Aging and cognitive control

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Chapter 1

Introduction

It is well established that performance of people on cognitive tests declines with age (e.g. Schaie, 1994; Verhaeghen & Salthouse, 1997). Several theories have been proposed to explain cognitive decline with age. Most of these theories can be categorized either as general factor theories or specific loss theories.

The currently dominant general factor theory is the global speed hypothesis (Salthouse, 1991, 1996). The global speed hypothesis states that age-related cognitive decline can be attributed to a decrease in the speed with which elementary cognitive operations are carried out. The decrease in information processing speed places limits on performance levels that can be reached on most cognitive tasks (Birren, 1956; Cerella, 1985; Eearles, Connor, Smith & Park, 1997; Salthouse, 1996). Evidence for the global speed hypothesis is mostly derived from mediational analyses, and studies show that the relation between age and cognition is reduced or diminished when statistically controlling for speed measures which relate to both the cognitive measures and age.

Among specific loss theories, age-related differences are often connected to age-related functional and structural changes in the brain. Specific loss theories are inspired by evidence that some cognitive abilities are not at all susceptible to age effects. This group of theories focuses on age-related changes in specific cognitive processes. Typically, in these theories a distinction is made between behavior that is dependent on executive control processes and supposedly affected by advancing age, such as switching between tasks, divided attention and selective attention (McDowd & Shaw, 2000; Braver, Barch, Keys, Carter, Cohen, Kaye, Janowsky, Taylor, Yesavage, Mumenthaler, Jagust & Reed, 2001; de Jong, 2001; Kramer, Larish & Strayer, 1995; Mayr & Kliegl, 1993), and behavior which is less or not dependent on control processes and is free from age-related effects.

A prominent theory of the relation between aging and changes in executive control function is the frontal lobe hypothesis of aging. This hypothesis holds that a differential decline in old age of neural tissue in the frontal lobe occurs (Raz, 2000; Van der Molen & Ridderinkhof, 1998; West, 1996). Correspondingly, cognitive functions that are related to the frontal lobe are hypothesized to be affected by age more strongly than cognitive functions related to other regions of the brain. Performance on executive control functions have been found to rely strongly on the integrity of the frontal cortex as evidenced by studies with patients with frontal lobe lesions, and with neuroimaging studies (West, 1996; Fuster, 1997)

In this introductory chapter first executive control functions and the relation to other psychological constructs (intelligence, intention and goal activation) and neurobiological constructs (frontal lobe function, neuromodulation) will be discussed. Then these aspects of cognitive control functions will be discussed in relation to cognitive aging. Finally, an outline of the rest of the thesis will be given and the other chapters will be introduced.

1.1 Cognitive control

The concepts of cognitive control and executive functions are often used interchangeably. The term ‘cognitive control’ is used more in the context of the cognitive processes and in the field of cognitive and experimental psychology. ‘Executive function’ is used in the field of neuropsychology and in the context of functions/outcomes of the cognitive system that accommodate tasks in every day life situations. Executive functioning is conceptualized as super-ordinate control and as a top-down system sub-serving several basic cognitive domains (Baddeley, 1998; Shallice, 1982). In this thesis ‘cognitive control’ and ‘executive functions’ will also be used interchangeably.

Cognitive control refers to organizing and monitoring cognitive processes. It is crucial for making behavior adaptive and controlling behavior according to intentions and internal goals. The concept of cognitive control implies endogenous control of processes and, in that sense, can be contrasted with situations in which behavior is cued, triggered or prompted explicitly from or by the environment. Situations which place a high demand on cognitive control processes are situations in which tasks to be performed are novel or characterized by weak environmental support. Examples of those are situations in which an automatically triggered response needs to be suppressed, and situations in which two or more tasks need to be performed at the same time or in succession (see e.g. Baddeley, 1986; Meyer and Kieras, 1997; Monsell, 1996; Norman and Shallice, 1986).

Cognitive control has been conceptualized as a unitary process that is the same in different situations. It has also been conceptualized as a composite of fractionated control processes. In the latter case, cognitive control process operations in one situation can be different and distinct from those operating in another situation. Several models of cognitive control have been developed from both conceptualizations.

1.1.1 Models of cognitive control

Two of the first and most influential models of cognitive control are the model by Baddeley and Hitch (1974) and the model developed by Norman & Shallice (1986).

