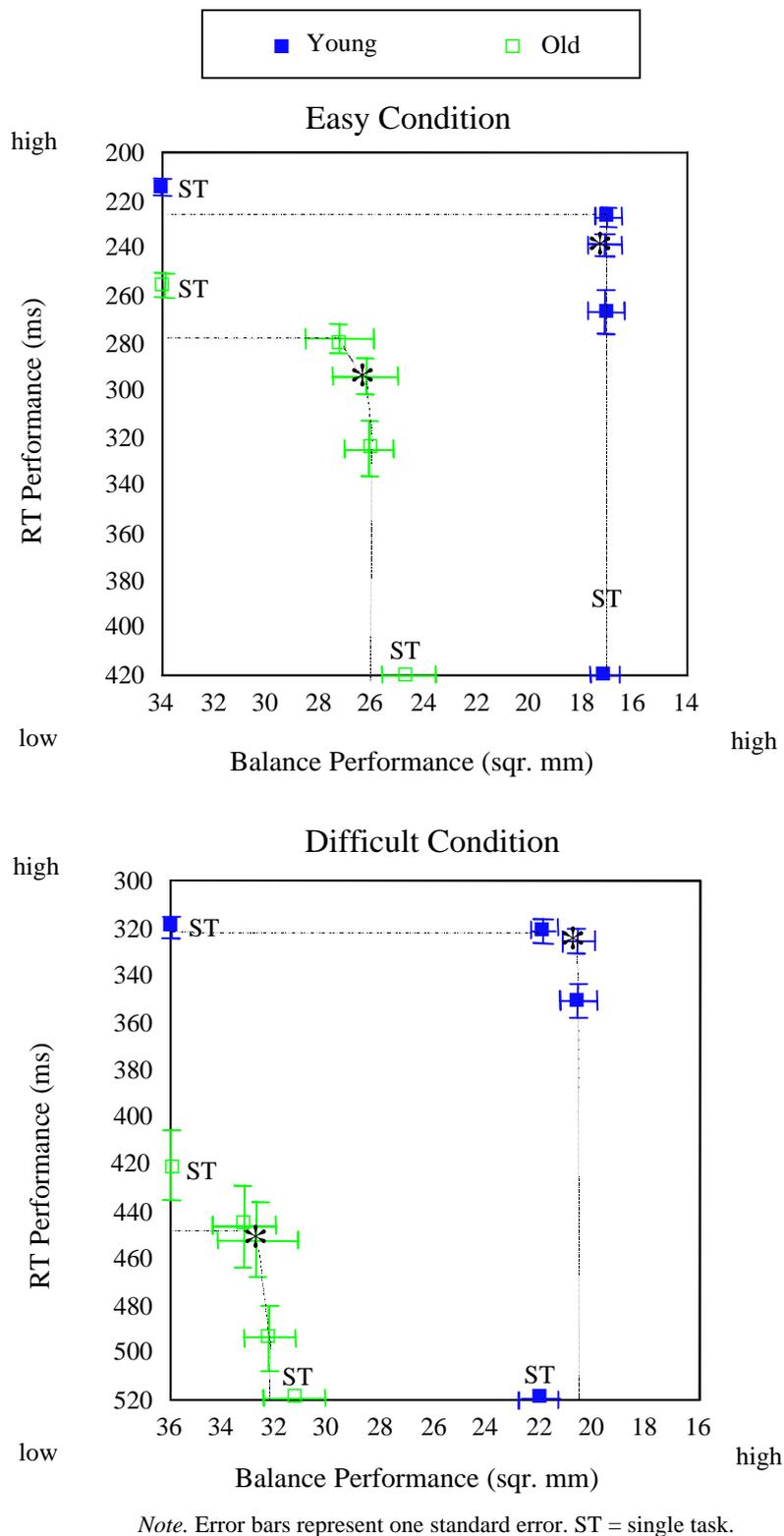


Figure 21. POCs for raw scores in reaction times and areas of COP as a function of age group and difficulty

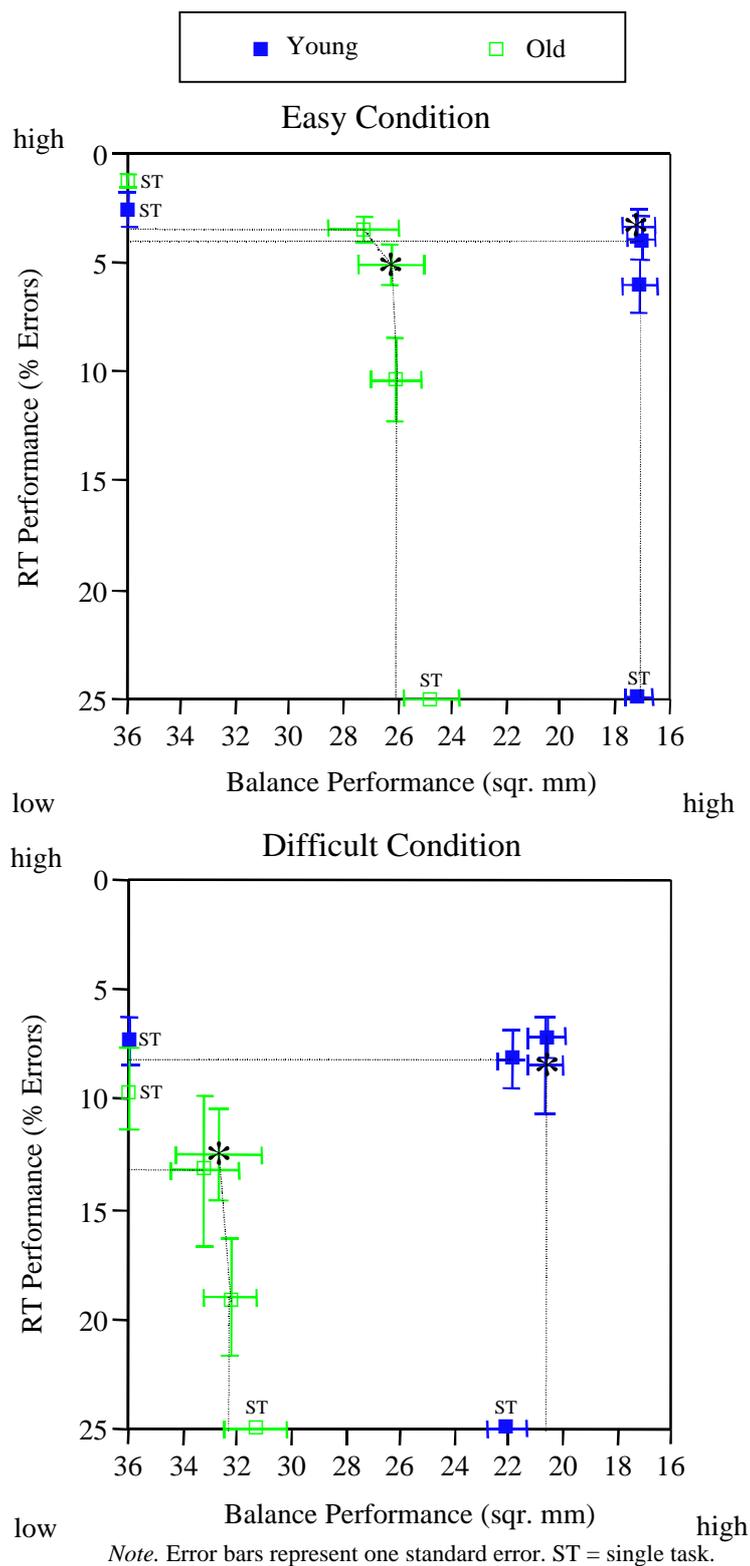


Figure 22. POCs for raw scores in percentage of errors and areas of COP as a function of age group and difficulty

In the balance domain, older participants tried to adjust their performance in the easy condition and swayed more under the instruction “Focus on RT”. Young individuals demonstrated similar balance behavior in the difficult condition. This pattern might suggest that older adults prioritized balance particularly in the difficult condition. However, in order to infer about the prioritization behavior, the POCs based on dual-task costs (i.e., the same unit for both component tasks) should be evaluated.

