6. DISCUSSION

The main purpose of this study was the investigation of resource allocation in a dual-task situation involving a sensorimotor and a cognitive task. Specifically, the aim of the current research was to determine whether young and older adults can deliberately allocate their mental resources, that is, to adjust their performance to task-priority instructions.

Planning this study, the intention was to specifically consider the methodological problems known from the available research on sensorimotor aging and dual-task performance. Two major contributions of this study are of special importance: First, the dual-task performance was measured under three emphasis instructions and thus independent of resource allocation strategies. Second, the study consisted of a practice and a test phase, that is, the participants were provided with considerable amount of practice in both tasks performed separately and concurrently, then, the performance of a more stable system was measured. To circumvent other methodological limitations discussed in the literature on aging and divided attention, the baseline level for the cognitive and balance performances was assessed; the task difficulty was manipulated; and the age-related divided attention effects were examined relative to each age group’s performance under single-task conditions (i.e., in terms of proportional dual-task costs).

6.1 Major Findings and Interpretations

In the present study, the following research questions were asked: Within a dual-task situation involving a cognitive and a balance task, how do individuals allocate their mental resources? Are there differences in resource allocation by age group and domain? Can individuals deliberately allocate their resources? If resource allocation is under individuals’ control, are there differences by domain, difficulty level, and age group? The data of this study strongly suggest that: (a) there is an age-related deficit in concurrent performance of a sensorimotor and a cognitive task beyond that of a general decline; (b) there is a domain-specific asymmetry in resource allocation, that is, individuals invest more resources into the sensorimotor than into the cognitive domain; (c) individuals are able to deliberately allocate their mental resources, however, their cognitive performance is more under control than their sensorimotor performance and this control is reduced when resource limitations are more pronounced; and (d) older adults prioritize a sensorimotor component of a dual-task situation. Evidence supporting these suggestions is reviewed and discussed according to two main issues: domain-specific resource allocation and its control, and age-related differences in resource allocation.

6.1.1 Evidence Supporting Domain-Specific Resource Allocation and Its Control

One of the central findings of this study confirmed previous results by showing that when a sensorimotor task is paired with a cognitive task and participants are instructed to perform both tasks equally well (i.e., under the instruction “Equal Emphasis”) performance is reduced markedly. This reduction is more pronounced in the cognitive than in the sensorimotor domain (Figure 10). Thus, the dual-task condition, as compared to the single-task condition, reduced the RT task performance, in terms of speed, more than the balance task performance as indicated by higher DTCs (9.04% versus 1.54%, respectively). Contrary to the prediction, this asymmetry was not more pronounced in the difficult than in the easy condition, the general pattern of larger DTCs in the cognitive than in the balance domain was present on both difficulty levels.

The finding of domain-specific asymmetry may have two implications. First, the study participants could not follow the instruction to perform both tasks equally well and arbitrarily allocated more resources to the balance task, thus keeping its performance on a higher level. Second, it is possible that the study participants performed better on the balance task because this task was more relevant to them. If the first possibility is true, one can assume that individuals’ performance is generally insensitive to experimental conditions that manipulate instructions. If the latter possibility is true, the balance performance should be on a higher level than the cognitive performance even if participants are induced to focus primarily on the cognitive task and thus to “sacrifice” their stability. In order to find out which of the two possibilities is true, the differential emphasis instructions were introduced to the study design. In the dual-task blocks, the adults were instructed to vary their relative emphasis given to each of the two simultaneous tasks according to three instructions (i.e., “Focus on RT”, “Focus on Balance”, and “Equal Emphasis”).

The findings based on the RT data rule out the possibility that individuals’ performance is insensitive to instructions and thus confirm one of the hypotheses that task-priority instructions have influence on performance of experimental tasks. For the RT task performance, greater emphasis on the RT task was associated with faster RTs (or smaller DTCs). Greater emphasis on the balance task was associated with slower RTs (or larger

DTCs). Additionally, this study demonstrated that the RT performance was differently sensitive to instructions in the easy and difficult conditions: In the easy condition, the RTs and DTCs under the instruction “Equal Emphasis” were on the intermediate level in comparison to the two other instructional conditions suggesting that individuals can perfectly adjust their reaction times to the experimental requirements if a task is not very demanding. However, with a more challenging task, like in the difficult condition of this study, the RTs and DTCs were comparable under the instruction “Focus on RT” and “Equal Emphasis”. This finding indicates that the individuals’ ability to adjust the reaction times to instructions is reduced when the available resources are not sufficient to meet the task requirements.

The findings based on the balance task data suggest that the second possibility is true. Most probably, the balance task is more relevant for individuals than the cognitive task because of its “survival” value. The finding that the manipulation of instructions hardly influenced the amount of sway (Figure 18) proposes that individuals set their own priorities (i.e., not to fall) and do not change them even if they are induced to do so. Specifically, only the greater emphasis on the RT task was associated with slightly larger areas of COP movement (or larger DTCs). The study participants swayed, however, to a comparable extent under the two other instructions. This pattern of results was present in both difficulty conditions.

Taken together, the influence of the task-priority instructions was larger in the cognitive than in the balance domain. Thus the pattern of domain-specific asymmetry was found under the instruction “Equal Emphasis” and further confirmed by the finding that the larger dual-task performance decrement in the cognitive than in the balance domain was observed under all instructional conditions (Figure 19). This finding suggests that although the study participants were asked to emphasize either the one or the other component of the dual task, they always emphasized the balance task to a greater extent as indicated by the smaller DTCs in the balance domain. Note, however, that under the instruction “Focus on RT” the dual-task costs in both domains were comparable. This result might imply that the study participants equally emphasized both tasks not under the instruction “Equal Emphasis” but in the situation, in which they were required to prioritize their cognitive performance. The general pattern of resource allocation under all instructional conditions was taken to mean that mental resources were always protected for balance performance.

Within the metatheoretical framework of the SOC-model, the findings on domain-specific asymmetry demonstrate that when individuals experience resource limitations they are pressurized to select those domains that are more relevant to them. Because motor control, as a prerequisite for almost all other activities, is of great importance, and because goals (instructions) are likely to operate as motivators only when there is a reasonable expectation that higher efforts will result in gains (cf., Bandura, 1989), individuals are not ready to risk their stability and, therefore, restructure the goal hierarchy imposed by the experimental conditions. As human beings are able to anticipate losses and are motivated to avoid them, they select the sensorimotor domain in a dual-task situation and invest more resources into it. In terms of SOC, this strategy is defined as loss-based selection.