The model by Baddeley and Hitch (1974) proposed that short-term memory involves not only passive storage but also active manipulation of information that is attended to in order to transfer the information to long-term memory. The model fractionates working memory into two 'slave systems', and an attentional control system. The slave systems are a visuospatial sketchpad capable of holding and manipulating visuospatial information and a phonological loop performing a similar function for verbal information. The control system, termed central executive, coordinates the two slave systems and links to long-term memory. The central executive in the model is not fractionated, which makes the model prone to the objection that the central executive is just a convenient homunculus (Baddeley, 1996).

The model of Norman and Shallice (1986) is based on a production-system architecture. In this model specialized routines (thought and action schemata) are triggered by conditions which are linked to specific schemata by if-then statements (productions). If a condition triggers multiple schemata, a mechanism termed 'contention-scheduling' is used to prevent response conflict and errors. Control by contention-scheduling works by means of lateral inhibition between the triggered schemata, resulting in a dynamic of more and less activated schemata. Eventually the most strongly activated schema will direct action or thought. Contention scheduling is efficient in producing routine behavior in well-known situations. Norman & Shallice (1986) outline five situations in which this routine, automatic control will not be sufficient for optimal performance (see also Burgess, 1997). These are situations that require planning or decision making, situations that involve error correction or troubleshooting, novel situations, dangerous situations and situations that require the overcoming of a strong habitual response. To enable the model to incorporate optimal behavior in these situations, Norman & Shallice (1986) introduced a second, higher order, level of control termed Supervisory Attentional System (SAS). The SAS exerts control in order to accommodate behavior to the overall goals of a person. In line with these goals, it can intervene in the contention scheduling. This schema modulation intervention by the SAS is realized by biasing the operation of contention scheduling by additional activation or inhibition of lower level schemata. In terms of this model executive control (by

SAS) is necessary because the automatic processes of the contention scheduling mechanism are inadequate with respect to goal-directed behavior. The SAS implies constant monitoring of the results of actions and comparing it to the goals one has set (Brouwer and Fasotti, 1997).

Several researchers have proposed, and worked on, deconstructing SAS or the central executive (Myiake, Friedman, Emerson, Witzki and Howerter, 2000; Stuss, Shallice, Alexander and Picton, 1995; Tranel, Anderson and Benton, 1994). These studies are often inspired by findings of dissociations in performance among executive tasks, for instance some patients fail on one executive test but not on another (e.g. Godefroy, Cabaret, Petit-Chenal, Pruvo & Rouseaux, 1999).Also, computational models of cognitive control have been developed (e.g. Kimberg & Farah, 1993; Cohen, Dunbar & Servan-Schreiber, 1990) that provide a more detailed account of control processes than the unitary SAS or Central Executive, but are mostly constructed to model the performance characteristics of a specific task. Also other studies, focusing on individual differences (e.g. Lehto, 1996, Lowe and Rabbitt, 1997; Myiake et al., 2000; Robbins et al. 1998; Burgess, 1997; Burgess, Alderman, Evans, Emslie and Wilson, 1998; Duncan et al., 1997), mostly using batteries of executive tasks, provide evidence for a non-unitary view of executive functions. A consistent pattern in the results of these studies is that the intercorrelations among different executive tasks are low and often statistically not significant. Also, exploratory factor analysis tends to yield multiple separable factors of performance measures on a battery of executive tasks, rather than a single (unitary) factor. Nevertheless, there are weaknesses and limitations connected to these correlational approaches and consequently to the conclusions that can be drawn from them (Baddeley, Della Sala, Gray, Papagno and Spinnler, 1997; Rabbitt, 1997). The lack of strong correlations between different executive tasks can also be a result of differences in the non-executive performance requirements of the different tasks.