Figure 23 demonstrates that both age groups showed a larger performance decline in the cognitive than in the balance domain. All points on the POCs are in the right bottom part of the Functional Performance Region (FRP), suggesting that in the dual-task situation involving the reaction-time and the balance task the latter is generally biased. However, the almost straight line that represents the DTCs of young adults in the easy condition intersects the abscissa on the zero point and thus indicates that they have no dual-task costs in the balance domain. The POC of older adults clearly shows that their balance performance was attentionally demanding. Similar pattern can be seen in the difficult condition. Taking into consideration this difference and the fact that older participants had higher dual-task costs not only in RTs but also in the percentage of correct responses (see Figure 24), age-related differences in performance trade-offs can be inferred.

In order to quantitatively evaluate the pattern of results showed in Figure 21 and 22, the raw scores were evaluated. The performance trade-offs presented in Figure 23 and 24 were tested by conducting analyses on dual-task costs.

5.3.2.2 Analyses of Raw Scores

The raw scores (RTs and areas of COP) were analyzed within each domain with an Age Group (2) x Instruction (3) x Difficulty (2) repeated-measures ANOVA. Presenting the results on the age-group differences in the performance under the experimental instructions, I refer to the between-subjects phase of the analyses³⁶.

³⁶ There were neither univariate nor multivariate outliers in the data on RTs (see Appendix F, F1 – F2). Evaluations of assumptions of normality and homogeneity of variance-covariance matrices were acceptable. The assumption of sphericity was violated: the Mauchly’s test was significant for the effect of instruction and for the interaction involving the instruction and difficulty factors. Moreover, the Greenhouse-Geisser estimates of the degree of sphericity were $\epsilon = .76$ and $\epsilon = .77$, respectively. Thus, I reported Greenhouse-Geisser corrected significance levels for these effects.

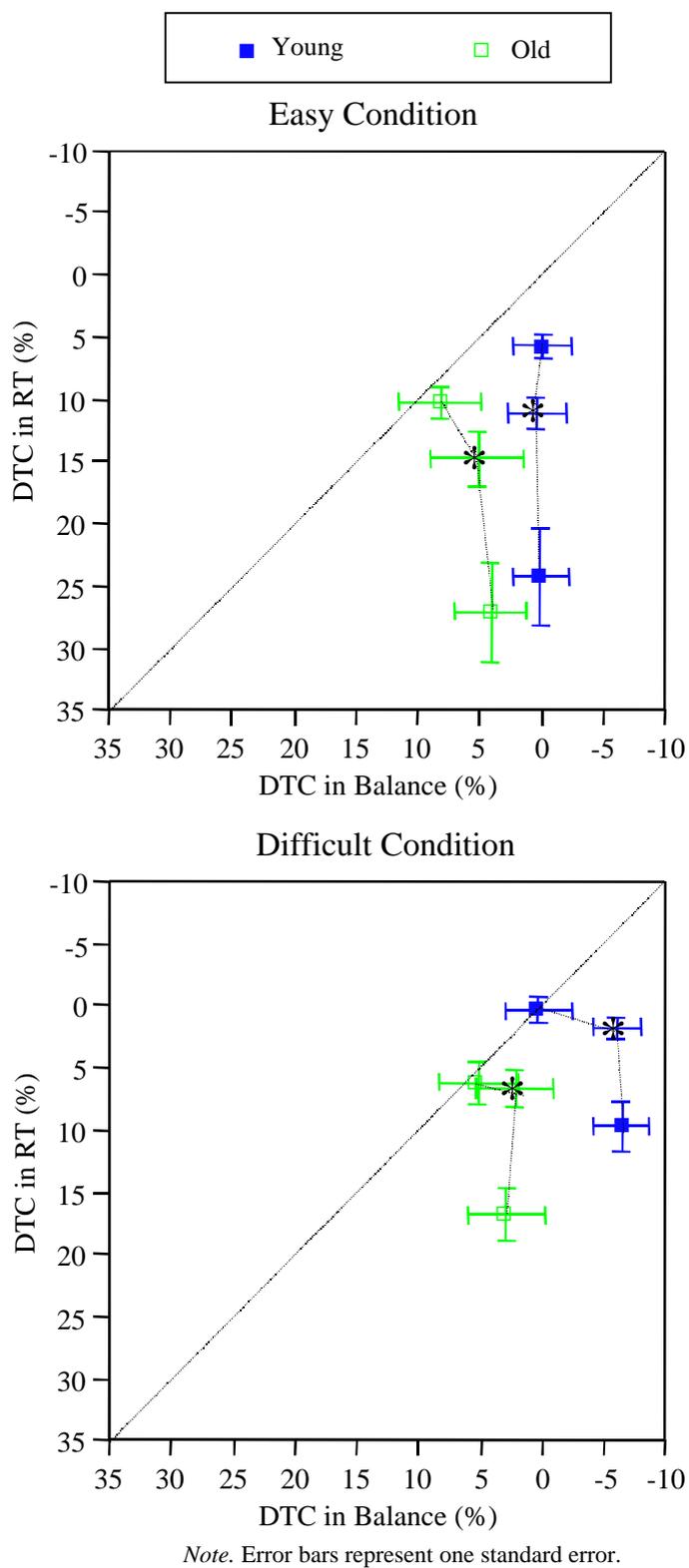


Figure 23. POCs for dual-task costs in reaction times and areas of COP as a function of age group and difficulty