In order to test the research predictions of the present study, experimental tools (i.e., the dual-task paradigm and the task-emphasis technique) as well as the theoretical rationales underlying them were adopted from the resource theories. From the perspective of the resource theories, disruption is inevitable if resources are insufficient to meet the demands placed on them by, for example, two tasks. As performance of a difficult task requires more resources, which are limited, the amount of disruption suffered by either task should be larger if the tasks demands are higher. Additionally, the amount of disruption is affected by the ways in which the available resources are allocated. The more resources are allocated to one component of the dual-task, the less are left for the other component. The extent to which this linear exchange works depends on how demanding the tasks are (i.e., less linearity should take place in more difficult task combinations). Can the study results be clearly understood in terms of resource theories? The finding that performance of both tasks was worse in the dual- than in the single-task conditions and the amount of dual-task interference was larger in one (cognitive) than in the other (balance) task is in line with the resource theories predictions. The fact that, in the present experiment, the dual-task performance was sensitive to the task-emphasis instructions and that this sensitivity was reduced in the difficult condition additionally supports the viability of the hypothetical resource construct in explaining dual-task performance. Nevertheless, the data of the present study are not supportive of the hypothesis that dual-task interference is larger under more resource-demanding conditions and that there is a linear exchange of resources between two tasks. Why? It is possible that some methodological limitations of the present study prevented the expected results to be found. On the other hand, the possibility remains that the results of the current research could also be explained by alternative accounts. The next section addresses the issue of alternative interpretations. Methodological limitations are considered later.

6.1.1.1 Alternative Interpretations

The domain-specific pattern of interference and trade-offs (i.e., improving the performance of one task at the expense of the performance of the other concurrent task), which were found in the present study, might be alternatively explained within the framework of the multiple resource approach (e.g., Gopher, Brickner, & Navon, 1982; Navon, & Gopher, 1979; Wickens, 1984). The multiple resource models predict that the amount of resource competition between tasks should decrease as the resource overlap or structural similarity between the tasks decreases. In other words, dual-task costs are expected to decrease as the component tasks utilize increasingly different types of resources. Wickens (1984) defines resources by stages of processing (perceptual versus response processing), codes of processing (spatial versus verbal processing), and input and output modalities (visual versus auditory and manual versus speech processing). There should be, for example, less or no interference if a dual task comprises cognitive tasks that are based on the visual and auditory processing. The second central prediction of these models is that greater resource allocation or performance trade-offs should be possible with increased resource overlap between the two tasks.

Based on these assumptions, it is conceivable that the performance of the balance task was hardly affected by the dual-task and instructional requirements because it tapped resources that were not relevant to the RT task. This explanation seems reasonable because, for example, the performance decrement in the cognitive domain under the instruction “Focus on Balance” did not result in the better performance in the balance domain. This pattern of results proposes that individuals’ resources were hardly interchangeable between the two component tasks. As a result, the resources released from the cognitive task were not used to improve the performance of the balance task. In the cognitive research, there is empirical evidence that demonstrates differential degree of trade-offs depending on the resource overlap between the time-shared tasks. Using a memory task and a tracking task within different dual-task combinations and varying the input modality (visual versus auditory), Tsang, Velazquez, and Vidulich (1996) found that significant trade-offs were consistently observed for the condition in which two visual tracking tasks were combined. This finding is highly supportive of the multiple resource view. The question arises whether there are task combinations within the cognitive and sensorimotor domains that can be characterized as structurally similar. Because the balance system relies on the visual input to a great extent, a higher degree of structural similarity and resource overlap between tasks could be achieved through combining the balance task with a cognitive task that requires processing of visual information. Including task pairs with different degrees of shared resources might be helpful in finding out whether the balance task performance did not increase or decrease as the relative priority of this task changed because of the structurally dissimilar cognitive component of the dual task.

Within the resource theories, the observed performance trade-offs appear because of the scarcity of resources and inability to maximize joint performance of two tasks. Trade-offs are considered to be a demonstration of allocation control, which is one of the defining properties of resources. Alternatively, however, trade-offs may mean nothing more than the individuals complying with demand characteristics (Navon, 1984). This interpretation seems unlikely, however, because it is not clear why participants could meet the instructional demands in the cognitive domain, that is, could adjust their performance according to task-priority instructions, but not in the balance domain. What is behind this kind of “selectivity”? The present study suggests that the natural tendency of human beings to avoid losses (falls) restricts their flexibility in the balance domain. However, to rule out the possibility that individuals vary their performance according to task-priority instructions because they are expected to, future research may adopt an optimum-maximum method proposed by Navon (1984). Within this method, a performance level is designated for only one of the dual tasks. Participants are instructed to perform at precisely the designated level for the optimized task while performing their best for the concurrent maximized task. Several levels of performance of the optimized task can be specified to obtain several levels of joint performance. Using the optimum-maximum method in combination with the task-priority instructions, Tsang and colleagues (Tsang & Shaner, 1998; Tsang, Velazquez, & Vidulich, 1996) could demonstrate various degrees of trade-offs in the cognitive domain. It is an open question whether the more precise optimum-maximum method of measuring the ability to deliberately allocate resources can induce individuals to risk their body’s equilibrium.

The finding that the present study participants could better control their cognitive than their balance performance might alternatively suggest that not all resource-demanding operations are under cognitive control (cf. Anderson, Craik, & Naveh-Benjamin, 1998) or that the processes involved in the performance of the RT task are controlled, whereas the processes involved in the balance task have a substantial automatic component. The notion that the DTCs in the balance domain were small and statistically not different from zero lends support to this argument. On the other hand, there was a clear difference in the dual-task balance performance of the two age groups. This finding leads to a speculation that the pattern of results found in this study might rest on different reasons for young and older adults.

