2. THEORETICAL BACKGROUND

The following chapter is divided into four major parts. The primary goal of the first part is to provide a developmental perspective on the issue of adaptive behavior in the context of limited external and internal resources. I will introduce the SOC-model (P. B. Baltes & Baltes, 1990) as a theoretical framework for understanding adaptive processes within different domains of functioning and in different periods of the lifespan. The focus of the second part of this chapter is the cognitive perspective on individuals' ability to allocate limited resources. I will first discuss how "resources" can be defined within the framework of cognitive psychology. After a brief presentation of resource theories, I will introduce the dual-task techniques and discuss research on resource allocation in adulthood. The central issue in the third part of this chapter is age-related differences in cognitive resources and the ability to coordinate these resources in a situation in which concurrent performance of two tasks is required. After reviewing the literature on differential resource allocation in young and older adults within a dual-task context, I will address the issue of inconsistency in findings and develop a rationale for investigating age-related differences in performance of ecologically valid tasks. The fourth part of this chapter will introduce the topic of balance as an example of a domain of functioning that possesses a high degree of validity, especially in old age. After defining balance and the balance system, I explain why maintaining balance or upright posture becomes a demanding task as people age. Next, I provide a critical review of the previous research on concurrent performance of a sensorimotor and a cognitive task in an age-comparative design. At the end of each part, I will draw implications for the present study. The outline of the current investigation follows the "Theoretical Background".

2.1 Developmental Perspective on Resource Allocation

From the perspective of developmental psychology, humans are viewed as active agents who can actively select and change particular contexts, or flexibly adapt to a great range of environmental conditions, and even generate new systems of behavior (e.g., P. B. Baltes, 1997; Brandtstädter, Wentura, & Rothermund, 1999; Heckhausen, 1999; Marsiske, Lang, Baltes, & Baltes, 1995). For example, realizing the difficulty of performing concurrently several tasks, a person can place him- or herself in a context of one task at a time. However, in doing so, the individual will experience not only gains but losses as well, because the accomplishment in a given period of time is smaller in comparison to a multitask situation. Another possibility might be to try to increase one's capacities by, for example, investing more effort or planning more time, or to repeatedly practice simultaneous performance of several tasks, and thus, decrease the load the tasks produce. From the fundamental assumptions about human development, each of these scenarios seems possible: (a) the interplay of individuals' proactive creation of and reaction to their environments; (b) limitation of internal and external resources throughout the lifespan, and particularly in old age; (c) multidirectionality, that is, the joint occurrence of gains and losses (e.g., P. B. Baltes, 1997), and multifunctionality, that is, developmental outcomes have multiple consequences; and (d) human behavioral plasticity (P. B. Baltes, 1993). Plasticity enables individuals to increase or decrease their behavioral output to meet changing organismic and environmental demands. With age, plasticity changes due to both biological and environmental factors (P. B. Baltes & Singer, 2001). The successful activation of latent plasticity and the management of resource limitations is the key issue of human life and development (Marsiske et al., 1995). What are the processes that make it possible to master life through the life course?

Brandtstädter and colleagues (Brandtstädter, 1989; Brandtstädter & Renner, 1990) consider two alternative processes or strategies of optimizing the balance of gains and losses in personal development: assimilative coping and accommodative coping. The assimilative tendency (i.e., tenacious goal pursuit) means adjusting developmental situations to personal preferences. The accomodative tendency (i.e., flexible goal adjustment) denotes adjusting personal preferences to situational constraints. Brandtstädter and Renner (1990) emphasize that these processes aim at eliminating discrepancies between actual life perspectives and salient concerns of personal development, which typically occur in aversive situations and especially in later phases of life. The authors suggest that, in old age, a growing impact of uncontrollable events on personal development favors an age-related shift from an active and tenacious to a more accepting, accommodative mode of coping.

Paul Baltes and colleagues (e.g., P. B. Baltes, 1997; Staudinger, Marsiske, & Baltes, 1995) accentuate the role of resources for mastering life through the life course. Resources are defined as factors that help persons to interact with their environments (Freund & Baltes, 2000). As development has three general functions or outcomes (i.e., the function of growth; the function of maintenance, including recovery; and the function of regulation of loss), there is a systematic lifespan shift in the relative allocation of resources to these three functions. In childhood, the primary allocation is directed toward growth.

During adulthood, the predominant allocation is toward maintenance and recovery (resilience). In old age, more and more resources are directed toward regulation or management of loss. But how do individuals allocate their resources? Are there any effective strategies for dealing with developmental changes?

2.1.1 The SOC-Model: An Approach for Understanding Adaptive Development

Paul B. Baltes and Margret M. Baltes (1990) proposed that three fundamental processes – selection, optimization, and compensation – enable successful development and adaptation across the lifespan in general and in old age in particular (the SOC-model; M. M. Baltes & Carstensen, 1996, 1998; P. B. Baltes, 1997; Freund & Baltes, 2000; Marsiske et al., 1995). The SOC-model builds on the premise that resources are limited at any one specific point in time. Arising opportunities or losses that accompany development require choices about the allocation of these limited resources. Originally, the SOC-model was conceived of as one single "integrative" process of adaptive mastery (P. B. Baltes & Baltes, 1990). More recent work on SOC shows that the facets of the model can be viewed as separate processes, each contributing to successful development (e.g., Freund & Baltes, 1998).

Selection, the first component process, refers to developing, elaborating, and committing to a subset of possible alternative life-trajectories, goals, or functional domains. One central aspect of selection consists of narrowing the range of alternative ecologies, domains of functioning, or goals from the pool of available options that usually exceed the amount of internal and external resources that people possess. Without selection there would be no direction in development and energy would be diffused in many areas instead of being directed and focused on certain domains. The constraints and limitation of resources throughout the lifespan necessitate decisions on which goals and outcomes to undertake. Such resources include biological-genetic characteristics, psychological characteristics, and social-cultural characteristics. By delineating the range of goals or domains, selection is the first important step for successfully managing one's life (Freund, 2001). Selection is divided into two categories: elective selection and loss-based selection. *Elective selection* has a focus on aiming at desired states and refers to instances in which an individual's choice of domains of functioning is not based on losses. For example, with the goal to get to work everyday, one can either drive a car or walk. If a person wants to keep him- or herself physically fit, walking can be selected instead of driving. However, if a loss in goal-relevant means or resources that is threatening the maintenance of a given level of functioning in a specific goal-domain occurs, *loss-based selection* comes into play. The process of loss-based selection encompasses focusing on the most important goal, reconstruction of goal hierarchy, adaptation of standards, and search for new goals. For example, selection of driving instead of walking happens when health conditions do not allow walking of long distances any more. Loss-based selection represents an important process of life-mastery when encountering losses in resources (e.g., time, physical abilities) because it allows the focusing or adaptive redirecting of resources when means for compensation are either not available or would be invested at the expense of other, more promising goals (Freund & Baltes, 2002). *Optimization* refers to applying means aimed at achieving optimal functioning or desired outcomes. In the process of optimization, allocation or refinement of resources play an important role. For example, trying to reach some higher levels of physical fitness, one can invest more energy in walking and increase walking speed. *Compensation* addresses the aspects of decline and management of loss and involves substitution of means or use of alternative means to maintain a given level of functioning (e.g., if walking is not possible because of certain constraints, cycling could be an alternative means to keep oneself physically fit). Based on the assumption of joint occurrence of gains and losses across life, the SOC-model addresses how people maintain a given level of functioning in the face of loss or decline in resources. In this vein, the role of two processes – loss-based selection and compensation – is crucial. The distinction between compensation and loss-based selection is based on the difference between goal setting and goal pursuit (Freund, Li, & Baltes, 1999). Selection, optimization, and compensation can vary along the dimensions active – passive, internal – external, and conscious – non-conscious.

In order to further specify the strategies of SOC, a concrete behavioral context and a specific theory that is appropriate for the goal domain under consideration are needed. The SOC-theory, as a metamodel, provides a general framework for the understanding of developmental change across different stages of life, different levels of analysis, and various domains of functioning. The majority of research contexts in which the SOC-model was applied focused on development during adulthood and old age. Lerner and colleagues use this theory for understanding developmental regulation in adolescence (Lerner, Freund, De Stefanis, & Habermas, 2001). Freund and Baltes (1998, 2000) apply the SOC-model to the domain of personal goals within the action-theoretical framework. The authors describe Selection as the process of goal setting. Optimization and Compensation constitute the means and strategies of goal pursuit. B.B. Baltes and Dickson

(2001) address the processes of selection, optimization, and compensation within the context of industrial-organizational psychology. Specifically, the authors argue that the metatheory can be used for three specific areas: work-family conflict, leadership, and organization-level functioning. The processes of SOC were thus proposed to be important for individual as well as organizational behavior (see also M. M. Baltes & Carstensen, 1998).

The SOC is a theoretical framework that motivates the investigation of adaptive processes at different levels. That is why it permits the analysis of a variety of outcome criteria. For example, research can be focused on examining general personal functioning, individual's behavior in a specific task context, or the function of a certain body system (e.g., the balance system). Thus, the operationalization of the SOC-model can proceed along various methods of data collection and experimentation. In the next section, I first address the application of the SOC-model in the studies of individual differences using correlational methods. Next, I provide examples on how predictions about individuals' behavior in a specific task context can be tested using an experimental settings.

2.1.1.1 Empirical Evidence

There is empirical evidence that the SOC processes are related to adaptive life management across the entire lifespan. For example, Wiese, Freund, and Baltes (2000) investigated the relation between the self-reported use of SOC and satisfaction with functioning in the two domains of partnership and work. Abraham and Hansson (1995) focused on examining the links between SOC strategies and subjective ratings of competence maintenance and goal attainment in the work domain. Freund and Baltes (1998) applied the SOC framework to the issue of "aging well". Duke and colleagues investigated how older adults compensated for physical or social activity reduction and loss by adopting less effortful behaviors that met valued goals (Duke, Leventhal, Brownlee, & Leventhal, 2002). In a study by M. M. Baltes and Lang (1997), the scope of the model's application was aging and effective functioning in everyday life. To get closer to how people master specific everyday life situations, Riediger (2001) used a diary method. The author investigated how the relations among goals (i.e., conflict and facilitation) affect adaptive life management in young and older adults. Applying an experimental method, Thompson (1995) examined whether visual compensatory mechanisms (e.g., visible speech and gestures) differently influence language understanding in young and older adults (see also Thompson & Guzman, 1999).

Another way of investigating how people manage their lives is to study multitasking in humans. As individuals often find themselves in situations in which more than one activity has to be accomplished at a time, multitasking and timesharing ability are at the very heart of competency in everyday life. Walking down a flight of stairs while planning a meeting, crossing a busy street while memorizing a shopping list, reading a newspaper while standing in a subway are just some examples of everyday tasks individuals are frequently confronted with. In terms of SOC, multitasking can be described as a life-management situation in which multiple domains or goals need to be coordinated. The study of dual-task processing in the laboratory represents an attempt to understand the manner in which humans cope with demands inherent in many real-world situations. Assuming that at any moment the human system possesses a finite amount of processing facilities, the question arises how individuals timeshare within a dual-task situation that is supposed to be more resource-demanding than a single-task condition. In this sense, the dual-task paradigm helps to investigate how humans establish and maintain a balance of the two, possibly conflicting, goals in the face of limitations in resources such as time, energy, ability, and expertise (Freund, et al., 1999).