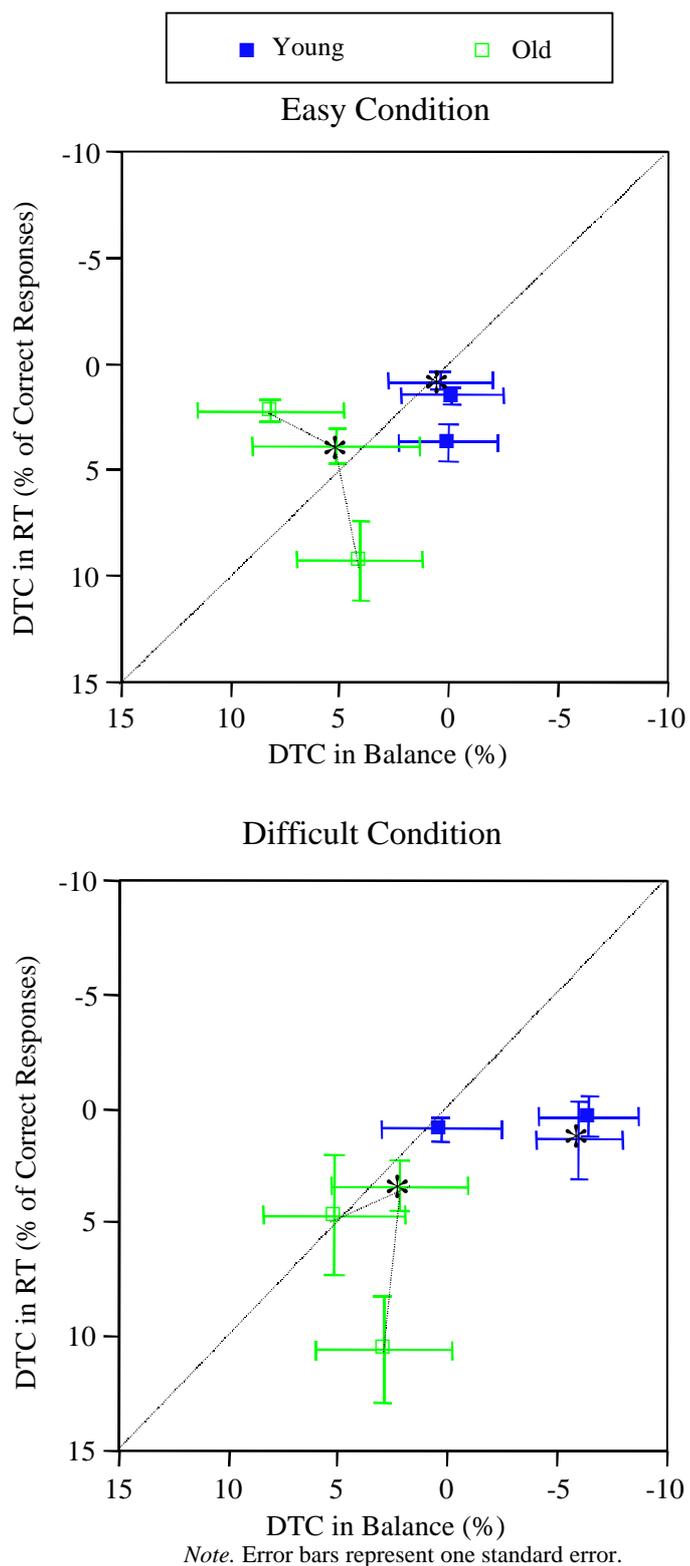


Figure 24. POCs for dual-task costs in percentage of correct responses and areas of COP as a function of age group and difficulty

The analysis of age-group differences in the performance of the reaction-time task revealed a main effect of age group, $F(1, 34) = 69.13$, $MSE = 2269.18$, $p < .0001$, $\eta^2 = .67$, indicating that older adults reacted generally slower than their younger counterparts. However, neither the interaction involving the age-group and instruction factors, nor the three-way Age Group \times Instruction \times Difficulty interaction, were statistically reliable, ($F = 1.12$, $1 - \beta = .21$; $F < 1.0$, $1 - \beta = .16$, respectively). The planned contrasts on both higher-order interactions also did not reach significance: for contrast (a), ($F = 1.21$, $1 - \beta = .19$; $F = 1.24$, $1 - \beta = .19$); for contrast (b), ($F < 1.0$, $1 - \beta = .08$; $F < 1.0$, $1 - \beta = .06$). The mean RT data are presented in Figure 25. It can be seen that in both difficulty conditions the performance of older adults was as sensitive to the instructional manipulation as the performance of younger adults. In the easy condition, both age groups were slower under the instruction “Focus on Balance” than under the instruction “Equal Emphasis”. The fastest responses were under the instruction “Focus on RT”. In the difficult condition, the RTs of both young and older adults were high under the instruction “Focus on Balance”, but did not significantly differ under two other instructions.

In order to rule out the possibility of age-related speed-accuracy trade-offs, I analyzed the percentage of committed errors as well as the relation between the RTs and errors. The information on age-group differences in terms of accuracy is presented in Table 12. An Age Group (2) \times Instruction (3) \times Difficulty (2) repeated-measures ANOVA on the

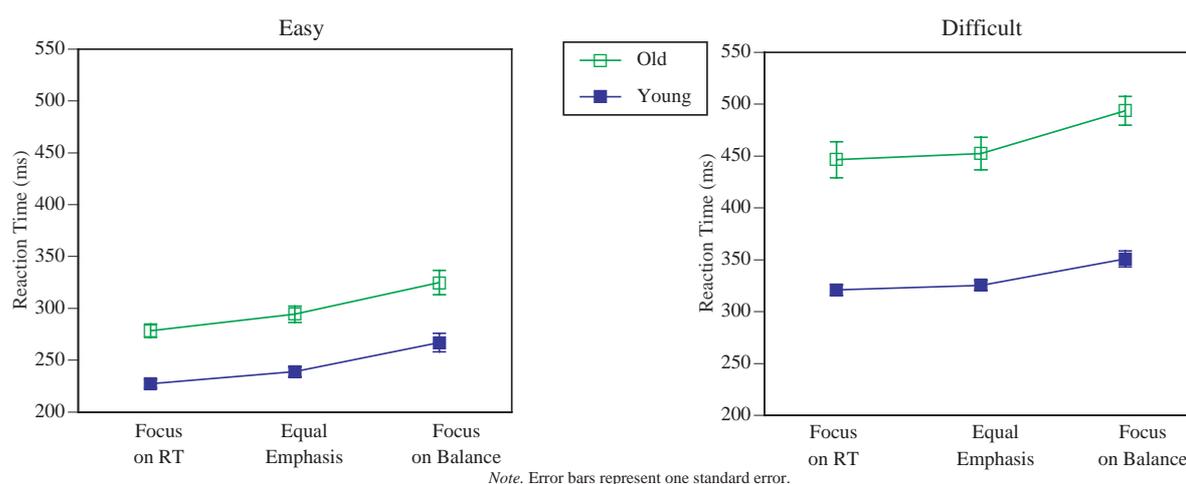


Figure 25. Sensitivity of reaction-time performance to instructional manipulation as a function of age group and difficulty

percentage of errors³⁷ revealed a main effect of age group, $F(1, 34) = 5.32$, $MSE = 66.54$, $p < .05$, $\eta^2 = .14$, indicating that, in all dual-task blocks, older adults made more errors than their younger counterparts. This main effect was qualified by two higher-order interactions: Age Group \times Instruction interaction, $F(1.50, 50.97) = 7.05$, $MSE = 34.31$, $p < .001$, $\eta^2 = .17$ and Age Group \times Difficulty interaction, $F(1, 34) = 5.26$, $MSE = 67.20$, $p < .05$, $\eta^2 = .13$. Table 12 and Figure 22 show that older adults committed more errors than young adults in the difficult condition. The contrast (a) that compares the performance of young and older participants under the instruction “Focus on Balance” with performance under the instruction “Equal Emphasis” was significant, $F(1, 34) = 7.15$, $MSE = 66.69$, $p = .01$, $\eta^2 = .17$, such that the age-group difference was especially pronounced under the instruction “Focus on Balance”. Moreover, this pattern was also found in the difficult condition. The contrast (a) specified on the Age Group \times Instruction \times Difficulty interaction reached significance, $F(1, 34) = 4.78$, $MSE = 25.55$, $p < .05$, $\eta^2 = .12$, indicating that the percentage of errors was higher in older adults under the instruction “Focus on Balance” particularly in the difficult condition³⁸.

Table 12. Means (SD) in Errors (%) as a Function of Sample, Difficulty, and Instruction

Sample	Easy			Difficult		
	Focus on RT	Equal Emphasis	Focus on Balance	Focus on RT	Equal Emphasis	Focus on Balance
<i>Young</i>	3.93 (3.77)	3.33 (3.22)	6.08 (5.08)	8.18 (5.61)	8.44 (9.47)	7.15 (4.05)
<i>Old</i>	3.47 (2.39)	5.10 (3.81)	10.39(8.10)	13.21(14.43)	12.54(8.91)	19.00(11.26)

³⁷ The description of dependent variables is given in Appendix F, Table F3. There was one univariate and one multivariate outlier. The normality assumption was partially violated. Evaluation of assumption of variance-covariance matrices was acceptable. The assumption of sphericity was violated for the factor instruction. The Mauchly’s test of sphericity was significant and the Greenhouse-Geisser estimate of the degree of sphericity was $\epsilon = .75$. Therefore, I reported Greenhouse-Geisser corrected significance level for this effect.

