Summary

In our modern society, complex technological systems typically require people to perform several tasks in a limited period of time. In order to be able to optimize such technological systems, the present thesis aims at explicating some difficulties with regard to the fundamentals of multiple-task performance theory—especially in relation to aging—and at providing some basic theoretical improvements.

First, the fundamental assumptions of the main recent theories concerning multiple-task performance—i.e., resource theories along with the two-modes-of-processing theory—are critically examined. In brief, these theories are based on the notion that human performers possess one or a few 'pools' or supplies of central limited-capacity resources ('fuel metaphor'). On the basis of training, subjects can learn to allocate these limited resources more efficiently to the subtasks—e.g., by optimal allocation strategies or by circumventing the limitations of central attentional resources (automaticity). A theoretical analysis shows that these current frameworks offer rather trivial explanations, lack neurobiological support, and do not sufficiently account for behavioral plasticity with training. The prevalent conception of attention as 'central supervisory control' does not provide an explanation for what has to be explained, i.e., the control process itself. Therefore, the present capacity theories lack the conceptual depth needed to acquire accumulating knowledge—that is, knowledge concerning the underlying mechanisms determining performance in complex psychomotor tasks.

In this connection, a cognitive neuroscience framework is invoked, which starts with current knowledge concerning the basic principles of brain functioning in combination with the nature of capacity limitations in human performance. According to this framework, the problem of limited behavioral capacity can not be successfully explained by postulating any a priori capacity limitation, but rather by the way biological systems satisfy two conflicting requirements: massive associative processing power and flexibility against coherent and goal-directed action control. This control conflict is not solved by a mysterious supervisory attentional system. Behavior control basically emerges from the elementary, self-regulating, characteristics of neuronal information processing, such as coincidence detection or mutual inhibition. Such basic mechanisms also determine capacity limitations as shown in multiple-task performance.

In addition, neurobiology and psychological evidence indicates that the nervous system is well-suited for integrated information processing. Hence, attentional limitations generally occur when perceptual, cognitive, or motor operations have to be
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Summary of the text: Require people to optimize such difficulties with the degree to which dual-task elements are related or coherent, such that subtasks can be performed as a whole. The question whether or not task elements can be integrated or should be kept separate depends on the available control parameters in the combination of subtasks. In general, when there is coherence or compatibility in the processes that have to be combined and difference or incompatibility in processes that should be kept separate, attentional performance will be enhanced. In contrast, when there is difference or incompatibility in the processes that have to be combined and coherence or compatibility in processes that should be kept separate, mutual inhibition and cross talk will hamper attention performance.

In this connection, the global concept of similarity was invoked as an important factor determining the difficulty of coping with specific dual-task requirements. Similarity refers to elementary relationships among subtask with reference to all possible task variables, such as semantic or grammatical similarities, or similarities in color, form, or orientation. Similarity was supposed to facilitate a combined or integrated performance of subtasks and thus to enhance task performance when it involves coherent inputs, processing routines, actions, or subtask goals. This was termed coherent similarity. Coherence refers to common, related, corresponding, correlated, or supplementary subtask elements, in relation to the overall objectives of the dual-task. When subtask elements are characterized by coherent similarity, subjects may integrate them into higher-order elements, such that the limitations inherent to the organization of different processes are overcome.

Degradation of similarity were supposed to appear when subtask goals, processing routines, timing mechanisms or stimulus-response mapping between subtasks are different or unrelated. This was termed incoherent similarity. The selective activation of processing routines and actions will then become more critical. Consequently, subjects may unintentionally combine the subtasks, such that cross talk or confusion results. When tasks are characterized by incoherent similarity, the extent of cross talk interference will depend further on the availability of other control parameters (e.g., elementary visual or phonological cues) enabling segregation of task elements. This was termed consistent difference.

With regard to the mechanisms underlying effects of training, skill development can be understood as a gradual transition from information processing by general-purpose brain programs, covering a broad range of task processes, to special-purpose brain programs. Special-purpose brain programs are smart neuronal networks with a specific aim and an efficient organization. In comparison to general-purpose programs, special purpose brain programs require lower degrees of activation in order to dominate (inhibit competing programs). Their execution shows lower metabolic
activity, which may be experienced as effortless and subconscious. However, they also require very specific input constellations in order to be activated.

Special-purpose programs will usually dominate over general-purpose programs (mutual inhibition) when both are activated by the same task elements. However, when both refer to different levels of the same task or at different tasks, special-purpose and general-purpose skills can very well co-exist, e.g. steering a car and route planning in a driving task (different levels) or steering and calculating (different tasks).

By dual-task training, subjects can learn to benefit from coherent similarity or to handle incoherent similarity. With regard to subtasks sharing consistent relationships, individual single-task skills (or brain programs) may be associated and integrated into a common special-purpose skill of a higher-order. This new special-purpose skill capitalizes on the specific peculiarities of the overall task situation. Hence, the dual task will, to a certain degree, be performed as a single-task.

With reference to subtasks characterized by incoherent similarity, training may increase the specificity of skills. When skills become more specific, the chance that simultaneous actions will depend on the same brain programs will decrease. Training may involve separate training of individual task components, or complete dual-task training. Accordingly, both single-task and dual-task training may strengthen the specificity of skills, and thereby enhance dual-task performance. As opposed to single-task training, however, only in dual-task training, interacting or correlated activity among (to-be-segregated) brain programs can be faced, e.g., capitalizing on control parameters enabling segregation of task elements.

The experimental literature reports one major hypothesis explaining why older adults are more penalized than young subjects in multiple-task situations, i.e., the slowing-complexity hypothesis. The slowing-complexity hypothesis states that on the basis of cumulative effects of generalized slowing, aging-related performance deteriorations increase with task complexity. Because dual-tasks represent just one of several ways to increase overall task complexity, older adults perform relatively poor in dual tasks.