Karen Z. H. Li, Lindenberger, Freund, and Baltes (2001) investigated how young (20 – 30 years) and older (60 – 75 years) individuals deal with basic life demands such as simultaneous walking and memorizing. The sensorimotor task required skilled walking on a narrow track. The cognitive task demanded memorization of a list of words using a mnemonic technique. In the dual-task condition, the participants were instructed to perform both concurrent tasks equally well. After difficulty levels of both component tasks were estimated for each participant, the authors systematically manipulated task difficulty in the dual-task condition in order to induce the experience of losses and, consequently, loss-based selection. Moreover, participants were provided with compensatory means, that is, a handrail for walking and a time prolongation device for memory. In general, older adults performed on a lower level in dual-task situations than young individuals. Older individuals were slower in walking and less efficient in memorizing. However, this age-related difference was especially pronounced in the memory domain. In the condition in which both tasks were made more difficult, and both compensatory aids were available, older adults benefited from handrail use, whereas young participants successfully compensated by using the memory aid. According to K. Z. H. Li et al. (2001), the age-related differences in the level of concurrent performance of both tasks indicate that older adults selected the domain that was more important to them, that is, walking. More evidence for loss-based selection was obtained with the analysis of aid use efficacy. In sum, the study by K. Z. H. Li et al. (2001) illustrates how in old age, individuals address declining abilities by prioritizing what should be preserved (i.e., motor control), and then maintaining prior performance levels by using compensatory means.

Another possibility to investigate loss-based selection in the context of simultaneous performance of a sensorimotor and a cognitive task is to induce anticipated losses due to falls, by asking individuals to focus primarily on the cognitive component of the dual-task situation. This was one of the experimental manipulations in the present study.

2.1.2 Implications for the Present Study

The general purpose of linking this work with the SOC-framework pertains to the question whether adults, particularly in old age, are able to reconstruct their goal (domain) hierarchy and to prioritize the cognitive but not the sensorimotor task in a dual-task situation. Taking a lifespan developmental perspective and following the SOC-theory, three main assumptions underlie the study: First, the internal resources are limited and there are individual differences in the quantity of resources people possess. Moreover, humans do not only vary with respect to the amount of resources they possess but also with regard to how efficiently they use them. Paul B. Baltes (1997) argues that there are systematic age-related differences in both availability and the efficient use of resources across the lifespan. He suggests that older people have access to fewer resources and that they are less efficient in using them. Nevertheless, people are active “forces” in the process of their life management. The second assumption, relevant for the present work, is that humans are capable of budgeting and managing their resources (i.e., they are self-organizing systems). The high degree of individuals’ behavioral plasticity has enormous importance for the regulation of their behavior. However, biology-based age-related changes contribute to losses in resources and plasticity. These losses lead to increased demand for maintenance rather than growth (Staudinger, Marsiske, & Baltes, 1995). This means that, across the lifespan, individuals vary in the pattern of selective investment, although investment does not necessarily connote conscious or volitional strategies. Finally, the assumption that human organisms have the capability to employ available resources in ways that produce desired developmental outcomes while minimizing undesired outcomes plays an important role for the present investigation. Human beings are highly motivated to avoid losses (Tversky & Kahneman, 1981). An unfavorable balance of gains to losses in old age forces individuals to reconstruct the existing goal hierarchy in favor of maintenance and regulation of loss. In other words, in the face of (anticipated) losses, loss-based selection comes into play.

Summarizing the assumptions referred to above, the most relevant issue for this study is how individuals budget their limited resources in young and especially in old age. Because the resource limitations are more pronounced in older adults, I expect that coordination of several concurrent tasks, like in a dual-task situation, is more challenging for older individuals than for young adults. In general, behavioral plasticity enables individuals to adjust their performance to changing external conditions or experimental demands. However, people are highly motivated to avoid losses. That is why adults can meet the experimental requirements only as long as these demands are in line with the natural tendency to maximize desired and minimize undesired outcomes. As instruction to focus primarily on a cognitive task in a dual-task situation involving a sensorimotor and a cognitive component could potentially lead to loss of equilibrium, I expect that this experimental manipulation has less influence in the sensorimotor than in the cognitive domain. The experience of reduction in resources and plasticity and the ability to anticipate losses and their consequences lead older adults particularly to invest selectively into the sensorimotor domain. The presence of task bias would suggest that despite the experimental instructions to allocate resources primarily to the cognitive task or to distribute the resources equally between two component tasks, participants use selection processes to manage the two tasks. Particularly for older adults, bias might be indicative of loss-based selection.

The issue of finite resources and their efficient use is of great importance for each domain of functioning. The present work addresses the cognitive and the sensorimotor domain. In the following section, the focus is on the cognitive domain. First, I will briefly address the cognitive perspective on the issue of resource allocation. Specifically, the concept of *mental resources* within the framework of resource theories will be introduced. Next, I outline the experimental techniques the resource theories apply, in order to understand the perspective of cognitive psychology on how individuals manage a situation that requires concurrent performance of two tasks. Although several theoretical approaches provide an explanation for this account, for the purpose of this study, resource theories are most relevant because they allow assumptions about age-related differences in resource budgeting.

2.2 Cognitive Perspective on Resource Allocation

Although it seems intuitively highly plausible that performance of a (cognitive) task, and even more so parallel processing of two tasks, demands investment of mental effort or resources, most approaches in the field of cognitive psychology avoid the concept of resources. As an answer to the question what accounts for variations in the efficiency with which tasks can be carried out simultaneously, different hypothetical intervening variables have been proposed. Meyer and Kieras (1997a) mentioned that a person's ability to cope with complex situations depends on how information processing is coordinated across the tasks at hand. Those who advocate the single-channel hypothesis (e.g., K. J. W. Craik, 1948; Telford, 1931; Welford, 1952) propose that some mental processes needed for one task must necessarily wait whenever a person engages in another prior task. Within the framework of the perceptual bottleneck model (e.g., Broadbent, 1958), the process that identifies stimuli and determines their meanings is limited. For concurrent tasks, this limit could force people to deal with only one task at a time. Others (e.g., Pashler, 1984, 1990; Welford, 1967) argue that there is rather a response-selection bottleneck that allows accommodation of only one task at a time. However, examples abound of everyday life situations in which people are effective in performing two tasks concurrently (e.g., walking while talking or planning some activities). Thus, parallel processing should be assumed to be possible. This assumption was made by resource theories. I will elaborate on this theoretical approach in detail in the following section. First, I will introduce some accounts on the question of what mental resources are.

As Sperling (1984) argued, there are two approaches to this question. On the one hand, it is of great interest to learn precisely what particular mental resources are involved in cognitive functions. With respect to particular mental resources, the critical resources for which there is competition vary with the task (e.g., information processing speed, working memory). However, evidence from cognitive-experimental psychology (Conway & Engle, 1994) and the cognitive neurosciences (Shallice & Burgess, 1991) suggests that the abilities to inhibit actions and thoughts and/or to avoid interference are crucial for the efficient functioning of working memory and processing speed. On the other hand, one might argue that it is not necessary to know what mental resources are. They can be defined as a set of functions or structures that are relevant for performing a task (Heuer, 1996) or just as effort or capacity. The main underlying idea is that some mental commodity is invested to improve performance (Wickens, 1991), or that there are behavioral processes that evidence an increment or decrement in the effectiveness with which an organism handles current information from a given source in its environment (Swets, 1984). It is this mental commodity or the fundamental energy available to initiate and sustain information processing mechanisms that resource theories are based on.

2.2.1 Resource Theories

Several versions of unitary- and multiple-resource theory have been proposed to account for aspects of multiple-task performance. These models share a common perspective of resource limitation. As well as consensus, however, there is also disagreement on the issue of distinction between general and task-specific resources. A general resource, referred to as processing capacity (Moray, 1967), processing space (Kerr, 1973), processing power (Kiss & Savage, 1977), energy pools (Gopher, 1986), or mental effort and attention (Kahneman, 1973), is placed within a relatively undifferentiated pool of resources, and is one that can be allocated to any mental task. A task-specific resource arises from a certain set of resources that is assumed to have its own separate divisible source of capacity, and is restricted to a particular type of mental operation (Navon & Gopher, 1979; Wickens, 1984). Various disjoint sets of processing resources are used in combination for performing individual tasks. As it is not critical for the purpose of this work to differentiate whether two component tasks compete for resources from one large resource pool or from a subpool, I address basic conceptual ideas of the unitary-resource theory and summarize those assumptions that are most relevant to the present context.

2.2.1.1 Unitary-Resource Theory

Kahneman (1973) proposed the most influential version of the unitary-resource theory in which the terms ‘capacity’,‘attention’, and ‘effort’ are used as synonyms. This conceptual framework of generalized central capacity is based on four assumptions. First, attention is limited, but the limit is variable from moment to moment. Second, attention or effort exerted at any time depends primarily on the demands of current activities. The more demanding the task the greater the proportion of the performer’s limited processing capacity that will be allocated to maintain an acceptable level of performance. However, the increase is typically insufficient to fully compensate for the effects of increased task demands. That is why the unitary-resource theory assumes that interference between two concurrent tasks may occur if the demands of competing activities exceed a general limited central capacity. Consequently, the interference is larger, the more difficult the tasks are.

Third, attention is divisible. The allocation of attention is a matter of degree. As more resources are allocated to one task, fewer are available for the other. Fourth, attention is selective or controllable. It can be allocated to facilitate the processing of selected perceptual units or the execution of selected units of performance.

The decision whether a certain activity in a multi-task context should be prioritized (i.e., the allocation policy) is influenced by the three main factors[1]: (a) enduring predispositions (e.g., allocate capacity to any novel signal), (b) momentary intentions (e.g., allocate capacity to a selected activity), and (c) evaluation of demands (e.g., when two activities demand more capacity than is available, one is completed). An example from everyday life may help to clarify these ideas. When a young and an older person hold a conversation while hiking in difficult terrain (i.e., momentary intention) and facing an obstacle, the older person allocates attention to an obstacle as a potential cause of falls (i.e., enduring predispositions). Simultaneously, he or she stops talking and navigates the obstacle (i.e., evaluation of demands). The young person can, most probably, continue talking while stepping over the obstacle. Taking into consideration not only the approach of the resource theories but also the developmental perspective, this scenario demonstrates how individuals who differ in the amount of the limited capacity and enduring predispositions evaluate the task demands and deploy their resources between two concurrent activities.