³⁸ As can be seen in Appendix F, Table F3, there were two outliers. In general, the analysis without outliers yielded similar results but for one exception: the a priori specified contrast (a) on the Age Group \times Instruction \times Difficulty interaction was not reliable, $F(1, 32) = 3.06$, $MSE = 13.49$, $p = .090$, $\eta^2 = .09$, $1 - \beta = .40$.

Note however the different pattern of correlations in young and older adults (see Table 13). It is conceivable that the found age-group differences in the accuracy of responses appeared because younger participants traded off speed for accuracy.

Table 13. *Correlations among RTs (ms) and Errors (%) as a Function of Sample, Difficulty, and Instruction*

Sample	Easy			Difficult		
	Focus on RT	Equal Emphasis	Focus on Balance	Focus on RT	Equal Emphasis	Focus on Balance
<i>Young</i>	-.74**	-.48*	.04	-.37	-.38	-.25
<i>Old</i>	.31	.67**	.75**	.46	.44	.58*

Note. * $p < .05$, ** $p < .01$.

The analysis of the type of errors³⁹ that were committed under the three instructions in the two-choice RT task revealed that, in general, older adults omitted more responses than young adults in the dual-task condition, $F(1, 34) = 64.23$, $MSE = 280.31$, $p < .0001$, $\eta^2 = .65$, (see left panel of Figure 26). However, as indicated by the significant contrast on the factor instruction, both age groups committed more “Time-Out” errors under the instruction “Focus on Balance” than under the instruction “Equal Emphasis”, $F(1, 34) = 4.54$, $MSE = 841.91$, $p < .05$, $\eta^2 = .12$, (see right panel of Figure 26). Neither the Age Group x Instruction interaction nor the two contrasts specified for this instruction reached significance, ($F = 1.07$, $1 - \beta = .23$; $F = 1.61$, $1 - \beta = .24$; $F < 1.0$, $1 - \beta = .05$).

The analysis of the balance data⁴⁰ revealed that with respect to age-group differences and interactions the results were similar to those found in the reaction times.

³⁹ The “Time-Out” errors under three instructions were analyzed with Age Group (2) x Instruction (3) repeated-measures ANOVA.

⁴⁰ In the data on balance performance, there were neither univariate nor multivariate outliers (see Appendix F, F1 – F2). Evaluations of assumptions of normality and homogeneity of variance-covariance matrices were acceptable. The assumption of sphericity was not violated. Thus, I reported results according to Wilks’ Lambda.

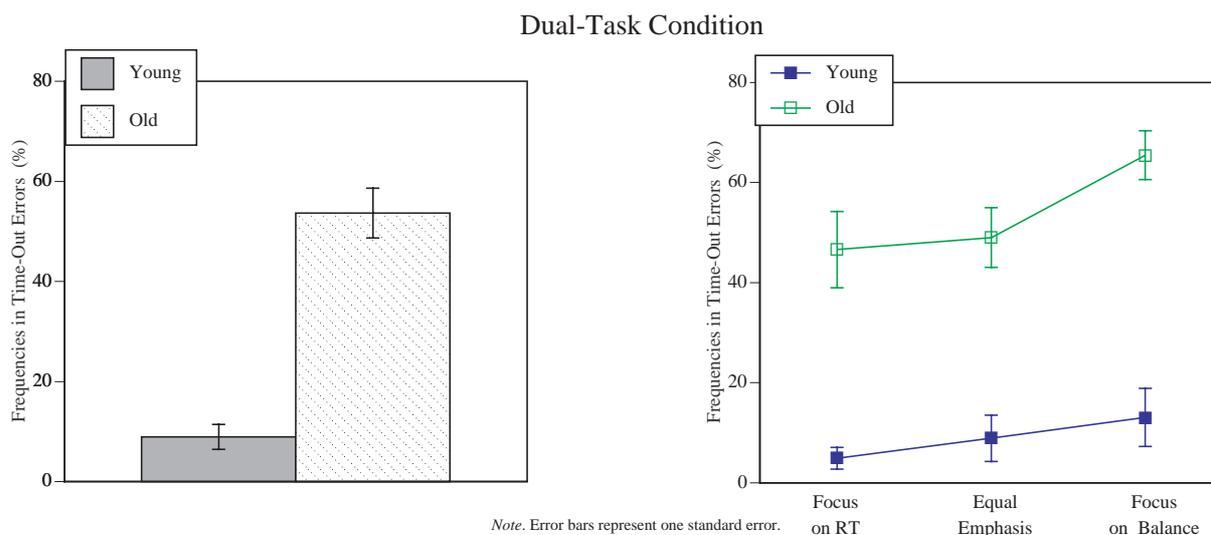


Figure 26. Age-group differences in frequencies of “time-out” errors in dual-task condition

A main effect of age-group was highly significant, $F(1, 34) = 80.78$, $MSE = 24.86$, $p < .0001$, $\eta^2 = .70$. However, neither the Age Group \times Instruction nor the Age Group \times Instruction \times Difficulty interaction reached significance, ($F < 1.0$, $1 - \beta = .07$; $F = 1.5$, $1 - \beta = .30$, respectively). The planned contrasts for the Age Group \times Instruction interaction were not significant, (both $F < 1.0$, $1 - \beta = .06$). Although contrast (a) for the Age Group \times Instruction \times Difficulty interaction was not statistically reliable, ($F < 1.0$, $1 - \beta = .06$), contrast (b) could be treated as marginally significant, $F(1, 34) = 3.08$, $MSE = 5.09$, $p = .088$, $\eta^2 = .08$, $1 - \beta = .40$. Figure 27 shows the results from the balance task. Older adults swayed more than young individuals in all dual-task blocks. In general, the performance of both age groups was similarly sensitive to the instructional manipulation. Although the ability to adjust one’s balance performance according to instructions seems to be limited, there was one condition in which a tendency to sway more under the instruction “Focus on RT” was found in young adults.

Taken together, the analyses of raw scores showed that neither in the RT task (at least in terms of reaction times) nor in the balance task the Age Group \times Instruction interaction was significant. That is, the experimental manipulation of instruction had a comparable influence on the performance of young and older adults in the reaction-time and in the balance task. This finding is contrary to my prediction (Hypothesis 2b-1).

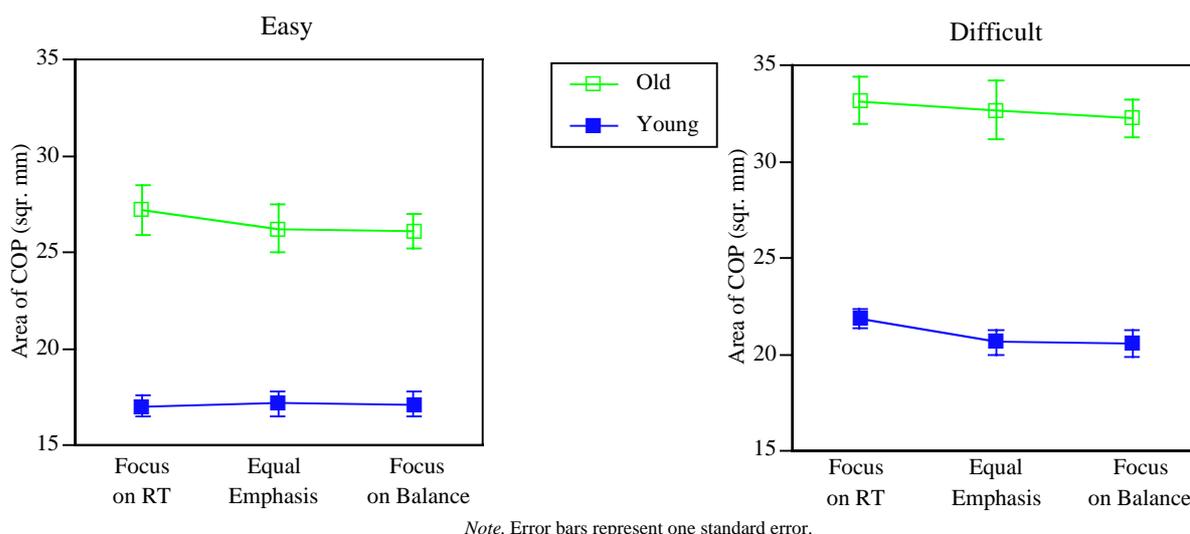


Figure 27. Sensitivity of balance performance to instructional manipulation as a function of age group and difficulty