There are several problems with the slowing-complexity hypothesis. The hypothesis, for example, tends to neglect decrease of neuronal connections accompanied with hypertrophic changes in neuroglia and decreasing plasticity. This decline of neuronal connections does not occur generally, but concerns only selective parts of the brain. For example, large neural losses are found in the prefrontal areas and in the hippocampus. These areas are particularly associated with behavior adaptation and organization and with the consolidation of adaptations. These losses reflect a global distinction that can be made between abilities that are relatively sensitive to the effects of aging and abilities that are less sensitive, or 'age-irrelevant'. Age-irrelevant tests generally involve familiar and over-learned skills, such as verbal abilities that do not require
However, they also require special-purpose programs that are not integrated into the general-purpose elements. However, different tasks, special-purpose programs, such as driving a car and route calculating (different tasks), are not integrated into general-purpose skill programs. Hence, the dual-task training may increase. Training leads to complete dual-task training may strengthen the specific-purpose skill programs. As opposed to the slowing-complexity hypothesis, capitalizing on the basis of several ways to perform tasks requiring self-initiated activity and behavioral adaptations, and finally, to process information quickly. The behavioral effects of these problems will increase with task complexity, or the number of required processing operations.

On the basis of the cognitive-neuroscience orientation, it may be supposed that dual tasks require processing operations that are especially difficult for older people. These operations globally can be grasped in terms of the integration and segregation of skills (brain programs), as determined by coherent and incoherent similarity among subtasks. In this context, the experiments described in this thesis were focused on the identification of problems that older subjects may have with task variables that are specific for dual-tasks and thereby gaining more insight into underlying mechanisms that determine the magnitude of age-effects in (complex) dual-tasks.

Like older people, subjects who have sustained diffuse brain damage usually are also hampered by general psychomotor slowing. In order to explore specific aging-related effects of general slowing on information processing, in the first, exploratory, study older subjects were compared with brain-damaged subjects in laboratory RT tasks and in more complex car driving RT tasks. The first question concerned possible differences between older-, brain-damaged-, and control subjects in the level of persistent processing activity, which is considered a basic mechanism of generalized slowing. The data showed that only with regard to the effects of stimulus alternations, confirmation was found for the hypothesis that the level of residual neuronal activity increases with age.

Speed-related differences between the older subjects and the controls were not significant in a familiar driving task (platoon-car-following), even when task load was increased. Furthermore, correlations between perception-response speed, as determined in laboratory RT tasks, and perception-response speed in car driving as an over-learned practical aggregate of skills, were only found to be high for the brain-damaged subjects. Thus, as opposed to brain-damaged subjects, for older subjects,
be expected, with compound stimuli, problems of older people in dual-task allocation of task elements, and the characteristic that was expected differences as a characteristic that was assumed to affect asymmetry (similarity of display and coherence). It was assumed to affect the same processing mechanisms. It was therefore expected that older in dual-task procedures. Besides, only the negative effects of dual-task performance. Because dual-task processes are independent, the 'resources', the dual-task conditions varied in the requirement to alternatingly prioritize one of the two subtasks. In general, the older subjects' performance did not differ from younger counterparts, except when the single- or dual task involved routine modification in car following. This is in support of a presumed age deficit in modifying existing brain programs or in suppressing the activation of irrelevant brain programs. Introducing demand alternation in counter-phase did not affect dual-task performance and showed no age effects. The finding that counter-phase difficulty alternation did not affect task performance may be explained by the fact that this variation probably was so clearly imposed by the visual input, that subjects automatically responded adequately accordingly. Finally, the data were not completely consistent with the complexity hypothesis.

The magnitude of age effects in single- and dual tasks may be affected by the degree to which performance depends on well-learned skills that were previously developed. In addition, age-effects may be affected by the requirement to modify these skills and by attentional requirements emerging from the mutual relation of subtasks. In the fourth, final, study, described in Chapter 9. Effects of skill modification and emerging dual-task processes were examined in an experiment, in which experienced drivers performed a vehicle steering task and a speed-following task in a driving simulator. Car-following was performed under two conditions of familiarity, determining whether or not a normal psychomotor routine had to be modified. In dual-task performance, the demand of subtasks was constant or alternating in counter-phase, which means that the dual-task conditions varied in the requirement to alternatingly prioritize one of the two subtasks. In general, the older subjects' performance did not differ from younger counterparts, except when the single- or dual task involved routine modification in car following. This is in support of a presumed age deficit in modifying existing brain programs or in suppressing the activation of irrelevant brain programs. Introducing demand alternation in counter-phase did not affect dual-task performance and showed no age effects. The finding that counter-phase difficulty alternation did not affect task performance may be explained by the fact that this variation probably was so clearly imposed by the visual input, that subjects automatically responded adequately accordingly. Finally, the data were not completely consistent with the complexity hypothesis.

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Data (correlations between independently disturbed tracking axes) partially confirmed this 'incompatibility of integrality hypothesis'. In general, negative effects of incompatibility of integrality were the greatest when partial integration involved integration of the response component. Both performance measures indicated that with increasing axis similarity of subtasks, task performance of the old subjects was more hampered than that of their young counterparts. These data were too specific for a multiple-resource explanation.

As has been stated before, with increasing age, the isolation between active brain mechanisms may decrease. It will then become more difficult to keep simultaneous processing operations separate. This will increase the susceptibility for cross talk in task performance. The paradoxal combination of increased cross talk with incoherent similarity (Chapter 8) and decreased benefit from coherent similarity (Chapter 7) with increasing age, can be explained on the basis of a simple neuronal model, consisting of stable pyramidal and degenerating granular cells.

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