Supplementing the main four unitary-resource theory assumptions, Kahneman (1973) admitted that the effort invested in a task is mainly determined by the intrinsic demands of the task, and that voluntary control over effort is quite limited. For example, there appear to be situations in which individuals simply cannot try as hard in a relatively easy task as they do when the task becomes more demanding. Thus, the interference between two competing tasks is not obligatorily larger for more difficult tasks than for easy ones. Additionally, Navon and Gopher (1979) pointed out that a dual-task situation could be more than the sum of two single tasks in terms of capacity demands. In such a case, ‘concurrence costs’ are likely to arise. Even if one task is strongly emphasized over the other, performance is typically worse in the dual-task context than in the single-task context. This Cost of Concurrence (COC) may be due to such things as distraction by the secondary task (resulting in the inability to allocate sufficient attention to the primary task)

[1] Kahneman (1973) pointed out the effects of arousal as an additional factor that controls the allocation policy. As it is not relevant for the present study, I will not elaborate on this aspect.

and the need to coordinate the two tasks. In order to analyze whether the deployment of attention is flexible, as predicted by unitary-resource theory, Norman and Bobrow (1975, 1976) applied the tools of economics such as utility functions relating performance to amount of capacity allocated.

Some assumptions of the unitary-resource theory can be tested using a single-task paradigm and varying difficulty levels. However, the notion of humans' limited capacity comes into play especially in situations when two or more activities have to be performed simultaneously, because if tasks compete for the same limited capacity, significant performance decrements should occur. Moreover, in order to clarify whether capacity is divisible and controllable, two or more concurrent tasks are needed. The research questions of the present study were investigated with the help of the experimental techniques that are used within the framework of resource theories. Therefore, I elaborate them in greater detail in the following section. These techniques allow the assessment of capacity demands in general and the allocation policy in particular. In the present context, I applied them in order to answer the following questions: How do young and older adults allocate their limited resources in a dual-task situation involving a cognitive and a sensorimotor task? How does the allocation policy look when these two tasks have to be performed simultaneously? In other words, is the deployment of resources more flexible in the cognitive than in the sensorimotor domain? Is the allocation policy more constrained the more demanding the tasks are?

2.2.1.2 Resource Theories' Experimental Techniques

In order to assess performance tradeoffs between tasks the resource theories apply a dual-task method. As the name implies, this method requires participants to perform two tasks simultaneously. On the other hand, one of the main ideas of dual-task research is to understand how individuals cope with demands of time-sharing in real life. As everyday situations rarely comprise simple, "discrete" actions, in experimental studies, it is primarily important to investigate interference between more complex tasks, often involving continuous performance, which may be more representative of real-world tasks. Continuous tasks may be construed as a sequence of assignments each of which is to be met fast enough to keep up with the change of stimuli (Navon & Gopher, 1980). In the field of cognitive psychology, one continuous performance task that is often used in combination with a discrete task is "tracking." In a typical tracking task, an erratically moving point of light is presented on a screen, and the observer must follow it with a cursor controlled by a joystick or mouse. Real-world tasks such as driving and flying have a central tracking component. It is assumed that monitoring the target stimulus and controlling the tracking device impose a more-or-less continuous demand on attention. Different versions of a tracking task have been used in combination with a choice reaction time task, a counting task, a classification task, externally paced reading, a Stroop task, short-term memory task, and so on. Other examples of continuous tasks are a signal detection task and time judgments.

The critical variable in a dual-task paradigm is the decrement in the performance of one task resulting from concurrent performance of the other task. This deficit, referred to as dual-task costs (DTCs), is supposed to arise because of the capacity interference[2]. Damos (1991) emphasizes that the amount of dual-task interference depends on six characteristics of the task combination – the number of stimuli, the modality of the stimuli, the correlation between the stimuli, the central processing requirements, the number of response channels, and the modality of the response channels. The general conclusion based on empirical findings is that the dual-task decrement was observed if the following combinations were used: two physically separate stimuli (i.e., placed side by side), the same modality (e.g., both stimuli are presented visually), two response channels (e.g., the right hand is assigned to respond for one task and the left hand for the other task), and the same response modality (e.g., vocal responses to both tasks). Moreover, performance in dual-task was worse than in single-task if stimuli did not correlate, participants did not integrate two tasks into one (i.e., did not respond to the stimuli for the two tasks simultaneously), and tasks did not require integration (i.e., usage of information from one task did not aid in responding to the second task). Dual-task research is known not only for the variety of tasks and of task combinations, but for several different techniques as well. The basic difference between these techniques is the type of instruction they use.

Secondary task technique is applied in order to assess the capacity demands of a certain task. Therefore, subjects are instructed to regard this task as primary and protect its performance against interference from the secondary task. The performance of a secondary task is supposed to change. The amount of this change serves as an indicator for the

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[2] Multiple resource models predict structural interference that occurs if tasks involve the same perceptual modality or response mechanisms. Accordingly, dual-task performance of structurally similar tasks that use common resources (e.g., two manual tracking tasks) will compete for the same resources and, thus, will result in larger DTCs. Consequently, there will be small or even no dual-task interference of structurally dissimilar tasks that use separate resources (e.g., a manual tracking task and a verbal shadowing task). Thus, resource allocation is expected to be less smooth and less linear.

demands of the primary task (Abernethy, 1988). It is assumed that the more demanding the primary task, the greater the proportion of the performer's limited processing capacity that will be allocated to maintain an acceptable level of performance. Poor secondary task performance is therefore assumed to parallel high primary task demands, whereas good secondary task performance is implied to accompany primary tasks that demand little of the performer's limited processing capacity. However, research has proven that such protection is hard to achieve and that the performance on both tasks usually varies (e.g., Kerr, 1973). A more sophisticated version of the secondary task technique is to vary the difficulty of the primary task, and to assess performance change on the secondary task. The main assumption of the unitary-resource model is that the more difficult the primary task, the more it consumes resources. Therefore, the larger deterioration in the secondary task is observed.

Prioritization of both tasks is the second technique that is applied to assess the performance decrement from single- to dual-task situations. Participants are required to perform both component tasks equally well. Within this technique, it is often assumed that participants obey instructions to prioritize tasks equally. However, the possibility remains that individuals may, in fact, allocate their resources unequally across tasks. Thus, this technique is a poor indication for capacity interference, because the measurement of divided attention takes place independently of resource allocation strategies. But, even if subjects can follow the instruction of protecting the primary task or prioritizing both tasks, then performance is compared on just one arbitrary condition of resource allocation. This condition provides a limited view of the interaction between tasks. To draw conclusions about the resources that tasks demand, performance tradeoffs have to be observed when task priority is systematically manipulated (cf. Gopher & Navon, 1980).

Manipulation of priorities, known as "attention sharing", is the third technique used within the dual-task paradigm. Participants are required to perform the same two tasks (say, A and B) several times over. In one condition, participants might be told that task A is relatively more important than task B, an instruction that should lead them to direct the majority of their mental resources to task A. In other conditions, task B is the one prioritized, or the tasks are designated as being equally important. This method makes it possible to determine whether individuals can change their relative emphasis on the tasks by means of instructions or payoffs (Norman & Bobrow, 1976). Moreover, additional information is gained through assessment of the performance of Task A in relation to Task B. The rationale for this method is that if time-shared tasks are assumed to compete for allocation of the same resources and attention or effort is under the person's control, then increasing the priority of one task should result in an increment of its share of resources, thereby leading to an improvement in its performance. In a similar vein, the decreased amount of resources allotted to the other task should, at the same time, lead to a decrement in its performance. It is assumed that such smooth tradeoff reflects the performer's ability to allocate and reallocate resources freely across the two tasks. Technically, the consequences of allocating resources in different proportions among two concurrently performed tasks can be depicted in the form of a trade-off curve. Norman and Bobrow (1975) called such a curve the Performance Operating Characteristics (POC)[3]. Figure 1 illustrates the manner in which empirical POCs can be obtained.

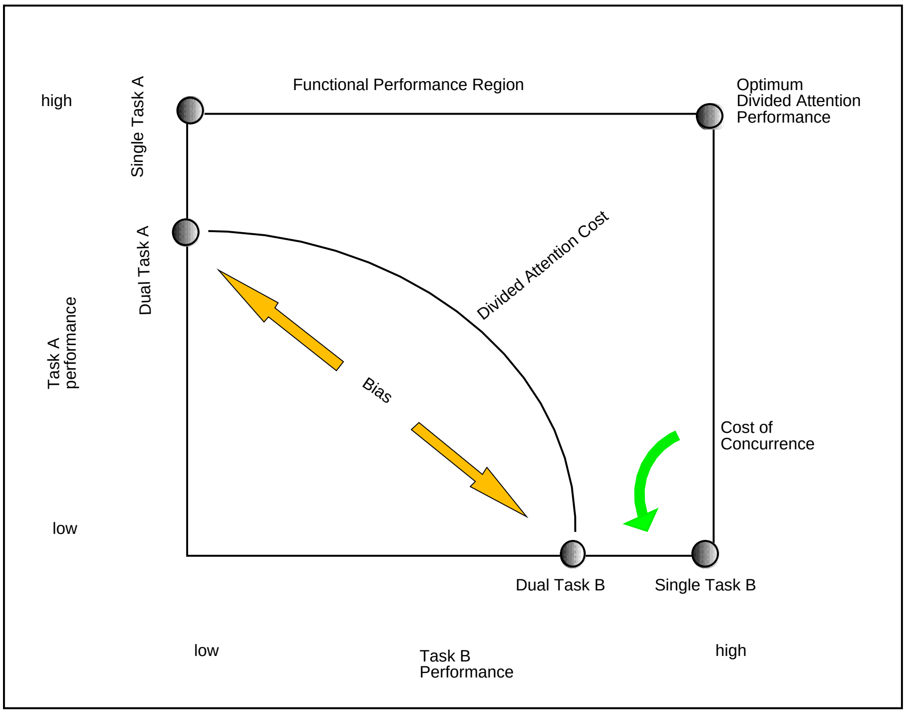

Figure 1. Hypothetical Performance-Operating-Characteristic (POC) function

[3] To obtain an empirical POC, performance on Task A is represented on the vertical axis and performance on Task B on the horizontal axis (see Figure 1). The maximum performance achieved by the subject on each task under the condition of full attention allows the delineation of the rectangular area called the Functional Performance Region (FPR). The point at the upper right corner of the FPR depicts the optimal divided attention performance. The Cost of Concurrence demonstrates that even if one task is strongly emphasized over the other, performance is typically worse in the dual-task context than in the single-task context. A POC curve is obtained by biasing the performer to emphasize one task over the other under different task priority conditions. This procedure can be used to yield several points from which a curve is derived to reflect the degree to which resources can be traded off between the two tasks. To the extent that there is a cost for dividing one's attention, the curve will be below the point of optimal divided attention performance. The region between the POC and the optimum is called Divided Attention Cost (DAC). The size of DAC is inversely related to one's divided attention ability.

When changes in resources affect performance in a way that a given number of units of resources removed from Task A (thereby decreasing its performance) can be transferred to and utilized by Task B (improving its performance), the process is called *resource-limited* (Norman & Bobrow, 1975). However, a possibility remains that performance change in one task does not occur concurrently with a change in the other. Wickens (1984) argued that such a situation exists if either (1) withdrawing resources from Task A will not deteriorate its performance but can improve the performance on Task B; or (2) the resources are not interchangeable between tasks so that resources withdrawn from Task A (thereby decreasing the performance on Task A) cannot be used to benefit performance on Task B. The first case is indicative of data limitation, because either a perfect performance can be achieved with little effort or the quality of the data is poor and one cannot improve performance no matter how much effort one invests.