An alternative explanation for the domain-specific asymmetry in resource allocation and reduced ability to deliberately control the balance performance might be the problem of maintaining “minimal control levels” (Gopher, 1993). Gopher argues that it is not easy to release resources for the performance of another high-priority task, while still maintaining minimal control over the low-priority task. Moreover, this phenomenon can be equally powerful in difficult and easy tasks. Therefore, much training efforts are needed to teach individuals to relax and release attention. Although this explanation seems plausible, it remains to be explained why, in the present study, the balance performance remained on almost the same level through all instructional conditions, whereas the RT performance changed according to instructions. One possibility is that two sessions of dual-task assessment under the task-priority instructions in each difficulty condition were enough for individuals to improve their resource-management skills relevant for the performance of the cognitive but not the balance task. Although the interaction involving the assessment, instruction, and domain factors was not significant, there were hints of training effects on the ability to deliberately control the cognitive performance. For example, in the first dual-task session of the easy condition, the study participants could not differently adjust their RTs according to instruction “Focus on RT” and “Equal Emphasis”. This was, however, possible in the second dual-task session. It is an intriguing question for future research whether a longer and differently scheduled training program could provide individuals with skills that are necessary for deliberate control of their sensorimotor performance.

Finally, one might argue that attributing the dual-task interference and the domain-specific asymmetrical pattern in this interference to limited capacity or general resources might be premature, because only serial but not parallel processing of dual tasks takes place. The so-called bottleneck models propose that, as a result of serial processing, the observed performance trade-offs could emerge due to “switching” between the component tasks. It is conceivable that study participants spent different amount of time processing the tasks according to priority levels. Very rapid switching would be difficult to distinguish from resource allocation. Pashler (1994) argues, for example, that DTCs and trade-offs may arise simply because individuals control the amount of time during which each task has access to the bottleneck mechanisms. Based on this point of view, one might argue that the study participants allotted more time to the balance task and thus performed it on the higher level than the RT task. The question arises then why did they choose the balance but not the cognitive task to spend more time on. The present study suggests that individuals "protect" their resources, even if they are defined as time, for the balance task at the expense of the cognitive task because the balance task has an obvious subjectively relevant criterion, that is, not to fall. However, by using aggregate measures (i.e., averaged RTs and area of COP movement), the present experiment did not control for the microstructure of dual-task processing strategies.

Because there were many operations to be carried out during dual-task trials and because the duration of an operation and the ordering of operations may change from trial to trial, it would be interesting to investigate the time course of dual-task processing systematically (see Appendix I, for an example). For example, analysis of moment-to-moment performance within different phases of a dual-task trial (e.g., external disturbance to balance or perturbation, reactive control or stabilization, and task preparation) might make it possible to find out in which of these phases the dual-task interference is the largest. If attention switch really takes place, it is reasonable to expect it at the beginning of a perturbation. Within auditory domain, Schröger and Wolff (1998) propose that an attention switch is triggered by a particular memory-related change-detection mechanism, which is involved in the process of discrepancy detection. Attention switching results in an orienting towards the perturbating event. As a consequence, less processing resources are devoted to performing another component of dual tasks. Moreover, Schröger and Wolff (1998) suggest that attentional orienting may not only be elicited via change-detection mechanisms but also according to a match mechanism. That is, meaningful events may have attention-capturing properties per se. As disturbances to balance may lead to falls, one might consider them to be meaningful events that should capture attention. An interesting question for future research is whether attention switches take place in particular at the beginning of perturbations and whether these switches lead to dual-task interference in the cognitive domain. A moment-by-moment analysis of the balance performance might reveal whether individuals reallocate their mental resources towards the processing of perturbations and therefore abandon the performance of the cognitive task completely during external disturbances to body's equilibrium.

The theoretical accounts favored in the current research as well as alternative interpretations of the findings seem to provide reasonable and not mutually exclusive explanations. However, the fact that age-related differences were found in this study implies that the performances of young and older adults might also be explained within theoretical frameworks that account for age-group specific phenomena underlying resource allocation. The next section summarizes evidence that supports age-group differences and provides interpretations for these findings.

6.1.2 Evidence Supporting Age-Related Differences in Resource Allocation

One of the central findings of the current research was that older adults performed on the lower level, in general, and were penalized more than younger individuals in the dual-task situations. Under the instruction "Equal Emphasis", the dual-task condition reduced the performance of older adults to a greater extent (i.e., by 8.76%) than the performance of young adults (i.e., by 1.81%). Note that the dual-task performance decrement measures took into account individual differences at the single-task level. This pattern of results emerged in both difficulty conditions thus indicating that a situation, in which a sensorimotor and a cognitive task are paired, is more resource demanding for older than for younger adults.

One further general result was that the dual-task condition had no effect on the balance performance in young adults, whose DTCs in balance were zero in the easy condition, and even negative in the difficult condition. By contrast, the balance performance of older adults appeared to be worse in the dual- than in the single-task blocks in the easy as well as in the difficult condition as indicated by 6.92 and 4.85 percent of dual-task costs, respectively. What does the finding that the balance performance of older but not younger adults was penalized by the dual-task condition imply? The main implication is that, in older but not in younger adults, performance of the balance task requires cognitive resources. Consider, however, that in the practice phase of the study, younger participants had dual-task costs in the balance domain, but only in the easy task (Figure 14).

Similar to other studies (e.g., K. Z. H. Li et al., 2001), the finding that, under the instruction "Equal Emphasis", the dual-task performance of older adults was reduced and the reduction, in terms of dual-task costs, was larger in the cognitive (11.64%) than in the balance domain (5.89%) might imply that older adults prioritized balance. On the other hand, this pattern of results might be taken to mean that older adults are less able to follow experimental instructions in a dual-task situation. Two further findings of the present study strongly support the first conclusion.

Older adults, in comparison to their younger counterparts, committed more errors in dual-task blocks. This pattern was especially pronounced in the difficult condition.

Moreover, the errors were more frequently "Time-Out" than "False Response" errors. Because the response latency is typically much shorter than the time allowed, a failure to respond to the RT task within the time allotted (i.e., 900 ms in the difficult condition) is likely to reflect deliberate withholding of the responses to the RT task stimuli until participants have processed the disturbance caused by the balance task. Note that this age-related pattern of results was found in the test phase of the study, that is, after participants have extensively practiced both component tasks in the single- as well as in the dual-task context.