Miyake et al. (2000) conducted an individual differences study on executive functions to provide an empirical basis for developing a theory that specifies how executive functions are organized and what role they play in complex cognition. They focused on separability of the three most postulated executive functions in the literature: shifting of mental set, monitoring and updating of working memory representations, and inhibition of prepotent responses. Furthermore they aimed at specifying the relative contribution of these executive functions to complex tests that are commonly used to assess executive functioning, by means of latent variable analysis. Three tasks for each of these executive functions were selected to be performed by the participants. To address the issue of the separate nature of the three executive functions Miyake et al. (2000) performed confirmatory factor analysis (CFA). They found that a three-factor model (in which each factor represents one of the three postulated executive functions) provided a better fit to the data then a one-factor model (which postulated unseparated/unitary executive function). They also tested two-factor models (in which two of the three executive functions were postulated as one factor) and even though these models provided reasonable fits, none provided a better fit than the three-factor model. The model that provided the worst fit, though, was an alternative 3-factor model in which the three factors were independent. Based on these findings Miyake et al. (2000) concluded that though the three executive functions are distinguishable, they are not completely independent and there is some underlying commonality. They also found that shifting, updating and inhibition abilities differentially contribute to performance on commonly used executive tasks, such as the Wisconsin Card Sorting Test (WSCT), the Tower of Hanoi (TOH) and the Random Number Generation task. Together with other theoretical proposals (Duncan et al., 1997) they argue that a simple dichotomy between a 'unitary' and a 'non-unitary' view on cognitive control will not suffice to help reconcile the controversy, and both views should be taken into account.

1.1.2 Cognitive control and the frontal lobes

In the field of neuropsychology, performance deficits in executive functions are often found as a consequence of lesions to the frontal lobes (West, 1996; Fuster, 1997). Consequently much research has been conducted on the relation between executive functions and the integrity of the frontal lobes. Frontal lobe damage usually leads to behavioral deficits like a tendency to perseverate and distractibility. These impairments are not in a specific cognitive or behavioral domain, but rather in the organization, control and monitoring of cognitive abilities (Duncan, 1986, Shallice, 1988, Monsell, 1996). Most researchers agree that the frontal lobes play an important role in the executive control of behavior and many studies have linked the two (Shallice & Burgess, 1991; Stuss, 1992; Stuss & Benson, 1984).

As a result the term 'frontal function' is sometimes used metaphorically to denote executive functions, even though they are conceptually and empirically not identical (Baddeley, Della Salla, Gray, Papagno & Spinler, 1997; Burgess, 1997; Myiake et al. 2000). Many of the tests that are referred to as "frontal tests" appear sensitive to damage in other areas in the brain (Della Sala, Gray, Spinnler & Trivelli, 1998). In other words, patients with lesions outside the frontal lobes can show severe deficits in tests of executive functioning (Anderson, Damasio, Jones & Tranel, 1991; Reitan & Wolfson, 1994). Moreover, not all patients with frontal lesions show problems with tasks of executive functions (Shallice & Burgess, 1991).

1.1.3 Cognitive control, general intelligence and goal activation

In every day life, executive functions make it possible to guide behavior intentionally according to internal goals. This means that executive functioning makes it possible to deal with novel conditions, to solve complex problems, to adapt to unexpected circumstances and to perform multiple tasks at the same time (see e.g. Cahn-Weiner, Boyle & Malloy, 2002; Grigsby, Kaye, Baxter, Shetterly & Hamman, 1998). Most of these abilities have also been linked to intelligence and it is therefore no coincidence that several researchers in psychology have studied executive function in relation to general intelligence.

Intelligence tests reliably predict performance across a wide range of different tasks assessing information-processing speed (Eysenk, 1986; Jensen, 1985, 1987), working memory capacity (Carpenter, Just & Shell, 1990; Just & Carpenter, 1992; Kyllonen & Krystal, 1990) and the efficiency of allocating attention to subtasks within highly complex tasks such as driving (Duncan, 1990).

In the psychometric literature on intelligence, a distinction parallel to the distinction between control functions and automatic functions exists (Phillips, 1997), namely between “fluid intelligence” (g_f) required for performance on tasks that are novel and complex on one hand, and “crystallized intelligence” (Horn, 1982; Horn & Cattell, 1966) on the other. Studies by Duncan and co-workers (1995, 1997) suggest that intelligence tests designed to tap fluid intelligence (i.e. Cattell & Cattell, 1960), are very good predictors of the level of executive functioning.