However, Gopher and Navon (1980) proposed an alternative explanation for the observation that improvement in performance of one task can come only at the cost of deterioration in the other one. Namely, that greater involvement in one task might produce more harmful conditions for the performance of the other one. The possible confounding of resource allocation policy with difficulty effects has led the authors to the argument that more converging operations are needed to support the model of central capacity. That is, task difficulty and task emphasis should be jointly manipulated (Gopher, Brickner, & Navon, 1982; Gopher & Navon, 1980; Navon & Gopher, 1979). If several levels of task emphasis are employed and cause a common processing resource to be allocated in different shares among concurrently performed tasks, then difficulty manipulations that tap this resource should typically have an interactive effect with task emphasis. Specifically, larger effects of priorities should be manifested with the easier variant of the task. The more difficult the tasks are, the smaller the performance range in terms of the flexible resource allocation that should be observed. This is in fact a central question underlying the present study.

Navon and Gopher (1979) emphasized that, in the cognitive research, only few studies have manipulated task emphasis and even fewer have combined the manipulations of emphasis and difficulty. Meanwhile, there are findings demonstrating individuals' ability to flexibly allocate resources within a dual-task situation involving two cognitive tasks or a cognitive and a motor task. The unique focus of the present study is, however, on the influence of the task priority instructions on the simultaneous performance of a cognitive task and a sensorimotor task that possesses a high degree of ecological validity.

In the following sections, I will first briefly review the empirical evidence that supports the assumptions of resource theories. The implications for the present study will be presented next.

2.2.1.3 Empirical Evidence: Resource Allocation in Adulthood

Effects of divided attention on performance and the ability to flexibly allocate mental resources have been examined in several studies. For instance, Strayer and Johnston (2001) addressed the question of how young adults manage a simultaneous performance of a pursuit tracking task and either a conversation task, a listening task, a shadowing task, or a word generation task. The tracking task required keeping a joystick as closely as possible to a moving target that unpredictably flashed red or green. Participants were instructed to manually react as rapidly as possible when they detected the red light. In the first study, 48 students (age range 18 to 30 years) were engaged either in a conversation with a confederate or listened to a radio broadcast while concurrently performing the tracking task. The probability of missing red lights increased from single- to dual-task conditions for the "conversation group" but not for the "radio group". Similar results were obtained for the reaction times. In the second study, the difficulty of the tracking task was manipulated. In the dual-task condition, 24 undergraduates (age range 18 to 26 years) performed either a shadowing task or a word generation task. No dual-task interference was found in the shadowing condition. However, the word-generation task produced significant increase in tracking error, and this effect was especially pronounced in the difficult driving condition. These experiments demonstrated that young adults could perfectly manage a dual-task situation involving two easy tasks. Nevertheless, the interference between tasks is inevitable if the component tasks are made more difficult.

Another investigation asked the question whether the level of dual-task interference is related to the relative emphasis of the two tasks. Seventeen participants aged 21 to 47 years were asked to control the amount of attention that they devoted to one (counting of animal names) or the other component (reproduction of time duration) of a dual-task paradigm (Macar, Grondin, & Casini, 1994, Experiment 1). Using the "sharing attention" procedure, this study found that the time error percentage steadily increased as the proportion of attention devoted to duration diminished. The opposite pattern was observed with the percentages of word errors, which tended to decrease when larger proportions of attention were attributed to words. The attention-sharing instructions had consequences for the performance with regard to both components of the dual-task paradigm. Friedman, Polson, and Dafoe (1988) obtained similar results combining a motor task (i.e., tapping) and a verbal memory task that comprised reading, memorization, and recall. Young adults, tested in this study, recalled more under memory task emphasis than under tapping emphasis. Similarly, in going from memory emphasis to tapping emphasis, the tapping performance improved. This result indicates that young adults can control and divide their attention according to instructions if a motor task is combined with a memory task.

Other studies manipulated both task difficulty and task emphasis, in order to investigate whether larger effects of task emphasis are manifested with the easier variant of a task. Gopher, Brickner, and Navon (1982), for example, conducted an experiment with six young participants (aged 19 – 25) where a two-dimensional pursuit-tracking task was paired with a letter-typing task, the difficulty of which was manipulated. In addition, differential emphasis instructions were employed. This experiment showed that young adults were more flexible in resource allocation in the easy than in the difficult condition. Gopher and Navon (1980) reported similar findings. In their study, each simultaneously performed tracking dimension (horizontal and vertical) of a tracking task was treated as a separate task and independently manipulated. Tracking difficulty on each dimension and their relative emphasis were jointly manipulated. When frequency or velocity of target movement served as difficulty parameters, trade-offs between dimensions in different priority conditions were small and task difficulty neither had an effect on the performance of the concurrent task nor did it interact with task emphasis. When control complexity was manipulated as the difficulty parameter, the overall range of performance variation contributed by the priority manipulation was much narrower. The authors argue that when the efficiency of resources is reduced, that is, when the task is difficult, resource costs per unit performance are increased and the effect of resource allocation on performance is reduced as indicated by the reduced range of effects of the priority variable.

To summarize, empirical studies on dual-task performance of two cognitive tasks demonstrated that, in young adults, there was task interference, that is, the performance was worse in dual- than in single-task conditions. Moreover, the decrement was especially pronounced when at least one of the component tasks was made more difficult. These findings are in line with the assumption of the resource theories that if both tasks need access to the same pool of resources, the limitations of the general capacity are reflected in dual-task costs[4]. The more difficult or complex a task, the larger were the DTCs, most probably because more resources were needed to meet the task demands. The finding that young adults could follow the instructions to prioritize one or both tasks in a dual-task situation involving two cognitive tasks (or a cognitive and a motor task) is in line with the assumption that processing capacity is divisible and under individuals' control. However, the extent to which young adults could vary the relative amounts of processing capacity assigned to different tasks depended on the difficulty of those tasks. In other words, the resource efficiency was reduced if resource costs per unit performance were increased.

2.2.2 Implications for the Present Study

Although considerable empirical evidence supports main ideas of the resource theory, there have been a number of critical reviews of the resource metaphor in general and unitary-resource theory assumptions in particular. Navon (1984) argued that the graded trade-offs in the performance of two concurrently performed tasks might be due to demand characteristics rather than a real limit to available resources. Thus, performance deficit does not necessarily reflect a lack of resources. Other critics (Kieras & Meyer, 1997a; Pashler, 1994) noted that parallel processing may be impossible for certain mental operations. Some operations may simply require a single mechanism to be dedicated to them for some period of time. When two tasks need the same mechanism simultaneously, a bottleneck results, and one or both tasks will be delayed or otherwise impaired. Within the framework of the cross-talk models, interference between two concurrent tasks was explained in terms of different forms of outcome conflict, in which one task "produces outputs, throughputs, or side effects that are harmful to the processing of the other task" (Navon & Miller, 1987, p. 435). It remains an empirical question which of these ideas best explains the interference people encounter in performing various kinds of tasks concurrently (Pashler, 1994). Different accounts might be valid for different kinds of tasks. If the focus is on understanding of rather complex "real-world" activities such as coordination of a sensorimotor and a cognitive task in a dual-task situation, like in the present work, the resource theories provide a suitable theoretical framework.

[4] In their overview of recent studies on continuous dual-task performance, Pashler, Johnston, and Ruthruff (2001) show that practice can dramatically reduce dual-task interference. The authors argue that the very large interference effects observed with novel tasks might overestimate the amount of interference observed between pairs of highly practiced tasks in the real world.

Based on the assumptions of the resource theories and the empirical evidence that supports these theories, one of the expectations of the present study was that individuals would experience dual-task interference in a situation that requires concurrent performance of a cognitive and a sensorimotor task. The amount of this interference should vary according to task difficulty. If resources are divisible and controllable, as predicted by the resource theories, then individuals should be able to adjust their performance to instructions. However, to adjust one's performance according to instructions requires more effort (i.e., resources), the more difficult the tasks are. Thus, by manipulating difficulty level of the component tasks and combining this manipulation with the manipulation of task priorities, one of the specific research aims of the present study was to examine whether the effects of task emphasis are larger when both component tasks are easy than when they are difficult. In other words, this study investigated whether more demanding tasks would pressurize individuals to set their own priorities (i.e., to be less able to follow the experimental instructions) and to distribute their limited resources accordingly. The question arises, however, whether, in a dual-task situation that involves a task of high survival relevance, experimental manipulations of emphasis and difficulty and their specific combination would have different effects in the cognitive than in the sensorimotor domain. To my knowledge, this study is the first to address this crucial question. In the previous section, I have explained why a domain-specific asymmetry should be expected from the perspective of the SOC-model.

With respect to the age-related differences in resource allocation, I expected that young people would be able to allocate their resources flexibly. The flexibility, however, should be reduced in the more demanding condition when the issue of finite resources becomes especially important. The question then arises how individuals who experience pronounced limitations in resources manage dual-task situations. The resource models, in contrast to non-resource models, allow predictions with respect to age-related differences in concurrent performance of two tasks. These predictions could rest on the following rationale: Given resources are finite in general, it can be assumed that these limitations are especially pronounced in old age because of the biology-based changes in this phase of life. As old age is accompanied by resource reduction, the performance of older adults should generally be on a lower level. Moreover, these age-related differences should be particularly reflected in more demanding (dual-task) situations. Whether the pattern of resource allocation differs in young and older adults, is the central question of the present study. That is why the next section elaborates the issue of age-related differences in dual-task processing and their reasons.

2.3 Cognitive Aging and Resource Allocation

Advancing age is commonly accompanied by a decline in the efficiency of all the main systems important for everyday functioning. In the context of research on cognitive aging, three constructs were postulated to be responsible for age-related differences in intellectual abilities: information processing rate (e.g., Cerella, 1985; Salthouse, 1985, 1996), working memory (e.g., Babcock, 1994; Mayr & Kliegl, 1993), and inhibition (e.g., Hasher & Zacks, 1979). Research from all periods of the lifespan suggests that the functional levels of these three mechanisms follow the inverse U-shape pattern, that is, there is increment from childhood to early adulthood, and decrement thereafter (P. B. Baltes et al., 1998). Therefore, with age, performance on a large number of cognitive tasks declines (for review, see F. I. M. Craik & Salthouse, 2000). Additionally, it has been argued that older adults are especially penalized in situations that require division of attention between two cognitive tasks. What mechanisms underlie age-related differences in dual-task performance? Although much research has been done in an attempt to find answers to this question, there is still little agreement about the source of the deficit.

The most common assumption is that there is some *fundamental resource* on which all cognitive operations draw and that this resource is reduced in old age (i.e., diminished resource hypothesis; e.g., F. I. M. Craik & Byrd, 1982). In support of this view, Verhaeghen and Salthouse (1997) demonstrated that performance decrements are intercorrelated, suggesting that decline in a single cognitive “source” may lie at the foundation of those widespread age-related declines in cognitive performance. If older adults possess less resources, the age-related performance differences should become most apparent when individuals have to function at the limits of their cognitive functioning abilities (e.g., Kliegl & Baltes, 1987; Kliegl, Smith, & Baltes, 1990). A dual-task, in comparison to a single-task situation, is most probably more resource-demanding in particular for older adults.