The fact that the experimental manipulation of the instruction had a comparable influence on the RT performance of older and younger adults rules out the possibility that older persons are less able to follow the task-priority instructions. However, this ability was present only in the cognitive domain as indicated by the finding that, for the balance task, the task-emphasis instructions partially influenced the performance in young but not in older adults. Whereas, in the difficult condition, young participants swayed more under the instruction "Focus on RT" than under the instruction "Equal Emphasis", the balance performance of older adults was comparable under all instructions. This pattern of results suggests that young adults were actively sacrificing the low-priority balance performance to optimize the high-priority RT task (Figure 23). Older adults, however, protected their balance performance under all instructional conditions, while sacrificing both speed and accuracy of their responses to the acoustic stimuli.

With respect to the performance of older adults, this study strongly suggests that age-related resource limitations and the ecological relevance of the balance task forced older adults to prioritization of balance through all dual-task conditions. At least four findings provide empirical evidence that supports this conclusion: in general dual-task costs were greater in older than in younger adults, older participants had smaller DTCs in the balance than in the cognitive domain, they committed more frequently "Time-Out" errors than young adults did, and they could not adjust their balance performance to the task-priority instructions. These basic results thus confirm the previously reported findings that, in older adults, the dual-task performance in general and the motor control in particular is resource demanding. This study extends the existing literature in showing that older adults prioritize balance regardless of experimental conditions, that is, when measured independently of allocational strategies.

The age-group specific pattern of results is consistent with the developmental perspective in general and the theoretical considerations of the SOC-model specifically.

Within these frameworks, individuals are able to anticipate losses and are strongly motivated to avoid them. As the risks to fall increase with age and falls may have dramatic consequences, older adults have to invest more effort in the most relevant for them domain, that is, posture control. They can successfully cope with these demands and adapt to developmental changes in resource constraints, if they follow the loss-based selection strategy and prioritize their stability through all (experimental) conditions.

The resource theories make no direct predictions about age-related differences in the amount of inter-task interference and resource allocation. In order to understand the age-group specific pattern of disruption in the performance of dual tasks, one should assume that resource limitations are more pronounced in old age. This assumption was confirmed by the current research. Moreover, resource deficits should prevent linear exchange between two tasks particularly in older individuals. The finding that older adults kept their balance performance on almost the same level independent of instructions is in line with the latter prediction.

Although the central findings of this research on age-related differences in the concurrent performance of a cognitive and a sensorimotor task could be reasonably explained within the frameworks of the SOC-model and the resource theories, some alternative interpretations are conceivable.

6.1.2.1 Alternative Interpretations

One popular proposal that provides an explanation for larger dual-task costs in older than in younger adults concerns inhibitory function (Hasher & Zacks, 1988). Within the inhibition model, age-related differences in dual-task performance could occur due to inefficient selective attention, which could, in turn, result in the intrusion of task irrelevant information into working memory. One of the consequences of the entrance of irrelevant information into working memory is an increased processing time. It is conceivable that older adults, in comparison to their younger counterparts, had higher DTCs in the RT task because they could not effectively suppress or ignore the balance disturbances. More recent research suggests, however, that age-related inhibitory failures are specific rather than general in nature. Moreover, there is empirical evidence that old and young adults are comparable with respect to the efficiency of inhibitory processing (Kramer, Humphrey, Larish, Logan, & Strayer, 1994). As the present experiment did not adopt experimental tasks that are usually considered to measure inhibitory functions (e.g., Stroop and negative priming paradigms) it remains an open question whether the data of the current research are consistent with the age-related inhibitory failures account. It is intriguing to find out, for example, whether a concurrent performance of a Stroop task and the balance task, which was used in this study, would result in even higher DTCs for older adults in both domains.

Age-group differences in the amount of dual-task interference can also be interpreted in terms of the neuroanatomical and neurochemical perspectives. With age, the human brain undergoes a serious of deleterious changes: gray and white matter atrophy, synaptic degeneration, blood flow reductions, and decreased dopamine activity (Cabeza, 2001; Raz, 2000). Within the framework of the frontal lobe hypothesis of aging, cognitive abilities, which are sensitive to prefrontal lesions, would evidence earlier and greater age-related declines (Dempster, 1992; Moscovitch & Winocur, 1995; Perfect, 1997). On the behavioral level, the neuroanatomical and neurochemical changes lead to a decline in the individuals' performance of cognitive and motor tasks, which involve executive processes. Executive processes are usually conceptualized as domain-general control processes that monitor and regulate other cognitive processes to attain specific behavioral goals (for reviews, see Eslinger, 1996; Miyake, Friedman, Emerson, Witzki, & Howerter, 2000). Therefore, the age-group differential pattern of results, which was found in this study, might be alternatively explained from the perspective that advocates age-related differences in the general executive abilities.

De Jong and colleagues propose that age groups differ in cognitive control because older adults possess a reduced capacity for generating and maintaining goals in working memory (De Jong, 2001; De Jong, Berendsen, & Cools, 1999). Particularly under conditions of novelty or weak environment, this reduction in capacity in the elderly should result in pronounced goal neglect, defined as disregard of a task requirement even if it has been understood, resulting in a mismatch between what is known about task requirements and what can be done in principle, and what is actually attempted in behavior. Although all these alternatives are conceivable, the results of the present study with respect to the cognitive performance under the instructional manipulation clearly demonstrate that it was neither problematic for older participants to generate the production rules, nor they neglected the task requirements (i.e., they adjusted their cognitive performance to instructions), nor they have difficulties to switch between three different instructions.

Although the present study aimed at measuring the dual-task performance independently of resource allocation strategies, the possibility remains that the two age groups differed in global strategy use. The data with respect to life-management strategies hinted at age-group differences in elective selection and flexibility (see section 4.1.3.3). It is conceivable that the age-specific pattern of results emerged because older individuals used different strategies for the dual-task processing. Note, that strategy and its selection need not be a conscious method or choice, but can be defined broadly as the individual's approach to the task (Rogers, Hertzog, & Fisk, 2000). Meyer, Glass, Mueller, Seymour, and Kieras (2001) argue that in old age adults are generally more cautious and might prefer conservative strategies in dual-task situations. The "strategic" behavior takes place either because of the reduced processing capacity or because older individuals do not fully appreciate their preserved capacities, or because of both. Consistent with this view, Hertzog and Hultsch (2000) found that older adults typically believe themselves to have poor learning and memory abilities. Recent research has demonstrated quite convincing that older adults may in fact adopt different strategies and that such differences can mediate at least some of the age-related differences in cognitive performance (e.g., Hertzog, Vernon, & Rypma, 1993; Verhaeghen & Marcoen, 1994). Empirical studies, which use task-set switching paradigm, demonstrate that older adults have difficulties to alter a familiar strategy when it no longer meets the task demands and when more optimal strategies are available (Rogers, Andrews, Grasby, Brooks, & Robbins, 2000). Note, however, that the older participants of the present study did not trade off accuracy for speed, that is, they did not adopt more conservative strategy at least for the performance of the cognitive task.