However, the analyses of the percentage of errors and the type of errors committed under the differential emphasis instructions revealed age-group differences. These findings contribute to the interpretation of comparable abilities to follow the experimental instructions in young and older participants. Whereas young individuals adjusted their reaction times according to task-priority instructions while keeping the number of errors on average at the level of 4.45% in the easy condition and on the level of 7.92% in the difficult condition, older adults committed more errors in both difficulty conditions ($M = 6.32\%$, $M = 14.92\%$, respectively). Moreover, the “Time-Out” errors were more frequent in older than in younger adults in all dual-task blocks.

The lack of the significant Age Group \times Instruction \times Difficulty interactions suggests that both age groups were comparable in their ability to deliberately allocate resources in both difficulty conditions. However, their performance did differ in the balance domain after the task-difficulty manipulation: Young participants swayed more under the instruction “Focus on RT” than under the instruction “Focus on Balance” and “Equal Emphasis”. As expected, the balance performance of older adults was always on the same level regardless of instructions. Thus, on the level of raw scores the Hypothesis 2b-3 was partially confirmed. However, the conclusions about the differential influence of the task-emphasis instructions on the performance of young and older adults can be made only after taking into account the age-group differences in the baseline performance. That is why I tested the Hypotheses 2b-1 – 2b-3 on the level of proportional dual-task costs.

5.3.2.3 Analyses of Dual-Task Costs

The main purpose of this section was to find out whether the DTCs provided a parallel pattern of results the raw scores did with respect to age-group differences in the ability to adjust performance according to instructions. The proportional DTCs were submitted to Age Group (2) x Instruction (3) x Difficulty (2) repeated-measures ANOVA for each domain separately. The dependent variables are described in Appendix F, Table F4 – F5. The presentation of results is restricted to the age-group effects and interactions involving the age-group factor.

In the cognitive domain⁴¹, the main effect of age group was significant, $F(1, 34) = 6.02$, $MSE = 80.55$, $p < .05$, $\eta^2 = .15$. However, neither of the interactions involving the age-group factor reached significance, ($F < 1.0$), most probably because of the fairly low power (i.e., from .06 to .14) to detect these interactions. Figure 28 shows that older adults had higher dual-task costs in the cognitive domain. However, the DTCs of both age groups were comparably sensitive to the manipulation of instructions under both difficulty conditions. This finding is perfectly consistent with the results based on the raw scores.

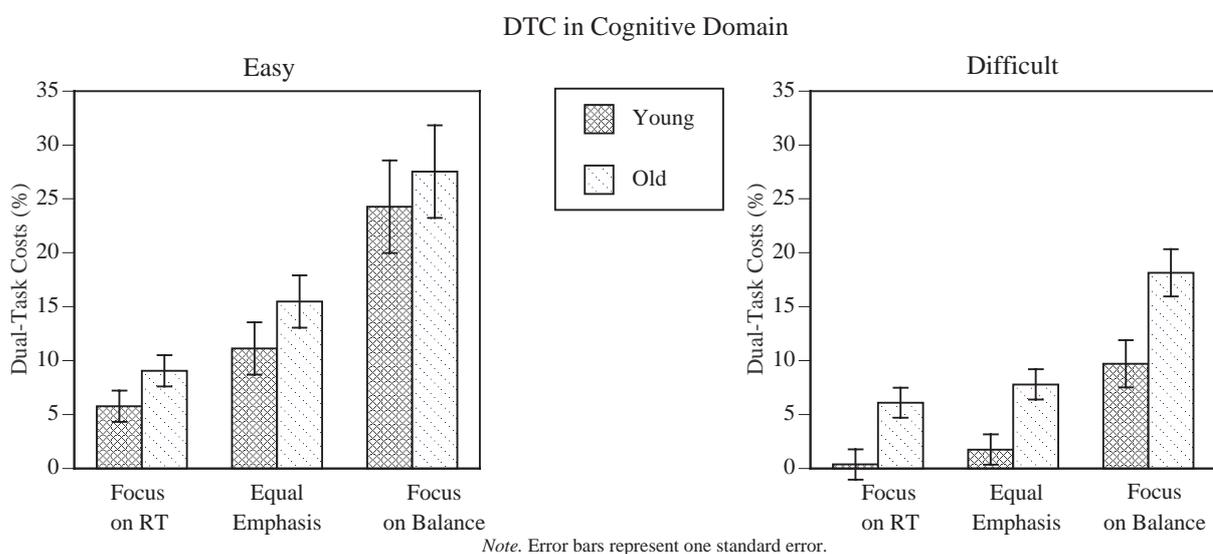


Figure 28. Sensitivity of dual-task costs to instructional manipulation in cognitive domain as a function of age group and difficulty

⁴¹ There were two univariate but no multivariate outliers. Thus, the dual-task costs were analyzed twice: with and without outliers. The analysis without outliers yielded similar results. Tests of normality, homogeneity of variance-covariance, and sphericity showed that these assumptions were slightly violated. The assumption of sphericity was violated for the factor instruction, and the Instruction x Difficulty interaction. The Greenhouse-Geisser estimates of the degree of sphericity were $\epsilon = .74$ and $\epsilon = .68$, respectively. Thus, I reported Greenhouse-Geisser corrected significance levels for these effects.

The lack of significant interactions might lead to the conclusion that, in terms of proportional costs older adults were as able as young individuals to adjust their cognitive performance to instructions. Moreover, the difficulty manipulation did not influence this ability differently in both age groups. However, two additional findings hamper the interpretability of these results. First, in the difficult condition under the instruction “Focus on RT” and “Equal Emphasis”, the DTCs of young participants were not different from zero, ($t(17) = .33, n. s.$; $t(17) = 2.02, p = .059$, respectively). This implies that, in the dual-task blocks under these two instructional conditions, the RT task was not attentionally demanding in the group of young adults. Second, young individuals had almost no DTCs in the percentage of correct responses (see Table 14)⁴². Thus, although in terms of interactions involving the age-group, instruction, and difficulty factors, the DTCs in the cognitive domain were comparably sensitive to the task-emphasis instructions in both age groups, marked age-related differences in the time-sharing efficiency were found, especially with the more difficult cognitive task (see also Figure 23 and 24).