Several authors argued that the same factors that are responsible for the age-related differences in single-task performance (e.g., information processing rate, working memory) affect concurrent performance of two tasks (e.g., Salthouse, 1985, 1996; Salthouse, Rogan, & Prill, 1984). Those who advocate the so-called “complexity assumption" suggest that division of attention simply increases the overall complexity of the situation. With respect to the effects of aging, it may be the case that the observed age decrement in performance would therefore be as great in a single complex task as in two shared tasks (McDowd & Craik, 1988). Impairment in dual-task performance, for example, could stem from the slowing of performance on the component tasks, as well as from slowing of processes that are necessary to coordinate the component tasks. In a similar vein, the more information has to be kept in working memory, the more difficult or complex the task is and, thus, the larger the difference between the dual-task performance of young and older adults is.

Neither the diminished general resource hypothesis nor the complexity assumption touch upon the alternative possibility that there is something about the divided attention situation itself that is especially difficult for older persons to handle. For instance, the availability of some specific abilities could be crucial in situations of divided attention (e.g., resource management and coordination). It is these abilities that were additionally proposed to account for age-related differences in dual-task processing. For instance, Hockey (1984) argued that, although specific resources are limited, the principal limitation on efficient performance is usually the limited capacity of the executive process. This system is responsible for the active direction of control between resources, for compiling temporary sequences of processes required for particular task demands, and for shifting the overall bias in processing from one pattern of resource availability to another in response to long-term priorities and current environmental influences on the resource state. Others proposed that reduced attentional control is an age-related phenomenon. Hasher and Zacks (1979), for example, suggested that aging is associated with reductions in consciously controlled processes (see also Jennings & Jacoby, 1993).

Another type of explanation appeals to the potential importance of age-group-specific strategies that might be used in dual-task situations. Glass and coworkers (Glass et al., 2000) argue that older adults, in comparison to young individuals, use a more cautious strategy when performing two concurrent tasks, that is, they allow less overlap of the processing stages for each task (see also Meyer, Glass, Mueller, Seymour, & Kieras, 2001). Therefore, Salthouse and colleagues (1982, 1984) as well as Kramer and collaborators (1996, 1999) postulate "strategy-independent" measures of divided attention in young and older adults. In terms of the resource theory techniques, assessing performance independently of the individual's strategies means applying different task-emphasis instructions. This kind of data collection is supposed to give information on whether age groups bias two component tasks differently in a dual-task situation.

Most probably, the nature of age-related differences in dual-task performance is multifactorial. Meyer and Kieras (1997a, 1997b) proposed an executive-process interactive control (EPIC) architecture that provides a basis for analyzing the combined effects of such distinct factors as general slowing, executive function, and task-coordination strategies on age-related decrement in the performance of dual tasks (see also Meyer et al., 2001). The authors argue that EPIC models yield accurate accounts of aging effects on reaction times[5] and accuracy in basic dual-task and working memory paradigms.

The current study was conceived and planned within the general framework of the SOC-model. In order to investigate whether young and older adults allocate their resources differently in a dual-task situation that involves a cognitive and a sensorimotor task, the present study used the resource theories in general and the task-priority technique in particular. Dual-task procedures (see Section 2.2.1.3) appear to provide an ideal test of the assumptions about age-group differences in multi-task behavior. If resources are more limited in older than in younger adults, then dual-task costs should generally be larger in older adults. It is possible that, under the instruction of equal prioritization of both tasks, one component task consumes a greater proportion of the available resource, leaving less for another component task and resulting in differentially poorer dual-task performance in older than in younger adults. This difference should be even more pronounced if the component tasks are more demanding.

The question then arises on which of the two component tasks older adults will perform better and why. Previous research on concurrent performance of two cognitive tasks generally did not pick out this issue. The experimental paradigms that investigated speed-accuracy trade-offs are an exception. Combining a cognitive task with a task of high ecological validity, like balancing, this study aimed at examination of age-group as well as domain-specific patterns of resource allocation. Additionally, the technique of task-priority variation allows the further specification of differential bias-tendencies in young and older

[5] Within the EPIC architecture, the assumptions about age-group differences in dual-task performance have been tested involving two tasks with the psychological refractory period (PRP) procedure. A trial starts with a warning signal, followed by a stimulus for the first task in which the participant must make a rapid choice reaction. Soon after the onset of Task 1 stimulus, the stimulus for the second task is presented, and the participant must make another rapid choice reaction to it. The time between the onsets of the two stimuli is the stimulus onset asynchrony (SOA), which can vary from short (0 ms) to long (1,000 ms or more). Participants are instructed to give Task 1 priority over Task 2. Reaction times are measured to assess how much Task 1 processing interferes with Task 2 processing.

adults. If performance is better in a certain task (domain) regardless of task-emphasis instructions, one could assume that participants prioritize this domain. However, any kind of prioritization might not necessarily be strategic and conscious, but can also be (intentionally modulated) automatic behavior. On the basis of the diminished attentional control hypothesis, older adults should have more difficulties in situations that require management and quick redeployment of resources. It is conceivable that the elderly select the task most important to them and invest more resources in its performance. For example, in a dual-task situation in which a tapping task and a memory task are performed concurrently, it is possible that especially older adults “protect” resources for the cognitive task at the expense of tapping, because within this particular task combination, memory performance is more important than a motor task (but see K. Z. H. Li et al., 2001, for findings on prioritization of the sensorimotor but not the memory task). Although these rationales seem logical, the literature on aging and divided attention provides contradictory results. In the following section, I present empirical evidence demonstrating that there are age-related differences as well as similarities in the simultaneous performance of two cognitive tasks or a cognitive and a motor task and the ability to distribute one’s resources across them. Afterwards, potential reasons for inconsistent findings as well as implications for the present study will be discussed.

2.3.1 Empirical Evidence: Are there Age-Related Differences in Resource Allocation?

In his summary of the dual-task and aging literature, F. I. M. Craik (1977) suggested that, “One of the clearest results in the experimental psychology of aging is the finding that older subjects are more penalized when they must divide their attention, either between two input sources, input and holding, or holding and responding” (p. 391). In recent years there have been a number of critical reviews of the methodological details of the earlier dual-task studies that suggest caution in interpreting the age-related differences in performance found in the 1960s and 1970s. Somberg and Salthouse (1982), for example, summarized the following factors that reduced the conclusiveness of the available research on aging and divided attention: (a) overemphasis on a single experimental paradigm; (b) failure to account for age-related differences in single-task performance; (c) failure to report single-task measures on all tasks; and (d) failure to measure divided attention independent of resource allocation strategies. However, some of the more recent and methodologically sophisticated examinations of the relationship between aging and dual-task decrements obtained results that confirm F. I. M. Craik's (1977) suggestion.

Crossley and Hiscock (1992) investigated age-related differences in the attentional capacity of young (20 – 40 years), middle-aged (41 – 65 years), and elderly adults (66 – 90 years). The single-session experiment involved three different cognitive tasks of two difficulty levels: reading, speaking, and maze completion. Each cognitive task was performed in conjunction with the same speeded finger-tapping task. All component tasks were measured under single-and dual-task conditions. Additionally, a task-emphasis manipulation was included to control for resource allocation strategies. The authors found that the decrement in tapping rate from the single- to dual-task condition increased linearly with age. Concurrent-task tapping was slowed more by difficult than by easy tasks, and difficult tasks had a disproportionately disruptive effect on the concurrent performance of older participants. Age-related differences in concurrent-task performance persisted even when a proportional decrement score was used as a statistical control for differences in single-task rate. With respect to a possible age-related shift in resource allocation strategy, this study showed that older adults were as able as young participants to emphasize either one (i.e., motor) or the other (i.e., cognitive) component task. Crossley and Hiscock (1992) discussed the results of this study within the framework of the reduced general-purpose processing resources model.

In another study, Salthouse, Rogan, and Prill (1984) compared young (18 – 22 years), and older adults (59 – 82 years), in their efficiency of remembering concurrently presented series of letters and digits in three separate single-session experiments. The participants were asked to shift their attention from one task to another according to five task-emphasis instructions. This study demonstrated that older adults were more penalized than young adults by the divided-attention requirement, even after the difficulty of the concurrent tasks was adjusted to the same proportional level for each individual subject, and even after controlling for age-group differences on each task when performed in isolation. However, despite less efficient divided-attention performance in older versus young adults, both groups allocated attention across task-emphasis conditions in a similar fashion. The authors attribute these findings to the preserved ability to distribute one's attention across two concurrent activities. Moreover, they argue that although less resources are available in old age, the effectiveness with which they are allocated among concurrent activities does not seem to be reduced between 20 and 70 years of age.

As Hartley (1992) concluded in his comprehensive review of age-related differences in attentional processes, there is strong evidence for substantial decrements in dual-task processing during aging across a wide variety of tasks and dependent measures. However, there are some examples demonstrating that older individuals' concurrent performance of two tasks do not differ from that of their younger counterparts. For instance, Somberg and Salthouse (1982) reported two single-session experiments in which dual-task scores were assessed relative to each subject's single-task scores. Participants were instructed to vary the way in which they allocated resources between two tasks. In the first experiment, young (18 – 23 years) and old (57 – 76 years) participants responded to two simultaneous visual displays. In the second experiment, response time was the dependent variable for manual reaction time and repetitive keying tasks. In both studies, the authors found neither age-related divided attention effects nor differences in the ability of young and old adults to divide their attention according to instructions. However, Somberg and Salthouse (1982) noticed that absence of age-group differences might be specific for the pairs of tasks they used, and that there might be other processes (e.g., memory or perceptual impairments) that are responsible for the poorer performance of older subjects.

Taken together, the empirical evidence mentioned above is mainly consistent with the diminished resource hypothesis. Older adults showed larger dual-task processing decrements compared to their young counterparts in tasks that rely heavily on working memory, speed, or motor components. Thus, it appears conceivable that some variant of the resource hypothesis might, in part, account for age-related decrements in dual-task performance. Moreover, these studies demonstrated that young and older individuals were equally good at varying their processing priorities between two tasks. The empirical evidence presented below is, however, in line with the hypothesis that performing two or more tasks simultaneously is more difficult for older adults because they are less efficient than younger individuals in the rapid and strategic redeployment of resources among two or more tasks or processes.

In a study conducted by Tsang and Shaner (1998), for instance, age-related difficulty in allocation control was found. Asking the young (20 – 39 years), middle-aged (40 – 59 years), and old adults (60 – 79 years) to perform dual tasks involving manual tracking, mental rotation, and working memory and using the POC technique, the authors found that the oldest group was not capable of transferring the resources released from one task to the other task. In addition, the precision of resource allocation control was investigated in this study. This was assessed by how closely participants adhered to an externally imposed performance standard. The results provide an illustration of an age-related deficit in controlling resource allocation, with the optimized performance becoming increasingly divergent from the standard with increased age.