Reder and Schunn (1996) propose that individuals tend to make strategy choices based on intrinsic task factors, such as familiarity with components of the problem at hand, or extrinsic task factors, such as success using a particular strategy in the past. It is conceivable, thus, that older adults might have already manifested differential allocation of resources to the balance versus cognitive domain prior to the experimental intervention, because of their everyday experience with such tasks. To put it differently, given an infinite number of potential actions to select from at any point in time (i.e., to react quickly and accurately to acoustic stimuli and to keep equilibrium), individuals implement a goal-directed action (e.g., not to fall) or strategy that is based on internal constraints, often referred to as mental sets (Logan, 1978). An implemented mental set has profound effects on the entire cognitive system because it "configures" the system to allow efficient, even automatic selection within a subspace of "allowed" actions (Mayr & Liebscher, 2001). Future research could focus on analyses of dual-task processing on more detailed level (e.g., moment-to-moment analysis) that might identify the extent to which older adults strategically reduce the load of a dual-task situation by concentrating primarily on one, the most relevant for them, task.

6.2 Methodological Considerations and Results Awaiting Explanation

One set of the present study hypotheses addressed the issue of domain-specific asymmetry in the dual-task interference. Specifically, the expectation was that due to the limited resources there should be interference between the two tasks. The amount of this interference should be larger in the cognitive than in the balance domain because the sensorimotor functioning is of primary importance for survival. Moreover, the domain-specific asymmetry should be more pronounced in the difficult condition, that is, when resources are especially limited and the survival issue plays a crucial role. The data of the present study did not support the latter hypothesis.

Another set of hypotheses made predictions about age-related differences in the ability to deliberately control resource allocation in a dual-task situation involving a cognitive and a sensorimotor task. The main rationale underlying these hypotheses was that older adults, in comparison to their younger counterparts, possess less resources. Given these pronounced limitations one might expect that they are less able to deliberately control the allocation of their mental resources and these reduced efficiency should be particularly pronounced in more demanding situations. The results of the present study do not support these hypotheses.

In the following sections, I elaborate on the methodological considerations that might explain the lack of the expected findings.

6.2.1 Was the Difficult Condition Resource Demanding?

To recapitulate the experimental manipulation of task-difficulty, in the cognitive domain a simple and a two-choice reaction time task were used. In the balance domain, the difficulty level was varied due to inclusion of small (3°, 4°, 5°) and large perturbations (7°, 8°, 9°). Although the experimental manipulation of task-difficulty worked in the single-task blocks, the results clearly showed that DTCs under the difficult condition were smaller than under the easy condition. This pattern was especially pronounced in the cognitive domain. Even more puzzling was the finding that young adults had negative dual-task costs in the balance domain[48]. Finally, the domain-specific asymmetry was not more pronounced in the difficult condition.

A rather general answer to the question, why the domain-specific interference was not more pronounced in the difficult condition, might be that the measure for the dual-task interference (i.e., proportional dual-task costs) is a problematic one. The proportional DTCs, which were adopted by Somberg and Salthouse (1982), are widely used in research on dual-task performance, and provide a powerful technique for comparison of tasks with different measurement scales. However, several authors pointed out a possibility that this ratio measure is a very conservative one, and it is possible that data transformed in this way overcompensate for baseline differences (Ackerman, Schneider, & Wickens, 1984). This explanation is somewhat unlikely, however, as the RT and balance performances of the study participants were not at a lower level in the dual-task situation when the tasks were difficult. That is, the interaction among the task (single versus dual) and difficulty (easy versus difficult) factors was not significant.

Another speculative reason for the smaller DTCs in the difficult than in the easy condition and the lack of interaction involving the domain and difficulty factors is that the overall decision time is taken up by mental operations that vary considerably in the resources they require. If the proportion of relatively undemanding operations increases with degree of choice, then the effects of divided attention would be absorbed more easily in the condition where several choices must be done. With greater degrees of choice, the relatively undemanding operations may occupy time that can also be used to perform a concurrent task. Smaller costs in the difficult condition are known in the cognitive research literature and were reported, for example, by McDowd and Craik (1988). These authors found that in the case of eight-choice RT task there was no substantial decrement due to divided attention in comparison to a less demanding two-choice condition.

Additional possibility follows from Kahneman's (1973) suggestion that individuals simply cannot harness as much effort in the easy tasks as they can in difficult tasks. It may be that in the simple RT task, no more effort could be directed to the task to prevent it from suffering some decrement under dual-task conditions. In the case of the more

[48] Interestingly, self-report data on the experienced task difficulty showed that, on a 7-point scale (1 = "very easy" to 7 = "very difficult"), the study participants rated the difficult condition higher than the easy condition ($p < .001$; $M = 3.27$, $M = 2.29$, respectively). This effect was more pronounced in young than in older adults ($p < .01$; for young adults: $M = 1.95$, $M = 3.28$; for older adults: $M = 2.63$, $M = 3.27$;) and especially in the cognitive domain ($p < .05$). Moreover, both age groups indicated that the dual-task was more difficult than the single-task situation ($p < .001$, for single task: $M = 2.00$, $M = 3.09$, for dual task: $M = 2.58$, $M = 3.45$).

difficult two-choice RT task, however, increased effort was accumulated and performance benefited, thus preventing any substantial decrement due to divided attention. Similarly, Düker (1963) argued that individuals invest more effort under conditions of reduced sensory acuity (e.g., large disturbances to balance) to compensate for a supposedly challenging experimental condition. He termed this phenomenon a reactive increase in attention and effort (reactive Anpassungssteigerung). The finding that DTCs were smaller in the difficult condition, and that in the balance domain younger adults had smaller costs in the difficult than in the easy condition is in line with the explanations given above and results from other studies. Lundberg (1982), for example, has shown that individuals may cope with having to perform calculations in noise by increasing effort and catecholamine output in order to maintain normal levels of performance. Similarly, Lindenberger, Scherer, and Baltes (2001) reported that middle-aged adults under age-simulation conditions of reduced visual or auditory acuity did not deviate negatively in their intellectual performance from middle-aged adults without such simulated losses. Moreover, individuals in groups with effective or placebo reductions of sensory acuity showed a tendency to perform above the level of the no-treatment control group. Although the explanations given above are speculative, it seems obvious that increase in task difficulty do not necessarily lead to concomitant decreases in performance.