Table 14. Means (SD) in Dual-Task Costs for Percentage of Correct Responses as a Function of Sample, Difficulty, and Instruction

Sample	Easy			Difficult		
	Focus on RT	Equal Emphasis	Focus on Balance	Focus on RT	Equal Emphasis	Focus on Balance
Total	1.85 (2.05)	2.36 (3.07)	6.47 (6.76)	2.79 (8.09)	2.37 (6.16)	5.13 (9.26)
Young	1.46 (1.83)	0.83 (1.72)	3.68 (3.75)	0.91 (2.42)	1.36 (7.25)	0.33 (3.86)
Old	2.23 (2.24)	3.90 (3.38)	9.27 (7.97)	4.68 (11.01)	3.38 (4.84)	10.59 (9.93)

Note. One-sample t tests revealed that, in older adults, the DTCs were different from zero in all conditions (from $p = .000$ to $p = .009$; alpha adjustment for six repeated analyses, $p < .008$), except for the instruction “Focus on RT” in the difficult task. In young adults, the DTCs were different from zero only in the easy condition under the instruction “Focus on Balance” and “Focus on RT” ($p = .001, p = .003$, respectively).

⁴² The DTCs in the percentage of correct responses are presented in Appendix F, Table F6. The data were submitted to an Age Group (2) x Instruction (3) x Difficulty (2) repeated-measures ANOVA that yielded a main effect of age group, $F(1, 34) = 13.84, MSE = 24.67, p = .001, \eta^2 = .29$, and an Age Group x Instruction interaction, $F(1.59, 53.97) = 6.61, MSE = 39.09, p < .001, \eta^2 = .16$. The a priori specified contrast (a) revealed that older adults, in comparison to their younger counterparts, had higher DTCs under the instruction “Focus on Balance” than under the instruction “Equal Emphasis”, $F(1, 34) = 7.20, MSE = 81.21, p < .01, \eta^2 = .18$. The analysis without outliers yielded similar results.

In the balance domain⁴³, a main effect of age group was significant, $F(1, 34) = 7.19$, $MSE = 192.78$, $p < .01$, $\eta^2 = .18$. Neither of the interactions involving the age-group factor reached significance: Age Group x Instruction, ($F < 1.0$, $1 - \beta = .05$), Age Group x Instruction x Difficulty, ($F = 1.89$, $1 - \beta = .33$). The analysis without outliers yielded similar results. Figure 29 shows that older adults had higher dual-task costs. The lack of significant interactions suggests that, similar to the raw scores, the DTCs of younger and older participants were comparably sensitive to the manipulation of instructions under both difficulty conditions. Although generally the difficulty manipulation did not influence this ability differently in both age groups, one of the a priori specified contrasts (“Focus on RT” versus “Equal Emphasis”) for the three-way interaction involving the age-group, instruction, and difficulty factors was marginally significant, $F(1, 34) = 3.80$, $MSE = 334.74$, $p = .060$, $\eta^2 = .10$, $1 - \beta = .47$. In order to understand the source of this trend, I conducted an Instruction (3) x Difficulty (2) ANOVA separately for each age group. In older adults, neither the Instruction x Difficulty interaction nor the a priori specified contrasts for this interaction were significant, ($F < 1.0$, $1 - \beta$ ranged from .06 to .10). The analysis of the DTCs in young adults revealed that the Instruction x Difficulty interaction was not significant, ($F = 1.91$, $1 - \beta = .36$). However, the contrast comparing the DTCs under the instructions “Focus on RT” and “Equal Emphasis” was marginally significant, $F(1, 17) = 3.64$, $MSE = 113.95$, $p = .073$, $\eta^2 = .18$, $1 - \beta = .44$.

Figure 29 shows that, in the difficult condition, the DTCs were higher under the instruction “Focus on RT” than under the instruction “Equal Emphasis”. Although graphically it appears as though the dual-task costs in older adults were partially sensitive to the instructional manipulation, statistically instructions had some effect only on the DTCs in young adults. Note, however, that similar to the findings in the cognitive domain, the group of younger participants had zero and negative DTCs in the balance domain when the tasks were difficult. Thus, the young group had almost perfect time-sharing, with performance from both tasks close to their single-task performance (see also Figure 23).

⁴³ The normality assumption was partially violated. Tests of homogeneity of variance-covariance and sphericity provided satisfactory results. I reported significance according to Wilks’ Lambda. There were two univariate but no multivariate outliers. Thus, the dual-task costs were analyzed twice: with and without outliers.

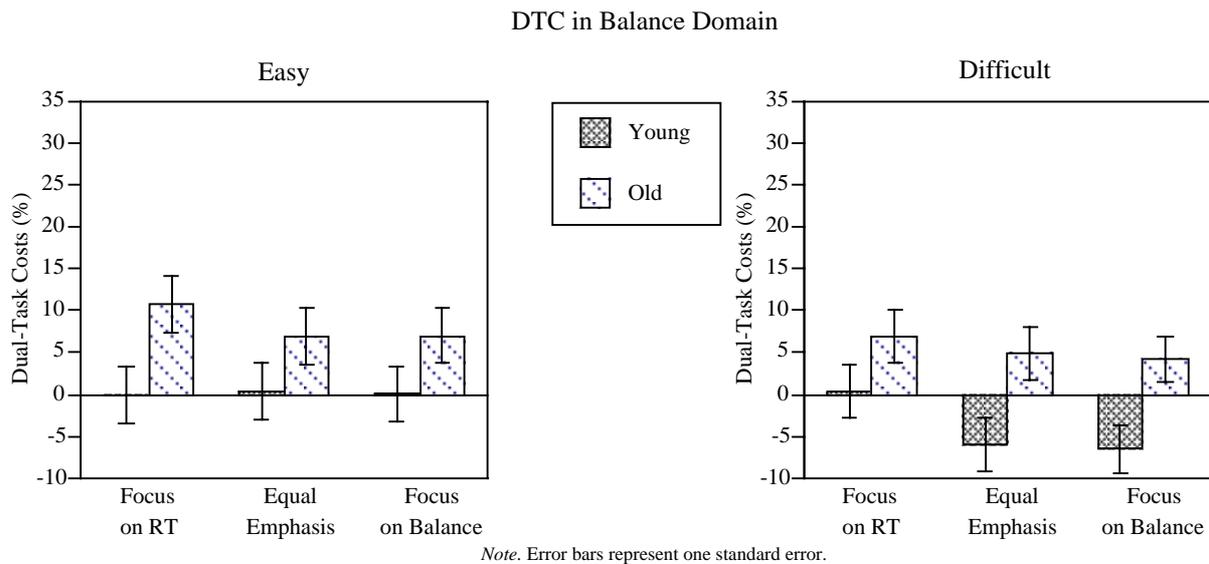


Figure 29. Sensitivity of dual-task costs to instructional manipulation in balance domain as a function of age group and difficulty

Taken together, with respect to age-related predictions (Hypotheses 2b-1 to 2b-3) the pattern of results based on the dual-task costs was parallel to the pattern found on the level of raw scores. The proportional DTCs of both age groups were comparably sensitive to the instructional manipulation in the cognitive domain under the easy and difficult conditions. In the balance domain, there was a strong trend indicating that young adults tried to adjust their balance performance according to the task-emphasis instructions particularly under the instruction “Focus on RT”. In general, the results are contrary to the Hypotheses 2b-1 and 2b-2, but partially confirm the Hypothesis 2b-3.

A twofold possibility remains, however, that the instructions had larger influence on the performance of young than older adults. First, difference in the DTCs under the two emphasis instructions could be more pronounced in young than in older individuals. Second, young subsample could change performance to a larger extent under the emphasis instructions “Focus on Balance” and “Focus on RT” in comparison to the standard instruction of “Equal Emphasis”. To rule out these possibilities, two new indicators were computed and the age-group differences were analyzed. The results of these analyses are presented in the next section.