Anderson, Craik, and Naveh-Benjamin (1998) addressed the question of age differences in cognitive control of episodic memory processes. In the second experiment of the study, for example, 24 younger (mean age = 21 years) and 24 older adults (mean age = 67.9 years) were asked to memorize 12 word pairs and to perform a secondary reaction-time task concurrently. Moreover, the participants had to vary their attention according to three emphasis conditions. This experiment found that age-related differences in relative memory costs were larger for the older adults during encoding but not during retrieval. However, only the younger adults' memory performance was affected by task-emphasis instructions and only during encoding. These results suggest that episodic memory requires more attentional resources in old than in young age, and that attentional control of encoding operations is reduced among the older adults.

In sum, the empirical evidence is inconclusive with respect to age-related differences in dual-task performance in general and in executive processes in particular (Salthouse, 2001). Some studies provide results suggesting that old participants showed decline in dual-task performance compared to young individuals (e.g., Hawkins, Kramer, & Capaldi, 1992; Korteling, 1991; McDowd & Craik, 1988). At the same time, enough data exist demonstrating that young and old adults are similarly disrupted in dual-task situations (e.g., Baron & Mattila, 1989; Korteling, 1994; Rogers, Bertus, & Gilbert, 1994; Somberg & Salthouse, 1982; Wickens, Braune, & Stokes, 1987). A similar picture emerges with respect to flexibility in resource management. The question arises why the findings on age-related differences in dual-task performance are inconclusive. I will address the issue of potential reasons for the lack of age-group differences in dual-task studies in the following section.

2.3.2 Potential Reasons for Inconsistent Findings on Age-Related Differences in Resource Allocation

Several authors have pointed out the need for a closer look at the conditions under which inconsistencies in findings on age-related differences arise. Rabbitt, Lowe, and Shilling (2001) emphasize such factors as indices of measurement, problems of task familiarity, of task specificity and construct validity, and finally, much-neglected problems of cohort selection. Similarly, Birren and Fisher (1995) argue that the performance of older individuals is differentially sensitive to particular task characteristics. That is why the extent of age-related differences might be related to the nature of the tasks being performed. Meyer and colleagues (Meyer et al., 2001) underline that cognitive strategies for performing tasks may vary greatly, depending on task priorities, personal predilections, training, and other contextual factors. Moreover, specific age-related effects may not hold for all adult subgroups. Special care is needed to interpret results from each subgroup.

Within dual-task research, Lindenberger et al. (2000) suggest that large age-related differences in dual-task costs appear when: (a) the two tasks share the same stimulus modality, working memory representation, or response modality, especially if the stimulus-response mappings of the two tasks overlap in incompatible ways (cf. Damos, 1991); (b) when information regarding the identity and sequencing of the two tasks has to be maintained and coordinated without the aid of external cues; (c) when one or more of the constituent tasks themselves impose high demands on cognitive control processes such as focusing attention, scheduling and planning, and updating and checking, as well as coding contextual representations. Additionally, task difficulty, complexity, familiarity, and specificity as well as the age of subjects were picked out as central answers to the question why dual-tasks do not consistently produce age differences in performance.

For instance, the Somberg and Salthouse (1982) study employed only simple perceptual detection tasks that may not have taxed the capacity of older adults. Wickens, Braune, and Stokes (1987) included relatively complex component tasks that ordinarily would have been expected to produce age-related divided attention deficits. However, they tested relatively young adults (mean age 58 years) in the older group and found that dual-task performance was intact. It has been demonstrated that various types of practice and familiarity serve to moderate findings of age differences. Rogers, Bertus, and Gilbert (1994) mentioned that some studies that have reported age differences on dual tasks provided much less practice. In contrast, those studies reporting an absence of age-related differences have tended to provide substantially more practice. Similarly, Mayr, Kliegl, and Krampe (1996) argued that age effects in performance, which are present even after extensive practice, can be considered more indicative of basic processing limitations than the “baseline” age differences usually obtained in single-session experiments. The closer subjects are to asymptotic performance, the more performance should reflect “hard” limitations rather than “soft” constraints such as inexperience with working under time pressure or problems understanding the task (Kliegl, Smith, & Baltes, 1989).

Several authors, however, argue that the extent to which older adults time-share well between dual-tasks is affected by the *type of training* they receive (e.g., Kramer & Larish, 1996; Meyer et al., 2001). Two general classes of training strategies have been employed in dual-task settings: part-task and whole-task training techniques. Part-task training has been defined as practice on a subset of components of a task or skill prior to practice on the whole task (Lintern & Wickens, 1991). The major advantage of this kind of training is that it serves to reduce the magnitude of the processing demands imposed upon subjects by the whole task. However, one of the disadvantages is that this technique does not provide the possibility to acquire critical attentional control and task coordination strategies. Accordingly, after being trained only in each component task separately, adults show large dual-task costs (e.g., K. Z. H. Li et al., 2001). Whole-task training involves the training of all components of a task at the same time. The main advantage of this training strategy is that it enables subjects to develop task coordination and attentional control strategies. However, the main disadvantage of whole-task training is the possibility that the processing demands will be so excessive that subjects are prevented from fully learning either of the tasks (Nissen & Bullemer, 1987). Given the relative strengths and weaknesses of these two strategies, Kramer and colleagues (1995, 1996, 1999) suggest a hybrid part-whole-task training procedure that has been demonstrated to be quite effective in dual-task settings. The basis of this training technique is the learning of flexible task coordination strategies that enhance the rate and level of mastery of dual tasks. However, others (e.g., Fisk & Rogers, 1991; Schneider & Fisk, 1982) argue that in order to eliminate dual-task performance decrements both consistent single-task component practice and subsequent dual-task practice are needed.

As cognitive aging is not gradual and uniform in all respects, some parameters change modestly over the lifespan, whereas other parameters remain almost constant until 70 years of age, but change more rapidly thereafter. It is conceivable, thus, that a particular combination of tasks to be performed simultaneously may be a critical factor for whether increased age differences are observed (cf. Nyberg, Nilsson, Olofsson, & Bäckman, 1997). Within the field of cognitive psychology, various combinations of reaction time, working memory, tracking, tapping, signal detection, and other tasks have been employed so far. Although these tasks range from being very simple to rather complex and difficult, they are primarily laboratory tasks by nature and their ecological validity is doubtful. As Somberg and Salthouse (1982) emphasized, more experimental paradigms are needed to fully understand the potentials and limits of an aging system in the situations of divided attention. The question arises whether age-related differences in dual-task performance actually exist when highly practiced skills, well-learned routines, or almost automatized tasks that are highly adequate for everyday "real-world" functioning, are paired with cognitive tasks. It is conceivable that, for example, being life-long experts in walking and talking older persons experience no problems in situations where they have to carry on a conversation while crossing a lively street.

Tun and Wingfield (1995) made an attempt to understand how young and older adults divide attention in everyday life situations. Using a self-assessment scale, the Divided Attention Questionnaire (DAQ), the authors examined whether adults report that dividing attention between two activities becomes more difficult with increasing age. In this study, young (18 – 27 years) subjects rated combinations of activities including fairly routine, overlearned motor activities that require little executive monitoring for their successful execution as significantly easier than did the young-old (60 – 71 years), the old (72 – 81 years), or the old-old (82 – 91 years). The authors suggest that there is some change in the perceived difficulty of such routine activities as talking and/or thinking while doing chores and talking while walking after young adulthood. It is reasonable to suppose that older adults not only *perceive* difficulties performing such daily activities but *experience* them in everyday life as well. As the information assessed through self-report data often differs from actual behavior (cf. Lindenberger et al., 2000), it is of interest to know whether there are age-group differences in performance if, for instance, a sensorimotor task is paired with a cognitive task.

2.3.3 Implications for the Present Study

Empirical evidence provides conflicting findings with respect to age-related differences in dual-task performance and the ability to adjust the performance of two cognitive tasks according to experimental instructions that vary the emphasis on the component tasks. Several authors proposed the age of participants, the difficulty or complexity of experimental tasks, and the task novelty as possible explanations for the inconsistent findings. I circumvented these problems in the present study by testing young individuals and adults of 70 years of age and older, by including task-difficulty manipulation, and by providing both age groups with both single- and dual-task practice prior to the assessment of performance. Moreover, the dual-task practice required variation of task priorities between the two tasks across different blocks. If the present study demonstrates age-group differences in the concurrent performance of a cognitive and a sensorimotor task and in the ability to prioritize either the one or the other component of the dual tasks, the age-group-specific pattern of results cannot be due to the age of study participants, task unfamiliarity, or lack of task difficulty manipulation.

A particular combination of tasks used in dual-task research provides an alternative explanation for inconsistent findings of age-group differences. It is an intriguing question to investigate whether there are differences in dual-task performance of young and older adults if an experiment requires a simultaneous execution of a cognitive (reaction-time [RT]) and a sensorimotor (balance) task. One can expect age-related deficits to be more pronounced in the cognitive than in the sensorimotor domain. Two possible rationales underlie this expectation. On the one hand, larger age-group differences in dual-task interference in the cognitive than in the sensorimotor domain might appear because the balance task possesses a high degree of ecological validity (i.e., has greater importance for survival). As it is of much relevance to older adults and their daily lives, they should protect their stability more than their cognitive performance. On the other hand, one can argue that keeping the body's equilibrium as in standing is a highly practiced automatic task. But is it really the case that in a dual-task paradigm involving a cognitive and a sensorimotor task, young and older adults differ only with respect to their cognitive abilities? The next chapter addresses this question.

2.4 Sensorimotor Aging and Resource Allocation

Aging is accompanied by many losses. Side by side with emerging deficits in the cognitive system, the efficiency of all the main sensory and motor systems tends to be impaired in old age as well. Such sensorimotor abilities as balance and gait are no exceptions. In other words, older adults experience reduction in different types of resources necessary for everyday functioning. Activities of daily living rarely consist of discrete tasks that can be accomplished one after another. In most cases, individuals are confronted with continuous tasks such as standing or walking that are, in turn, accompanied by talking, thinking, reading, memorizing, perceiving events, making decisions, and carrying out the action decided upon. How do older adults behave in common situations in which a sensorimotor and a cognitive task have to be performed simultaneously? Everyday observations suggest that older, in comparison to young individuals, must invest many more resources or pay more attentional effort to such activities as going up- or downstairs, crossing a slippery street, or keeping balance while standing in a bus. Sensorimotor functioning is even more challenged if resources (attention) are distracted from it by other tasks, like crossing a busy street while talking. Thus, standing or walking, which seem automatic at first glance, could be an example of everyday intellectual functioning. This chapter demonstrates that although posture control is viewed as a highly practiced skill, keeping balance becomes increasingly difficult in old age and that this deficit becomes especially apparent in dual-task situations. One of the assumptions of the present study is that decreasing resources lead older adults to "intelligent" resource management, that is, prioritization of balance in multi-task situations. However, a first step toward a better understanding of age-group differences in concurrent performance of a sensorimotor and a cognitive task is to explain how the sensorimotor system and its components function.