It is possible, however, that the domain-specific asymmetry was not more pronounced in the difficult condition because young adults had no or negative dual-task costs in balance. Why were the DTCs equal to zero in the easy and negative in the difficult condition? The zero costs in the easy condition appeared due to practice effects. Through out the dual-task sessions of the experiment, young adults got rid of DTCs in balance (see Appendix E and Figure 14). By contrast, negative costs in the difficult condition were already found during the first assessment of the dual-task performance. The latter finding could be explained in different ways. One might speculate that the perturbations of 7, 8, and 9 degrees were not challenging enough for young adults. The fact that difficulty manipulation worked in the single-task context would speak against this alternative. Nevertheless, the balance performance of younger adults was not worse in the dual- than in the single-task blocks. The negative DTCs suggest that it was even better in the dual- than in the single-task condition.

An alternative explanation for the negative DTCs in the balance domain might be the ordering of both difficulty conditions through the 8 sessions of the experiment. In order not to additionally penalize older adults (cf. Nesselroade & Labouvie, 1985), difficult condition was introduced always after participants had substantial experience in each component task performed separately and concurrently in the easy condition. This ordering could lead to larger training effects in young than in older adults. The analyses of the practice effects, which are presented in Appendix E, reveal, however, that there were no age-differential training effects in the balance task under the difficult condition. One might argue that a transfer of training effects from the easy onto the difficult condition might have taken place in young adults. However, it does not appear to be a case because, if any, a “near transfer” (i.e., within condition) should occur prior to the “far transfer (i.e., between conditions). As training effects were larger in the easy than in the difficult condition, it seems unlikely that the “near transfer” within the difficult condition took place.

The third reason for the negative DTCs in the balance domain under the difficult condition is a motivational component. This speculation is consistent with informal observations by the experimenters that young participants experienced difficulties in concentrating themselves on balance especially in the single-task situations. It is possible that the dual-task condition was more arousing, and, thus, could benefit individuals’ motivation (cf., Huddleston, 1974). Although it remains unclear why young adults had negative DTCs in balance under the difficult condition, this finding echoes the results reported by Lindenberger et al. (2000). In an age-comparative study on simultaneous walking and memorizing, the authors found, for example, that young and middle-aged adults did not show significant DTCs in walking accuracy. In spite of such evidence and plausible explanations, another pattern of dual-task costs could have emerged in the present experiment, being adaptive techniques used. In other words, the question is how the individually calibrated difficulty levels could have influenced the DTCs in young and older adults.

6.2.2 Why Could Older Adults Adjust Their Reaction Times According to Instructions?

The finding that the task-priority instructions had a comparable influence on the RT performance of older and younger adults under both difficulty conditions is in line with several studies that demonstrated no age-related deficits in deliberate resource allocation when two cognitive tasks were paired (e.g., Crossley & Hiscock, 1992; Ponds et al., 1988; Somberg & Salthouse, 1982). Why could older adults adjust their reaction times according to instructions as good as young participants? This question can be answered by appealing to the issues of speed-accuracy trade-offs, positively biased older subsample, effort and environmental support, lack of precise control of deliberate shifts in attention, and statistical power.

Age-group differences in speed-accuracy trade-offs. Although there is some evidence to suggest that older individuals put more emphasis on accuracy than on speed (Hertzog, Vernon, & Rypma, 1993; Salthouse & Somberg, 1982), it is reasonably safe to conclude that, within the present experiment, no age-differential speed-accuracy trade-offs were found. However, the fact that older participants were not only slower than young adults but also made substantially more errors in the dual-task and difficult conditions may be an additional explanation for the lack of age-group differences in adjusting the reaction times according to instructions. Most probably, older and younger adults worked on different points of the speed-accuracy curve (e.g., Wickelgren, 1977). A question arises then whether the pattern of results with respect to the reaction-time behavior under the task-priority instructions would be different if a criterion-referenced assessment procedure were used (e.g., Mayr & Kliegl, 1993). Specifically, time slots needed to perform correctly could have been estimated for each individual subject and, thus, both age groups had been forced to the same accuracy levels.

Positively biased older subsample. Obviously, the older participants performed on the level that was not representative for a "normal" population of the elderly. In terms of cognitive functioning and physical and mental health, the group of older individuals possessed more resources than a representative sample of the same age (see section 4.1.3.4)[49]. Moreover, the older adults were as engaged in sport activities as their younger counterparts. Additionally, the fact that volunteers were required to attend multiple testing sessions, tended to prevent more impaired persons from participating in the study. Taken together, the older subsample of this study, most probably, represents a positively selected sample. Rabbitt, Lowe, and Shilling (2001) argue that it seems certain that the older samples who have been assessed in all behavioral studies of cognitive changes in old age have been "elite" and atypical members of their age groups and that frailness and

[49] One could argue that the younger subsample of the present study is not typical of its age group in terms of, for example, intellectual ability, because all younger participants completed the highest track of the German high school system, typically encompassing 13 years of school (Abitur). Thus, the results from the younger subsample may have limited generalizability. However, there is some empirical evidence that the effects of student status are relatively small or possibly even completely nonexistent for several types of cognitive variables (e.g., Salthouse, Kausler, & Saults, 1988). Such findings imply that, in a number of different cognitive variables, the level of performance of highly educated young persons seems generally consistent with what one would expect among individuals of that age.

incapacity have filtered out precisely those individuals who might most clearly show “focal” or “modular” changes in cognition. Thus, the age-related effects, which were found in this study, may not hold for all adult subgroups. That is why one must be cautious in extrapolating these results to other populations. Those studies that examined the relationship between level of participation in activities and performance on various cognitive tasks provide support for this rationale. Their general finding is that greater participation in physical, social, and intellectual activities is associated with higher levels of cognitive performance on a wide range of cognitive tasks (e.g., Bunce, Warr, & Cochrane, 1993; Hultsch, Hertzog, Small, & Dixon, 1999; but see Aartsen, Smits, Tilburg, Knipscheer, & Deeg, 2002). Additionally, aerobic exercise programs have been found to improve dual-task processing of elderly adults (Hawkins, Kramer, & Capaldi, 1992). Thus, given a sample with a large proportion of individuals showing lower levels of functioning or sedentary old adults, it is possible that age-group differences in deliberate resource allocation in the cognitive domain would emerge. What else could have been a reason for the lack of some of the expected age-group differences?