5.3.2.4 Additional Analyses

In order to test whether differences in the DTCs under two emphasis instructions were more pronounced in young than in older adults, a new measure (i.e., “spread”) was derived separately for each domain according to:

$$[\text{DTCs under “Focus on Balance”} - \text{DTCs under “Focus on RT”}].$$

These data were then submitted to an Age Group (2) x Domain (2) x Difficulty (2) repeated-measures analysis of variance⁴⁴. Neither a between-subjects effect of age group, nor interactions involving the age-group factor were significant: for age group, ($F < 1.0$, $1 - \beta = .06$), for the Age Group x Domain interaction, ($F < 1.0$, $1 - \beta = .06$), for the Age Group x Difficulty interaction, ($F = 2.08$, $1 - \beta = .29$), for the Age Group x Domain x Difficulty interaction, ($F < 1.0$, $1 - \beta = .10$)⁴⁵. Thus, in terms of the amount of difference between the DTCs under the instruction “Focus on Balance” and “Focus on RT” the young and older adults did not differ.

It is possible, however, that the dual-task metric is too conservative to uncover the age-related differences in the performance under the two emphasis instructions. That is why I conducted an analysis in which performance under the standard instruction “Equal Emphasis” was taken as a baseline level for the performance under the two differential emphasis instructions: “Focus on Balance” and “Focus on RT”. A new measure was derived according to:

$$[(\text{Focus on Balance} - \text{Equal Emphasis}) / \text{Equal Emphasis}] \times 100\%$$

$$[(\text{Focus on RT} - \text{Equal Emphasis}) / \text{Equal Emphasis}] \times 100\%.$$

This measure reflected a percentage of change in individuals’ performance under the task-priority instructions relative to their performance under the standard instruction. These data were then submitted to an Age Group (2) x Emphasis (2) x Domain (2) x Difficulty (2)

⁴⁴ The dependent variables are described in Appendix G, Table G1. There were neither univariate nor multivariate outliers. Evaluations of assumptions of normality, homogeneity of variance-covariance matrices, and sphericity were acceptable. Thus, I reported significance levels according to Wilks’ Lambda.

⁴⁵ The main effects of domain and difficulty were significant, $F(1, 34) = 38.75$, $MSE = 297.52$, $p < .0001$, $\eta^2 = .53$; $F(1, 34) = 8.24$, $MSE = 124.86$, $p < .01$, $\eta^2 = .20$, respectively. The Domain x Difficulty interaction did not reach significance, $F = 1.51$, $1 - \beta = .22$. The difference in DTCs under the two task-emphasis instructions was larger in the cognitive (14.60%) than in the balance domain (3.30%), and in the easy (8.32%) than in the difficult condition (2.98%).

repeated-measures analysis of variance⁴⁶. When reporting the results, I focused only on the main effect of age group and the interactions involving the age-group factor, as the age-group differences were of primary interest.

Neither the between-subjects effect of age group nor interactions involving the age-group and emphasis factors reached significance: for age group, ($F < 1.0$, $1 - \beta = .05$); for the Age Group \times Emphasis interaction, ($F < 1.0$, $1 - \beta = .06$); for the Age Group \times Emphasis \times Difficulty interaction, ($F = 2.17$, $1 - \beta = .30$); for the Age Group \times Emphasis \times Domain interaction, ($F < 1.0$, $1 - \beta = .05$); for the Age Group \times Emphasis \times Domain \times Difficulty interaction, ($F < 1.0$, $1 - \beta = .13$)⁴⁷. The means are presented in Figure 30. For the reasons of better graphical illustration, plus and minus signs of mean values were reversed. Thus, the positive values mean increase in performance, whereas negative values indicate decrease in performance. It can be seen that generally the study participants followed the differential emphasis instructions more in the cognitive than in the balance domain, and under the easy than under the difficult condition. With respect to age-related differences, both young and older adults changed their performance under the two emphasis instructions relative to the standard instruction to a similar degree. However, the inspection of Figure 30 (see right panel) reveals that, in the easy condition, the balance performance of older adults slightly decreased under the instruction “Focus on RT”. In the difficult condition, the decrement was quite pronounced in younger adults. Although statistically not reliable, this age-group differential pattern is in line with findings based on the raw scores and DTCs. That is, under the instruction “Focus on RT” older adults showed a slight tendency to sway more in the easy condition. In young participants, this trend was more pronounced in the difficult condition.

⁴⁶ The dependent variables are described in Appendix H, Table H1 and H2. The normality assumption was partially violated. Evaluations of assumptions of homogeneity of variance-covariance matrices and sphericity were acceptable. I reported significance levels according to Wilks' Lambda. As there were outliers (three univariate but no multivariate), the data were analyzed twice: with and without outliers. The analysis without outliers did not change the pattern of results.

⁴⁷ The main effect of emphasis was highly significant, $F(1, 34) = 19.66$, $MSE = 90.10$, $p < .0001$, $\eta^2 = .37$. Moreover, it was qualified by two higher-order interactions. The Emphasis \times Difficulty interaction, $F(1, 34) = 5.83$, $MSE = 407.63$, $p < .05$, $\eta^2 = .15$, such that percentage of change in individuals' performance under the instruction “Focus on Balance” was larger than under the instruction “Focus on RT” in the easy than in the difficult condition. The significant Emphasis \times Domain interaction, $F(1, 34) = 37.29$, $MSE = 124.64$, $p < .0001$, $\eta^2 = .52$, indicates that the change was larger under the instruction “Focus on Balance” than under the instruction “Focus on RT” in the cognitive domain (for means see Appendix H and Figure 30). The analysis without outliers revealed that the Emphasis \times Difficulty interaction did not reach significance, $F(1, 31) = 3.90$, $MSE = 65.86$, $p = .057$, $\eta^2 = .11$, $1 - \beta = .48$.