2.4.1 Balance and the Balance System

Although keeping balance seems an easy task, the "simple act" of balancing is actually a series of behaviors involving the coordination of many body parts to maintain equilibrium under different postural demands (Slobounov, Moss, Slobounova, & Newell, 1998). Moreover, maintaining an upright stance can be characterized as controlling the position and orientation of each individual body segment so that the line of gravity of the center of mass of the entire body falls within the supporting surface delimited by the position of the feet. A balanced static stance is therefore obtained as long as this criterion is met and muscular action to overcome gravitational pull is present. Most balance researchers take the systems approach to understand motor behavior in general and balance in particular. The *"systems"* or *"distributed control"* model evolves from the work of Bernstein (1967). In systems theory, the body is modeled as a mechanical system with mass that is subject to gravity and inertial forces. Because these factors change as human beings move, the same motor program yields different movements depending on the position the body is in. Bernstein's model asks questions about the organism as an active agent in a continuously changing environment. Within the systems framework, the physiology of activity, not reactions, is explored. According to the systems model, the nervous system is seen as part of a flexible complex of systems and subsystems sharing in the control process. Thus, movement is always an emergent property that comes from the complex interactions of these systems.

In this framework, balance is viewed as a behavior that emerges from the complex interaction of a number of subsystems, including the sensory systems, the motor system, the musculo-skeletal components, *and* a high-level adaptive system that has a strong cognitive component (e.g., Woollacott, 2000; Woollacott, Moore, & Hu, 1993). The sensory inputs originating from the somatosensory, visual, and vestibular sensory organs provide highly redundant information on the position and movement of the body, and conditions of the surrounding environment. This complex sensory information needs to be analyzed and integrated in a manner that will generate an efficient functional motor output required to maintain balance and perform such tasks as standing or walking. One might think that posture control and standing upright can be performed automatically; however, this can by no means be generalized to the entire lifespan. The next section addresses the question of age-related changes in the components of the balance system. Following that, I discuss the specifics of balance behavior in old age.

2.4.2 Age-Related Changes in the Balance System

Infants at around one year of age are incapable of keeping balance simply because maturation of the system is not accomplished until the age of around 4 to 6 years (Dietz, 1992; Shumway-Cook & Woollacott, 1985; Woollacott & Shumway-Cook, 1990). In contrast, older adults usually find balance a demanding task because several functions that are relevant for balance behavior become less efficient in the elderly (for reviews, see Kenshalo, 1977; Simoneau & Leibowitz, 1996; Sloane, Baloh, & Honrubia, 1989; Stelmach & Worringham, 1985). In the following, I summarize age-related changes in specific subsystems.

The vestibular system. The primary functions of the vestibular organs are to assist in the production of postural corrections and to provide awareness of head position and motion in space. With age, the vestibular organs deteriorate progressively. For example, vestibular sensory cells begin to degenerate at about the age of 40 years, and this decline is approximately linear from then on, reaching about 40% loss by the age of 75 (Rosenhall, 1975). Similarly, Lopez, Honrubia, and Baloh (1997), based on a linear model, found that there was approximately a 3% neuronal loss in the human vestibular nuclear complex (VNC) per decade from age 40 to 90. As VNC is a major visual-vestibular interaction center, age-related neuronal loss in this organ leads to dizziness and disequilibrium.

The visual system has two distinct functions that contribute to the control of balance: spatial orientation and recognition. Impaired spatial visual ability may provide distorted information on the location, orientation, and movement of the body in relation to its environment. Such visual deficits as decreased light transmissivity, visual acuity, contrast threshold sensitivity, ability to adapt to sudden changes in ambient light, and the reduction of the size of the useful field of view (UFOV)[6] lead to impaired recognition in terms of identification of environmental hazards. Except for depth perception and color vision, visual performance deteriorates sharply as individuals become older. For example, developmental changes of the visual acuity have the inverted U-shape (Verrillo & Verrillo, 1985). After the age of 50 there is a steady decline. The results of the Berlin Aging Study (BASE; P. B. Baltes & Mayer, 1999; Mayer & Baltes, 1996) showed that each additional decade of life, from 70 to 100 years, was associated with significantly lower visual acuity (Marsiske et al., 1999). Ball, Beard, Roenker, Miller, and Griggs (1988) could demonstrate that UFOV shrinks with age. However, Sekuler, Bennett, and Mamelak (2000) argue that the UFOV size is the same in young and older adults, but that older observers process information within the UFOV less efficiently (see also Seiple, Szlyk, Yang, & Holopigian, 1996). The culmination of the visual deficits may reduce a person’s ability to rely on vision, to use stable orientation cues, and to identify conditions that may cause a fall.

The somatosensory system provides afferent information from nerve endings located in the skin, joints, and muscles throughout the body. Mechanoreceptors located in the cutaneous and subcutaneous structures of the plantar surface of the foot contribute to the control of balance during stance and gait by mediating the perception of touch, pressure, and shear taking place under the feet during these movements. Empirical evidence shows that there are age-related changes in the cutaneous vibratory perception of the foot (Wu, 1998) and that older adults are less sensitive to pressure than young persons. For example, S.-C. Li, Jordanova, and Lindenberger (1998) found a significant negative age trend in pressure threshold sensitivity. Moreover, Stevens and Choo (1996) demonstrated that declining spatial acuity of the body surface with age was especially pronounced in toes and sole. The deteriorations in the somatosensory system may lead to inability to detect stimuli and to provide correct sensory information needed for balance and locomotion.

The motor system. The muscular action needed to maintain posture and to achieve mobility requires proper function of the cerebellar motor system, the lower motor neurons, the neuromuscular junctions, and the muscle contractile units. It is necessary to control more than 700 muscles in a synchronized and purposeful way in a multi-link system, in order to maintain an upright posture during bipedal standing (Era et al., 1996). Empirical

[6] UFOV is defined as the total visual field area in which useful information can be acquired without eye and head movements, that is, within one eye fixation.

evidence shows that the motor component of the balance system deteriorates in old age. For example, Lexell (1993) could demonstrate that aging atrophy in terms of muscle area, total number, size, proportion, distribution and arrangement of two fiber types begins at around 25 years of age and accelerates thereafter. With age there is a loss of motor neurons in the spinal cord and a reduction in the number of functioning motor units. Additionally, it was found that there are significant changes in dynamics of postural muscle activity during quiet standing associated with aging (Huang, Rubin, & Leod, 1999). However, the literature on the lower level reflex abilities (for an overview, see Hay, 1996) provides findings that there are no age-related changes in the function of reflexes (e.g., Achilles tendon reflex, the Tonic vibration reflex).

One could assume that degeneration processes taking place in these different components of the balance system might jointly lead to age-related changes in balance behavior. However, a reduced flexibility of the central integrative mechanisms responsible for configuring the postural systems was put forward to explain the difficulties met by elderly adults in regulating posture (e.g., Woollacott, 2000). Thus, it is not the decrement in peripheral sensibility conditions per se that influences the age-related instability, but rather the reduced peripheral sensation may demand increased cognitive regulation and/or a decreased automaticity in sensory integration processes. In other words, as people age, sensory inputs contributing to balance control are reduced, and there is less redundancy of sensory information. Human beings are induced to rely more on the adaptive system that modifies motor behavior according to changes in internal or external environment. As the efficiency of cognitive functioning is reduced in older adults, one would expect that especially aging individuals have more difficulties with sensorimotor tasks, and particularly in situations in which they have to keep balance and to accomplish some mental activities.

Several studies have addressed the relationship between the functions of cognitive and sensorimotor systems on the correlational level. They suggest some general ideas hinting at potential relationships between sensorimotor and cognitive functioning. Results of BASE show an impressive magnitude of the relationship) between balance/gait and intellectual functioning in older adults aged 70 to 100 years ($r = .56$; Marsiske et al., 1999). In this study, intellectual functioning represented an aggregate of the five primary intellectual abilities (perceptual speed, memory, reasoning, fluency, knowledge). Balance and gait was assessed in terms of the *Romberg trial* and the *360° turn test* (Tinetti, 1986). Similarly, Anstey, Stankov, and Lord (1993) demonstrated that balance correlated with performance on several cognitive tests. The authors examined women between the ages of 65 and 91 years. Body sway was measured using a simple sway meter that measured displacement of the body at the level of the waist in a 30-s period. The relationship between the balance measure and simple reaction time was positive (r = .23), whereas correlations between sway and performance on some measures of fluid intelligence (e.g., perceptual speed: r = -.30; induction: r = -.19) were negative.

In the following sections, I briefly address the issue of age-related differences in balance behavior if a sensorimotor task is performed alone. Next, I provide a review of empirical evidence on how young and older adults allocate their resources between a cognitive and a sensorimotor task in a divided attention situation.

2.4.3 Empirical Evidence: Age-Related Differences in Balance Behavior

One method to investigate whether balance performance of young and older adults differs is to objectively quantify the amount of sway during quiet stance using a force platform. This technique allows recording of the movement of the estimated center of pressure (COP) of the body. Several dependent variables can be derived when assessing balance behavior in this way. For example, it can be calculated how long the path of the COP is for a given period of time. Next, the velocity with which the body moves can be computed. Finally, the area within which the COP can move safely without a change in the support base can be an indicator for the ability to keep one’s stability. It has been proposed that the longer the COP path, the higher the COP velocity, or the larger the COP area, the less stable the body is[7] (e. g., Means, Rodell, O’Sullivan, & Winger, 1998; Thapa, Gideon, Brockman, Fought, & Ray, 1996).

2.4.3.1 Single-Task Situations

Several empirical studies have demonstrated that the elderly exhibit a greater amount of body sway and have higher sway velocity when standing quietly on a force platform. For example, Toupet and colleagues tested 500 adults, ranging in age from 40 to 80 years, and found that postural sway in terms of COP movement increased with each decade of life (Toupet, Gagey, & Heuschen, 1992). However, others found that the age-related

[7] Patla, Frank, and Winter (1990), suggested, however, that increased body sway is not necessarily an indication of a lesser ability to control upright posture. Instead, the greater sway noticed in the elderly may be in response to a shift in the primary sensory system relied upon to control posture. It is hypothesized that, in the older population, increased sway may serve to augment proprioceptive input through the increase in joint movement at the ankle.

differences in stability are more pronounced when the feedback from one or more balance subsystems is reduced. For example, using a stable balance platform and varying visual flow conditions, Wade and collaborators observed that healthy older adults moved significantly more in terms of COP measurements than their younger counterparts in response to visual flow simulating sway (Wade, Lindquist, Taylor, & Treat-Jacobson, 1995). Because measures of balance during quiet stance may be insensitive to many balance problems in older adults, and are quite different from the requirements needed in everyday life, scientists have begun to use an additional paradigm to measure reactive balance function (Woollacott, 2000). This is a moveable platform that produces external disturbances to body's equilibrium and, thus, can simulate balance threats. With the help of this technical device, the ability to restore balance after perturbations can be measured, and it is this ability that is considered to be more adequate for predicting everyday functioning. The empirical findings can be summarized as follows: First, age-related differences in the amount of body sway are more pronounced in the dynamic (moveable platform) than in static conditions (e.g., Baloh et al., 1994). Second, older adults are less stable than their younger counterparts if input from two or more subsystems involved in balance is distorted (e.g., Baloh et al., 1994; Manchester, Woollacott, Zederbauer-Hylton, & Marin, 1989; Woollacott, Shumway-Cook, & Nashner, 1986). Third, older individuals take longer to stabilize their balance after external disturbance to balance (e.g., Stelmach, Teasdale, Di Fabio, & Phillips, 1989; Stelmach, Zelaznik, & Lowe, 1990). Fourth, in old age, individuals use other strategies in order to control their balance (e.g., Brown, Shumway-Cook, & Woollacott, 1999).