Effort and environmental support. Additional explanation for the comparable ability of young and older adults to deliberately allocate mental resources within the cognitive domain could be that older adults invested more effort than younger participants in order to carry out a task optimally. Informal observations by the experimenters support this speculation. Those authors who advocate lifelong development argue that even in the face of aging-related decline of maximum potential, many older persons can maintain high levels of intellectual functioning. However, they have to invest more effort in a given class of behavior than their younger counterparts (P. B. Baltes & Willis, 1982). From the neuroanatomical perspective, Cabeza (2002) argues that it is adaptive to counteract age-related deficits by mobilizing additional brain regions during performance of cognitive tasks (compensation hypothesis). Cabeza and coauthors could demonstrate that high-performing older adults compensate for functional decrements by reorganizing brain functions (Cabeza, Anderson, Locantore, & McIntosh, in press). While performing a quite demanding memory task, they recruit homologous regions in the contralateral hemisphere instead of additionally activating the regions of the same hemisphere like low-performing older individuals do. From the cognitive perspective, shifts in resources produced by environmental (internal and external) changes do not impose any strict limitations on performance capabilities. Any deficits can be overcome due to attainability or maintenance of the appropriate balance of function by means of executive effort (Hockey, 1984). Within the framework of the environmental support hypothesis (e.g., F. I. M. Craik, 1986; F. I. M. Craik & Jacoby, 1996; Schooler, 1987), older adults may be less able to spontaneously initiate adequate strategies, they can, however, counteract performance declines by drawing on environmental support. Thus, provision of a cue (i.e., instruction) could have compensated for age-related reductions in processing resources that were needed to fuel complex cognitive operations during dual-task situations. By its very nature, experimental assessment systematically reduces just those variables that additionally challenge processing resources and capacities in real-life situations (Kerns & Mateer, 1996). For example, by reducing noise in testing rooms, arranging some time for familiarization, including practice prior to experimental assessment, and providing instructions, certain experimental environment is structured. Most probably, such set up has not enough potential to tap some of the requirements of everyday functioning. Thus, it remains an open question whether older individuals function on a comparable optimal level in everyday life. In other words, what works in the lab may not work in the real world.

Lack of precise control of deliberate shifts in attention. An obvious hypothesis is that had the instructions required more precise performance control, older adults could have more difficulties in adjusting their performance to instructional demands (see also Section 6.1.1.1). Tsang and Shaner (1998), for example, assessed the precision of resource allocation control between two cognitive tasks by how closely young and older adults adhered to an externally imposed performance standard. This study demonstrated an age-related difficulty in allocation control, with the optimized performance becoming increasingly divergent from the standard with increased age. One might also speculate that on-line continuous feedback on the change in performance according to instructions would have influenced the adjustment of performance differently for young and older adults. Although young participants were generally motivated, monetary pay-offs could have stronger encouraged compliance with the unequal-priority instructions and thus enlarge the age-group differences in the performance of both tasks.

Statistical power. Lack of age-group differences might be due to low statistical power. Salthouse (2000) emphasizes that the use of relatively small samples ($n < 20$) results in a systematic bias toward accepting the null hypothesis and claiming that there are no age-group differences when they may in fact exist. One strategy for increasing power may be to try to reduce within-person variability by addition of extensive practice. Although this strategy has been adopted in the present study, it is conceivable that the likelihood to detect age-group differences has been very low. For example, in case of the dual-task balance performance, there was sensitivity to the task-emphasis instructions, and there did appear to be a numerical asymmetry between the effects of task-emphasis instructions in the balance task, especially for young adults in the difficult condition. However, the interaction between the age group, instruction, and difficulty was marginally significant. In general, the power to detect the interactions involving the age group factor was fairly low (ranging from .05 to .49). Thus, had more participants been tested (much more than 60 individuals per group, see Salthouse, 2000 for review), or had the measures been less variable, these effects may have been significant.

6.3 Conclusions

The present study focused on a concurrent performance of a cognitive and a sensorimotor task and asked two general questions. How do young and older adults allocate their mental resources in dual-task situations that involve cognitive and sensorimotor tasks? Is resource allocation under individuals' control, that is, can individuals adjust their performance according to task-emphasis instructions? With respect to these two questions, the specific aim was to find out whether there are differences by age group, domain, and difficulty level?

The results of the present study add to the corpus of existing empirical evidence in four ways. First, the findings are in line with those that suggest a dual-task situation, which involves a cognitive and a sensorimotor task, to be demanding in general and for older adults in particular. Second, in such a situation, individuals appear to bias the resource allocation toward the more relevant (sensorimotor) task. Third, through testing with instructional variations, the current research presents the first evidence I know of that, with regard to deliberate control of their mental resources, young and older adults are more flexible in the cognitive than in the sensorimotor domain. The flexibility is, however, reduced in more demanding situations that tap resources to a greater extent than less demanding conditions. Fourth, the present experiment provided explicit evidence that despite reduced resources, as indicated by higher dual-task costs, older adults are able to deliberately allocate their resources within the cognitive domain. However, this ability seems to be absent in the sensorimotor domain. Thus, by including the experimental manipulation of instruction, the present study elaborated on previous research on age-group specific patterns of prioritization behavior in dual-task situations. What are the implications of the present findings for the cognitive and developmental perspectives?