A general finding in studies in which a battery of cognitive tasks is administered, is that correlations between the performance measures are always positive. To explain this phenomenon, Spearman (1927) introduced the concept *g* as a factor that plays some role in performance on all tests. Duncan et al. (1996,1997) proposed that this *g* factor reflects the efficiency of a general goal activation process. More specifically they suggest that *g* reflects “…a frontal process of mental programming, or constructing an effective task plan by activation of appropriate goals or action requirements” (Duncan et al. 1997). When this goal activation fails, a phenomenon Duncan et al. (1996) term goal-neglect occurs. Goal neglect is defined as a disregard of a task requirement even when it has been understood and remembered (Duncan 1995). Although the severity of goal neglect has been reported to be increased in patients with frontal lobe lesions (Duncan et al. 1996), it has been found that under conditions of novelty, multiple task requirements and weak error feedback it also occurs in the normal population.

Duncan et al. (1997) addressed the relation between general intelligence or Spearman's *g* and goal activation function. They administered a battery of conventional executive control tasks and a battery of test that are not usually considered as measuring executive function. They found positive but low correlations between the executive tests. Nevertheless, the overall aggregated indices of the two batteries correlated strongly. Duncan et al. (1997) argued that the common element in these tests reflect the contribution of goal activation function to all these tests. In a second experiment they tested this idea by administering a battery with executive tests as well as a test developed to measure goal neglect and a test for measuring *g*. In this experiment they found again low correlations between performance indices of different tasks within the executive task battery, but a close relationship between the overall index of performance on the executive task battery and goal neglect and *g*. Based on these findings Duncan et al. (1997) posed that each test is weakly influenced by goal activation. This goal activation function can be indicated by averaging performance over a number of tests, or by a single purer measure of goal neglect. From this viewpoint a general intelligence test consists of a composite or a battery of a diverse set of cognitive tests all sharing the need for goal activation in order to perform. In the line of reasoning of Duncan et al. (1997) this idea can also be reversed in the sense that any battery of diverse and heterogeneous cognitive tasks will produce an aggregated performance index that corresponds to *g* and to goal neglect or goal activation function.

A task domain in which goal neglect has systematically been studied is prospective memory. Typically in these tasks, subjects are required to place a task on hold, mostly while performing another (background) task, until a trigger (time or an event) occurs, after which the prospective task is required to be resumed. Duncan et al. (1997), for instance, used a task in which the background task was to monitor two streams of random letters and digits and speak out loud every letter that appeared on one side. Occasionally a central, symbolic cue ('+' or '-') was presented, indicating subjects on which side to continue reading. The goal or intention that subjects were to keep activated while performing the background task was to respond to the cue. Other studies on prospective memory have found performance to be dependent on the delay between instruction of the prospective memory component and the moment of carrying out the intention (Brandimonte, Einstein & McDaniel, 1996) and the saliency of cue signaling the prospective task (Einstein & McDaniel, 1996; Maylor, 1996). Most studies have found that goal neglect in prospective memory tasks can be attributed to failures to act upon the instruction at the required moment, and not to simply forgetting the instructions (e.g. Brandimonte et al., 1996).

The 'goal activation' conceptualization implies a probabilistic view on limitations of cognitive control. If cognitive control and its limitations are conceptualized as probabilistic instead of absolute, then intra-individual variability and within task variability of performance become much more relevant, instead of solely inter-individual and between task differences (Nieuwenhuis, 2001). Several studies have been performed to explore this view on executive control and its limitations. This view sprouts from the work previously mentioned on goal activation by Duncan and colleagues (Duncan, 1995; Duncan, Emslie, Williams, Johnson & Freer, 1996) and on intention activation by De Jong and colleagues (De Jong, 2000; De Jong, Berendsen & Cools, 1999). These studies directly or indirectly address the question of whether performance limitations on performance in cognitive control tasks reflects intrinsic, fundamental or static limitations or whether it reflects a failure to fully or consistently utilize the capabilities of executive control or a combinations of these factors.