To have an opportunity to concentrate oneself exclusively on one's balance is a rare occurrence in everyday life. As I have already mentioned, activities of daily living almost always require the concurrent performance of a sensorimotor and a cognitive task. If the ability to maintain equilibrium is reduced in old age and this is due to increased interaction between the functions of the cognitive and the balance system, how do the elderly coordinate their behavior in dual-task situations? It is conceivable that they cannot simultaneously perform two tasks equally well. The question arises which of the two domains is more relevant in old age. In order to understand the nature of prioritization behavior in older adults, it is necessary to examine the consequences of loss of balance in old age, that is, falls. Simoneau and Leibowitz (1996) suggest four discrete complications of falls: injury, fear, decreased mobility, and morbidity. These consequences often represent a continuum (from injury to morbidity) in the events following a fall. Therefore, although death may also occur as a sudden result of a fall, it is more likely to be the end result of a fall-related injury that is followed by increased fear of falling and concomitant decreased mobility.

How often do falls occur? The knowledge of the frequency of falls in the elderly population living independently at home is limited. It is estimated that 30% to 50% of adults 65 years of age and older and 40% of adults over the age of 80 experience one or more falls annually (e.g., Sattin, 1992). One could speculate that only those who suffer from severe diseases fall. However, the majority of falls in community-dwelling persons over 75 years occur in those with few or no neurologic or musculoskeletal abnormalities (Tinetti, Speechley, & Ginter, 1988). Moreover, the majority of falls in elderly persons occur during their usual daily life activities, such as walking or changing position (e.g., Tinetti, Speechley, & Ginter, 1988). As carrying out only one activity at a time, in isolation, is rare, it is possible to assume that everyday life is filled with activities that involve multiple-task performance. It may, thus, reasonably be asked whether doing several things simultaneously is per se a risk for falling in old age. If this is the case, it is conceivable that older adults experience more difficulties with posture control in a multiple-task context. Moreover, one could expect that if older adults have to share their limited cognitive and sensorimotor resources in a dual-task situation, they would invest more resources in their balance in order to preserve their stability and not to fall. The next section addresses the issue of age-related differences in sensorimotor behavior in multi-task situations.

2.4.3.2 Dual-Task Situations

The empirical evidence generally shows that if a sensorimotor and a cognitive task have to be performed simultaneously, there is dual-task interference. An additional finding is that the dual-task costs are higher in older than in younger adults. However, a great deal of inconsistency exists with respect to the domain-specific locus of this interference. Using either the technique of the secondary task or of equal prioritization, several investigations demonstrated DTCs in the cognitive domain. Lajoie, Teasdale, Bard, and Fleury (1996), for example, measured stance under two difficulty conditions (i.e., on a broad and narrow support surface) and RT in a secondary auditory reaction time task (i.e., give a verbal response to an auditory stimulus). They found that increasing the difficulty of the balance task significantly increased RT in the secondary task in older (66 – 79 years), but not in young adults (22 – 34 years). This finding indicates that with age there is an increasing cognitive involvement in balance and that, in a dual-task situation, older participants give preference to their stability but not to the performance of the cognitive task. Teasdale and colleagues obtained similar findings (Teasdale et al., 1992; Teasdale, Bard, LaRue, & Fleury, 1993). Additionally, the authors found that the position of the COP affected the RTs of the elderly. The closer the center of pressure was to the edge of the support surface, the longer were the reaction times. Lindenberger et al. (2001) carried out an age-comparative study to examine whether the simultaneous execution of a challenging locomotion task (i.e., skilled walking) and an episodic memory task becomes increasingly difficult with advancing age. The equal-priority technique was used in the dual-task phase. Results of this study show that the costs of concurrent performance of walking on a narrow track and memorizing a list of words increased significantly with age in both domains. Lindenberger and colleagues were the first who controlled age differences on each task performed in isolation. Thus, they not only examined the absolute change in dual-task in comparison to single-task performance, but also calculated the relative dual-task costs. In the study by Karen Z. H. Li and collaborators (K. Z. H. Li et al., 2001), the method of investigation was even more sophisticated (see Section 2.1.1.1 for a detailed description of the study). The authors found that age-group differences in dual-task costs were greater in memory performance than in walking, suggesting that older adults prioritized walking over memory. This finding not only reveals the inability of older adults to perform concurrent walking and memorizing equally well, but shows that in old age a sensorimotor task gains special priority because older adults used the walking compensatory device more often than their younger counterparts. These results suggest that, despite the instruction to prioritize both tasks, older adults selected walking instead of memorization in a dual-task situation.

However, several authors demonstrated that the locus of dual-task interference was primarily in the balance domain. For instance, Stelmach, Zelaznik, and Lowe (1990) investigated the effects of two cognitive tasks on the recovery of young (19 – 21 years) and older (66 – 74 years) subjects from the minor postural disturbances caused by arm swinging. The main result of this study is that when attention was occupied by a more demanding cognitive task, recovery in the elderly was impaired. Maylor and Wing (1996) have investigated the differential influence of five cognitive tasks on postural stability in two age groups (aged 57.1 and 77.2 years). Specifically, they have found that the performance on the balance task was more affected by secondary memory tasks (Brooks' spatial memory and backward digit recall) in comparison with other cognitive tasks (random digit generation, silently counting, and counting aloud backward in threes). A more recent investigation by Maylor, Allison, and Wing (2001) demonstrated that body sway of participants aged 20 – 79 years was reduced by encoding stimuli (particularly in the spatial task), but increased by maintaining stimuli (particularly in the nonspatial task). Shumway-Cook and Woollacott (2000) used more sophisticated equipment for balance assessment, that is, a movable force platform capable of sway-referenced rotation. They showed that the effect of the secondary auditory task on postural stability in different age groups depended on the six different sensory conditions. These conditions changed the availability of accurate visual and somatosensory cues for postural control. The auditory task required listening to one of two tones and identifying whether the tone was high or low as quickly and as accurately as possible. Results showed that in young adults (24 – 50 years), the auditory task did not affect postural stability in any of the sensory conditions. For healthy older adults (65 – 85 years), the addition of an auditory tone task significantly affected sway only when both visual and somatosensory cues for postural control were removed. In the balance-impaired older adults (76 – 95 years), the addition of the auditory task significantly affected postural stability in all sensory conditions. In sum, the results of this study suggest that, in old age, sensory conditions play an important role, especially in dual-task situations.

Taken together, findings on attentional demands of postural control in general support the hypothesis that sensorimotor performance requires more “attentional resources“ (F. I. M. Craik & Byrd, 1982) with advancing age. Three general findings emerge from these studies: First, maintaining a stable upright posture is a complex process that can be rather demanding cognitively, especially in old age. Second, with age, attentional demands for postural control increase as sensory information decreases. Third, dual-task activity has a greater impact on balance control in older than in young adults. With respect to the domain-specific locus of dual-task interference, there is more divergence than consistency in the empirical evidence. Whereas several investigations (e. g., Maylor, Allison, & Wing, 2001; Maylor & Wing, 1996; Shumway-Cook & Woollacott, 2000; Shumway-Cook, Woollacott, Kerns, & Baldwin, 1997) found (higher) dual-task costs in the sensorimotor domain, others (e. g., Brown, Shumway-Cook, & Woollacott, 1999; K. Z. H. Li et al., 2001; Teasdale et al., 1992, Experiment 2; Teasdale, Bard, Larue, & Fleury, 1993) demonstrated (higher) dual-task costs in the cognitive domain. Several authors have drawn the conclusion that the inability to allocate sufficient attention to postural control under multitask conditions may be a contributing factor to imbalance in older adults (e. g., Teasdale et al., 1992), and, therefore, DTCs in the sensorimotor domain. The finding of the dual-task interference in the cognitive domain might be explained as a natural reaction of human beings to protect their stability, especially in rather demanding situations. However, the opposite pattern of results was found as well. In the next section, I address the issue of possible reasons for the existing inconsistency in the empirical findings on the domain-specific locus of dual-task interference and draw implications for the present study.

2.4.4 Implications for the Present Study

Like earlier dual-task studies that combined two cognitive tasks, some problems hamper the interpretations of results from research on concurrent performance of a sensorimotor and a cognitive task (cf. Salthouse, Rogan, & Prill, 1984; Somberg & Salthouse, 1982). First, the unknown resource requirements for each component task made it impossible to draw conclusions about differences in performance of each single task compared to simultaneous execution of two tasks. Second, even if baseline level was assessed, the age differences on each task when performed in isolation remained uncontrolled. Thus, the dual-task costs were measured in terms of absolute but not relative decrement (see K. Z. H. Li et al., 2001; Lindenberger et al., 2000, for notable exceptions). Third, almost all extant studies are single-session experiments. This means that the age-group differences found may be the result of the insufficient task familiarity that plays a particular role for the performance of older adults. The present study circumvented the problems mentioned above and measured the performance of both component tasks on single as well as on dual-task trials. The age-group differences in both single tasks were controlled. However, the most critical point for the divergent findings in the available research on concurrent performance of a sensorimotor and a cognitive task is, in my view, the experimental instruction. Most studies applied either a secondary task technique or the instruction of equal task-emphasis. Some researchers do not report how the study participants were instructed for dual-task trials. It is conceivable, thus, that previous findings are inconsistent with respect to the domain-specific locus of dual-task interference because of lack of control over the individual’s relative emphasis on one task or the other. Subjects, thus, could “protect” resources for the cognitive task at the expense of balance (cf. Navon & Gopher, 1979) because many cognitive tasks have an obvious and absolute performance criterion (e.g., correct recognition or recall, rapid response), whereas balance very often does not. To my knowledge, the standard instruction used in most balance studies was to stand upright and to avoid taking a step if possible. Research participants might put effort primarily on the concurrent cognitive task, so that balance would suffer to some extent, whereas cognitive performance would not.

What can be done in order to shed more light on the phenomenon of resource allocation within a concurrent sensorimotor and cognitive performance and to investigate age differences in the coordination of these tasks? Employment of explicit instructions to emphasize either a balance or a cognitive task, or to perform both tasks equally well would provide a condition in which there would be no reason to protect performance on the cognitive task when the balance task is emphasized. This procedure would make it possible to demonstrate, first, whether older adults can follow the instructions and allocate their resources accordingly if a balance and a cognitive task must be performed concurrently, and, second, whether older individuals prioritize stability regardless of what experimental conditions require. These are the main goals of the present study.