For the cognitive research, the results of the current study imply the viability of the hypothetical resource construct in explaining dual-task performance. It remains an open question whether unitary or multiple resources are more viable. The fact that performances of both – sensorimotor and cognitive – tasks are resource-demanding in older adults might suggest that it would be premature to discount the importance of the “resource metaphor”. The fact that young adults had no interference in the sensorimotor domain might suggest that cognitive and sensorimotor functioning might rely on different resource pools or are conceptually quite different on the other end of the lifespan. In other words, that is, avoiding the “resource metaphor”, the magnitude of the intersystemic connection (Baltes & Lindenberger, 1997) appears to increase with age. Beyond and above the issue of mental resources, the cognitive research asks the question how specific processes are controlled and coordinated in multi-task situations. Toward the topic of executive functioning, the results of the present study imply that individuals can almost perfectly control cognitive processing as long as task demands do not overtax the individuals’ resources. The ability of deliberate control is, however, reduced in the sensorimotor domain.

Within the developmental perspective, these findings suggest that although general resources are more limited in older than in younger adults, the community dwelling elderly possess reserve capacity (i.e., cognitive plasticity) that underpins a certain degree of flexibility in dealing with mental resources and allows their efficient budgeting. The fact that older adults, in comparison to their younger counterparts, functioned on a significantly lower accuracy level suggests, however, age-related limits in plasticity. These limits become even more distinct if the results on the dual-task balance performance are considered. Whereas young participants demonstrated at least some flexibility in the balance domain, the decrement in general resources and anticipation of losses, in terms of falls, and their consequences seem to pressurize older individuals to invest more resources or effort into motor control regardless of experimental requirements to “sacrifice” their stability. This mismatch between the performance of older adults and the experimental requirements is interpreted as a consistent prioritization of the sensorimotor component of a dual-task situation or loss-based selection. In other words, it is considered to be a perfect match between available resources or internal environmental demands and personal preferences (goals). From the developmental point of view, it is a clear evidence of adaptive behavior. Taken together, the results of the present study illustrate the importance of experimental manipulation of task-emphasis for the better understanding of executive functioning in a dual-task situation that involves a cognitive and a sensorimotor component. Furthermore, this experimental manipulation provides a powerful device for discovering potentials and limits of the executive processes in older adults.

Although the results of the present study are clear, there are several limitations concerning the interpretations. The interpretation of reduced ability to deliberately control the allocation of mental resources in more resource-demanding situations (i.e., in the difficult condition) is not indisputable because of two reasons. As just mentioned, the difficult condition appeared to be not demanding for the young participants. Second, the study design comprised only two task-difficulty combinations (i.e., easy-easy and difficult-difficult). The information on resource allocation under the two intermediate conditions could provide a stronger piece of argumentation with regard to the role of resources in dual-task situations that involve a task of high ecological validity. If the survival aspect is true, as has been argued in the present study, ability to deliberately control the allocation of mental resources should decrease with increasing difficulty of the balance task.

The interpretation of age-related differences in the amount of dual-task interference, in the ability to deliberately control the allocation of mental resources, and in the prioritization behavior is limited by the fact that resource limits were not reached by the current experimental paradigm, although the task-difficulty was manipulated. This is particularly true for young adults. The finding that there were zero or negative dual-task costs in the balance domain and extremely small DTCs in the cognitive domain under the difficult condition suggests that the two-choice RT task and the difficult balance task did not tax the mental resources of younger participants. It seems plausible, thus, that the experimental requirements did not make equal demands on the performance of the two age groups.

On a more general level, the interpretation of age-related differences is limited by the methodological problems of cross-sectional studies within aging research (Baltes, Reese, & Nesselroade, 1988). The age-group differences found in the present study also represent cohort and other subject selection effects. Only additional research with cohort-sequential designs and more broadly based samples can answer the question of generalizability of the present findings, for example, to other sample characteristics (see also Kliegl, Smith, & Baltes, 1989).

6.4 Outlook

The results of the present study shed much light on the phenomenon of resource allocation in a dual-task situation that involves a cognitive and a sensorimotor task and generate some hypotheses for future research.

Although the pattern of findings obtained in this experiment is clear in demonstrating individuals' potentials and suggestive of age-related limits in these potentials, it remains an open question "What are the "true" limits of plasticity? By applying testing-the-limits methodologies (see Kliegl & Baltes, 1987; Kliegl, Smith, & Baltes, 1989; Kliegl, Smith, & Baltes, 1990), future research might approximate, step by step, maximum levels of performance potential. Age-related differences in this potential should be most clearly identifiable near limits of performance. Moreover, an adaptive format of testing (i.e., a finer adjustment of tasks to the level of each study participant) would help to avoid both cognitive overload and non-challenging task conditions.

Another interesting question is "What role does expertise play in resource allocation?" Investigating the issue of resource allocation in dual-task situations that involve such sensorimotor tasks as balancing or walking, the underlying assumption is that all individuals possess a high degree of a real-life expertise in these tasks, which appears due to many years of practice. However, experts are usually defined as persons whose performance on some criterion task is far superior to that of normal persons. Future research could investigate the potentials and limits of an expert system with respect to deliberate control of resource allocation between a sensorimotor and a cognitive task.

Finally, the question of generalizability of the present findings to other experimental paradigms and diverse samples is indisputably interesting. The main argument for the asymmetrical distribution of dual-task costs between the cognitive and the sensorimotor domain and reduced sensitivity of balance performance to instructions was the ecological relevance of balance, especially in old age. It is of great interest whether experimental paradigms that involve sensorimotor tasks of less relevance would yield similar patterns of results. It is possible that not all forms of sensorimotor abilities respond in the same way to instructional manipulations. It remains a topic for future research to investigate whether a combination of an ecologically relevant cognitive task and a less relevant sensorimotor task would yield an opposite pattern of resource allocation, that is, would pressurize individuals to prioritize the cognitive instead of the sensorimotor performance. There seem to be certain conditions where the effects of instructional manipulation do arise in the balance domain. Future investigations need to use a fuller range of measures in order to replicate the finding of this study with regard to the balance performance and to clarify whether older individuals can be flexible in dealing with their balance. Investigation of various cognitive tasks performed concurrently with the balance task may allow to ascertain the extent to which age-related differences in the ability to adjust performance according to external demands are independent of specific structural characteristics of the cognitive task. The issue of the positively selected older subsample raises the question of replicability of the present findings given a larger, clinically better investigated, and drawn from populations that are differently weighted by initial self-selection sample of older adults.