De Jong et al. (1999) concentrated on this issue with respect to Stroop-type interference and residual switch costs. Stroop interference is commonly attributed to an involuntary consequence of processing the meaning of a color word (e.g. blue) when the task is to respond to the color the word is printed in. This would then result in the usually slower and less accurate responses when the meaning of the color word and the color it is printed in are different (incongruent trials) than when it is the same (congruent trials). De Jong et al. (1999) argue that even if subjects would be able to completely prevent word meaning from influencing task performance, they might not always fully exploit this ability. If the task conditions do not induce subjects to fully use the ability to prevent irrelevant information having influence on task performance, this would result in the same Stroop effect. To test this idea De Jong et al. (1999) used a spatial version of the Stroop task and varied the pace in which the stimuli were presented, reasoning that a fast pace would induce or help subjects to stay focused on the instructed task and a slow pace would give rise to fluctuations at attentional state across trials and result in failures to fully bring to bear one's ability to inhibit the processing of the irrelevant information. The results supported evidence that Stroop interference is, at least partly, attributable to a failure to fully and consistently use capabilities of control. This account is in line with the demonstration by Logan and Zbrodoff (1979) of a decrease of the magnitude of the Stroop effect when increasing the relative frequency of demanding, non-corresponding trials (see also Kane & Engle, 2003; West 1999; Heathcote, Popiel and Mewhort, 1991; Mewhort, Braun and Heathcote, 1992)

1.1.4 Psychometric issues of cognitive control

Apart from the complexity of the relation between cognitive processes and physiological processes, measuring cognitive control poses several difficulties such as construct validity and task-purity.

Task-purity and construct validity

According to Miyake et al. (2000), "…Because executive functions necessarily manifest themselves by operating on other cognitive processes, any executive task strongly implicates other cognitive processes that are not directly relevant to the target executive function". This states the problem of task-purity of tasks that are used to measure executive function. Because performance on tests that are designed to tap executive control is dependent on executive control processes as well as on component processes, several attempts have been made to isolate control processes like inhibition. Rabbitt (1997), though, points out that the poor construct validity of terms such as "planning", "inhibition", "impulsivity" and "memory for context" is, at least in part, due to the fact that these terms come from the language of every day subjective experience, while the constructs are used by researchers for hypothetically distinct "components" of executive behavior.

Furthermore, several studies have examined the relation between indices of different tasks that are designed to measure the same executive process. Construct validity of executive processes would imply significant intercorrelations between different indices that tap the same postulated executive process. There is not much evidence for this type of construct validity for indices of executive control processes. An indicative example is a study by Shilling, Rabbitt and Chetwynd (2002) investigating inhibitory function in older adults. They administered four analogues of the Stroop interference paradigm to a group of older participants, and found no significant correlations between these different versions of the Stroop task. Also in other studies, intercorrelations between indices of the same postulated executive process are predominantly moderate to low and not higher than the intercorrelations with indices for other types of processes (Duncan et al. 1997; Rabbitt, 1997, Kramer et al.,1994, Nieuwenhuis et al. 2004).

1.2 Cognitive Aging

1.2.1 Global versus specific loss hypotheses of cognitive aging

The global speed hypothesis states that age-related cognitive decline can be attributed to a decrease in the speed with which elementary cognitive operations are carried out. The decrease in information processing speed places limits on the performance that can be reached on most cognitive tasks (Eearles, Connor, Smith & Park, 1997; Salthouse, 1996). This hypothesis is contrasted to hypotheses that contribute age-related effects on performance on executive control tasks to specific control deficits. With regard to several cognitive control functions the evidence on this issue is mixed (McDowd and Shaw, 1999). For example age-related differences in the Stroop-effect have been found to be accountable by the global speed hypothesis (e.g. Salthouse and Meinz, 1995; Verhaeghen & De Meersman, 1998) as well as by a specific-deficit account (e.g. Hartley, 1993). Another general factor that has been postulated to be able to account for a large part of age-related variance performance on cognitive tasks is general intelligence. For instance, as mentioned above in relation to psychometric issues of measuring executive control, Shilling et al. (2002) administered several different versions of the Stroop task. They found that age differences in inhibitory function as measured with the Stroop task, were not independent of fluid intelligence. They suggest that if subjects of different ages are matched in terms of intelligence scores they will not differ in terms of their ability to cope with executive control tasks (see also Rabbitt et.al 2001). Moreover, intelligence test scores have been found to act as a powerful mediator of age effects on simple tests of memory and information processing speed (Rabbitt, 1993). Apparently, empirical overlap exists between the consequences of different one-factor theories. In the paragraph of cognitive control it was discussed that most performance measures of executive and non-executive tests correlate positively but weakly (Duncan, 1997). Many tests, as argued by Duncan (1997), share the influence of a general (*g*) factor, and correspondingly an aggregate indicator of performance on these tests correlates strongly with measures of intelligence as well as with measures of goal neglect. Taken together, these findings suggest that a large part of the age-related variance in performance on most cognitive tasks may be explained in terms of a single factor that is strongly related to performance on intelligence tests. Still, some performance measures of cognitive tasks differentiate better between age-groups than other measures. A theory aimed at explaining these differentiated patterns from a neuropsychological perspective is the frontal lobe hypothesis of aging.