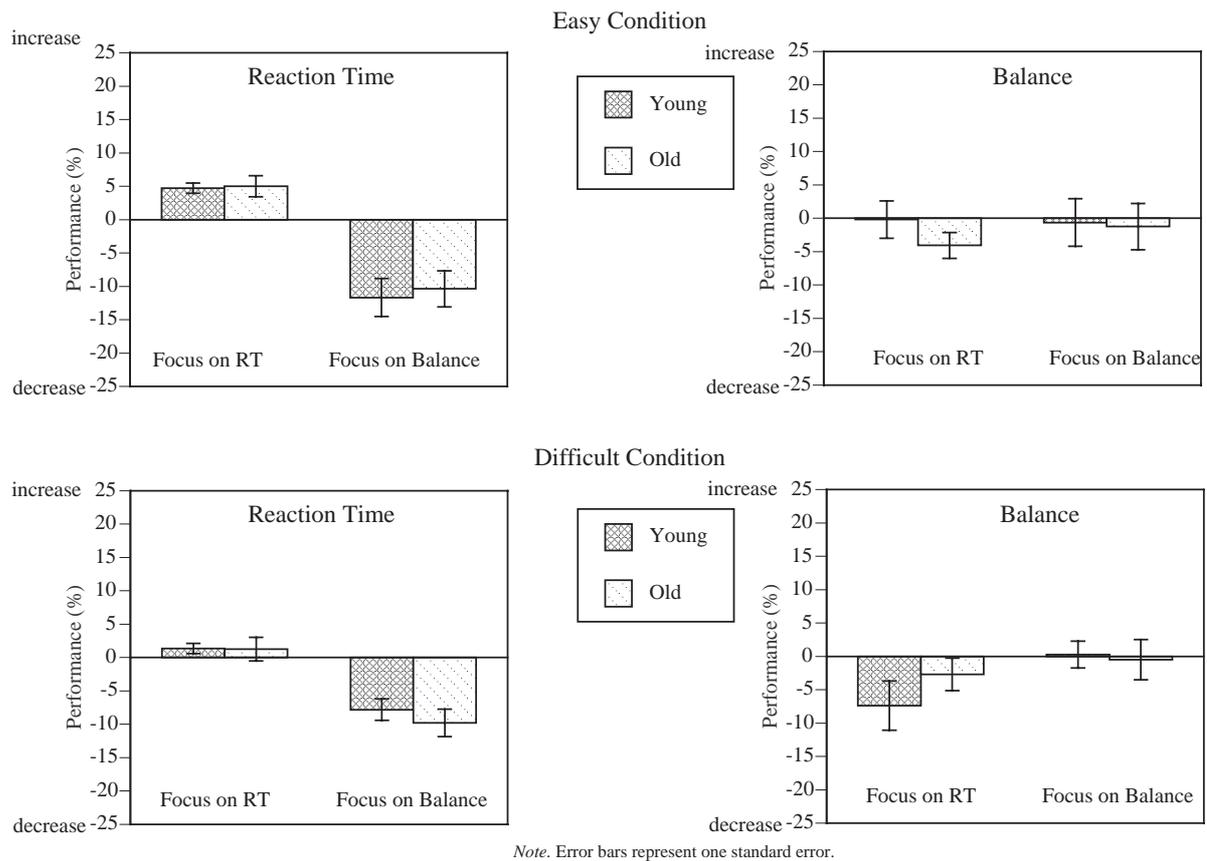


Figure 30. Performance under emphasis instructions relative to “Equal Emphasis” as a function of age group, difficulty, and domain

In sum, the analyses of two additional indicators (i.e., difference in the amount of DTCs under the two emphasis instructions and individuals’ performance under emphasis instructions relative to their performance under the standard instruction) confirm the results of the previous analyses with respect to the influence of instructional manipulation on performance. These data lend additional support to the finding that, in the cognitive domain, older and younger adults were comparable at using instructions to vary their processing priorities between the two tasks. In the balance domain, some mismatch between the performance scores and the instructions was found. Numerically, this mismatch was larger in older than in younger adults, especially in the difficult condition.

5.3.3 Summary: Deliberate Control of Resource Allocation and Age-Related Differences

With respect to deliberate control of resource allocation, the findings of the present study generally suggest that, in the dual-task situation involving the RT task and the balance task, individuals are able to adjust their performance according to task-priority instructions, that is, to deliberately control their resource allocation. As expected, the poorest performance was observed in the component task from which attention was distracted, and the best performance was in the task to which attention was allocated. Thus, the Hypothesis 2a-1 was confirmed. The adjustment of performance was more pronounced in the cognitive than in the sensorimotor domain and in the easy than in the difficult condition. These results are in line with Hypothesis 2a-2 and 2a-3. Analyses provided parallel results on the level of raw scores and dual-task costs.

With respect to age-related differences in the ability to deliberately control the resource allocation, the lack of the expected interactions suggests that both age groups were comparable in this ability. According to this pattern of findings the Hypotheses 2b-1 – 2b-2 should be rejected. Note, however, that in the cognitive domain young and older adults performed on different accuracy levels and older adults made more “Time Out” errors in the demanding RT task. In the balance domain, younger but not older adults showed a consistent (i.e., based on raw scores and DTCs) tendency to follow the instruction “Focus on RT” and to sway more under this instruction. This finding partially confirms the Hypothesis 2b-3. Moreover, the age groups differed in the time-sharing ability. Whereas young adults had minimal dual-task costs in the difficult condition, the cognitive performance of older adults was resource demanding as indicated by substantial DTCs in all instructional conditions. Similarly, young individuals could perfectly time-share the demands of the concurrent tasks showing no dual-task costs in the balance domain. In the group of older adults, stable dual-task costs in the balance domain imply that sensorimotor performance was resource demanding.

Table 15 provides an overview of the research hypotheses and results.

Table 15. *Summary of Hypotheses and Results*

Hypotheses	Supported by Results?	
	Cognitive Domain	Balance Domain
I. How Do Individuals Allocate Resources in Dual-Task Situations?		
<i>1a: Domain-Specific Asymmetry in Resource Allocation^a</i>		
<i>Level of Raw Scores</i>		
1a-1 In both the RT task and the balance task, young and older adults perform at a lower level in dual- than in single-task situations (main effect of Task).	Yes	Yes
1a-2 In both the RT task and the balance task, young and older adults perform at a lower level on a difficult than on an easy task (main effect of Difficulty).	Yes	Yes
1a-3 In both the RT task and the balance task, the performance of both young and older adults is at a lower level in a dual-task situation when the tasks are difficult (Task x Difficulty Interaction).	No	No
<i>Level of Dual-Task Costs</i>		
1a-4 Dual-task costs in young and older adults are higher in the cognitive than in the balance domain (main effect of Domain).		Yes
1a-5 This domain-specific asymmetry is more pronounced in the difficult condition (Domain x Difficulty Interaction).		No
<i>1b: Age-Related Differences^b</i>		
<i>Level of Raw Scores</i>		
1b-1 In both the RT task and the balance task, older adults perform at a lower level than younger adults do in both single- and dual-task situations (main effect of Age Group).	Yes	Yes
1b-2 These age-related differences are more pronounced in the difficult than in the easy tasks (Age Group x Difficulty Interaction).	Yes	Yes
1b-3 These age-related differences are more pronounced in the dual-task than in the single-task situations (Age Group x Task Interaction).	Yes	Yes
1b-4 These age-related differences are even more pronounced in the dual-task than in the single-task situations when the tasks are made more difficult (Age Group x Task x Difficulty Interaction).	No	No

(Table continues)

Table 15 (continued)

Hypotheses	Supported by Results?	
	Cognitive Domain	Balance Domain
<i>Level of Dual-Task Costs</i>		
1b-3 Dual-task costs are larger in older than in younger adults (main effect of Age Group).		Yes
1b-4 These age-related differences are more pronounced in the cognitive than in the balance domain (Age Group x Domain Interaction).		No
1b-5 These age-related differences are more pronounced in the cognitive than in the balance domain when the tasks are made more difficult (Age Group x Domain x Difficulty Interaction).		No
II. Can Individuals Deliberately Control Resource Allocation?		
<i>2a: Experimental Manipulation of Instruction and Difficulty in the Cognitive and Balance Domains^c</i>		
2a-1 Individuals can adjust their performance in the RT and the balance task according to the differential emphasis in the instructions (main effect of Instruction). This means that the poorest performance is in the task from which resources are distracted, and the best performance is in the task to which resources are directed. Under the instruction “Equal Emphasis”, the performance is on an intermediate level (a priori defined contrasts for the factor Instruction).		Yes
2a-2 Individuals can adjust their performance according to the differential emphasis in the instructions better when tasks are easy than when tasks are difficult (Instruction x Difficulty Interaction) ^d .		Yes
2a-3 Individuals can adjust their performance according to the differential emphasis in the instructions better in the cognitive than in the balance domain (Instruction x Domain Interaction).		Yes
<i>2b: Age-Related Differences^e</i>		
2b-1 In comparison to older adults, younger adults can better adjust their performance according to the differential emphasis in the instructions (Age Group x Instruction Interaction).		No
2b-2 These age-related differences are more pronounced with the difficult tasks than with the easy tasks (Age Group x Instruction x Difficulty Interaction).		No
2b-3 These age-related differences are more pronounced in the balance domain (Age Group x Instruction x Domain Interaction).		Partially

Note. Empirical findings for each set of hypotheses are presented graphically: ^a See Figure 9 – 10; ^b See Figure 11 – 13; ^c See Figure 16 – 19; ^d On the level of raw scores, the Hypothesis 2a-1 was confirmed in the cognitive domain and partially confirmed in the balance domain; the Hypothesis 2a-2 was confirmed only in the cognitive domain. ^e See Figure 21, 23, 25, 27 – 29.