1.2.2 Frontal lobe hypothesis of cognitive aging

From the viewpoint of a specific loss hypothesis, researchers search for more specific explanations for differential declining of cognitive functions as people age. The most dominant process-specific theories of cognitive aging concern 'executive functions' or 'cognitive control'. As people age, executive functions are found to be compromised (Bryan & Luszcz, 2001; Mayr, Spieler & Kliegl, 2001; Rabbitt et al. 1997; Wecker, Kramer, Wisniewski, Delis & Kaplan, 2000). Furthermore the executive function theory of aging finds support from neurobiological and neuropsychological studies on aging. It has been demonstrated that executive functioning is highly dependent on the integrity of the frontal lobes. West (1996) presents an overview of the relation between advancing age and functional and structural changes in the frontal lobes that occur earlier than in other regions in the brain. These changes involve a relatively greater loss of volume of frontal areas than of other cortical areas, a local decrease in the number of synapses, atrophy of dendritic processes, and reduced efficiency in cellular mechanisms that support the synthesis and transmission of neurotransmitters (West, 1996). Together these findings result in the frontal lobe hypothesis of aging. This hypothesis states that cognitive functions supported by the prefrontal cortex show signs of age-related decline at an earlier age and to a greater degree than cognitive functions supported by other brain structures (West, 1996; Perfect, 1997).

Some studies lead to a more differentiated view on this relation (for review see e.g. Band et al. 2002; Greenwood 2000). First, the age-related changes in the structure and function of the brain have been found to be differentiated, also within the frontal cortex. Neuronal loss has been found to differ even between cortex layers within the same subregions of the dorsolateral prefrontal cortex (Uylings & De Brabander, 2002). Second, neurobiological changes may not correspond in a direct manner to cognitive changes. Third, related to the former, several methodological problems exist with measuring cognitive control. As discussed above in the section cognitive control, construct validity of many tasks that are designed to indicate executive control is unclear (e.g. Rabbitt, 1997). Different indices that are designed to measure the same construct are often not strongly correlated (e.g. Burgess and Shallice, 1997, Rabbitt, 1997, Shilling et al., 2002). These complications call for a more differentiated view on the relation between age-related changes in cognition and neurobiological changes.

1.2.3 Neuromodulation models of cognitive aging

According to Li, Lindenberger and Sikström (2001), several theories of cognitive aging try to explain age-related cognitive changes in terms of a decline of cognitive resources. Li et al. (2001) argue that those resource-reduction theories are confronted with major difficulties. They posit that the different resources such as working memory, attention regulation or processing speed are interdependent. Working memory as a resource is for example not independent of attentional control mechanisms (Braver et al. 2001) or processing speed. Furthermore, Li and Lindenberger (2001) criticize the circular nature of these accounts. To overcome the difficulties of the resource-reduction theories they argue for the need of an integrative account that cuts across neural, information-processing and behavior levels.

Welford (1977) argued that any increase with age of random activity in the brain (“neural noise”) would affect a wide range of both sensori-motor en intellectual performances. Evidence from neurobiological and other studies is accumulating about changes with age in the dopaminergic neurotransmitter systems playing an important role in age-related changes in cognition and behavior (Backmann et al., 2000; Goldman-Rackic and Brown, 1981; Li and Lindenberger 1999; Braver et al. 2001; Nieuwenhuis et al. 2001). Two computational theories have tried to explicate the relationships between age-related decline in dopaminergic modulation, neural information processing fidelity and cognitive aging. Both theories manipulate the signal-to-noise ratio of neural information processing and in that way regulating neurons’ sensitivity to afferent signals (Li and Lindenberger, 2001). Li et al. (2000) focus in their computational theory on relating aging deficits and cortical representational distinctiveness to dopaminergic modulation and neural information processing fidelity. Braver et al. (2001) focus on relating age-related impairments in regulating context representations and maintenance with dysfunction of the dopaminergic system in the dorsal lateral prefrontal cortex. In general the theoretical frameworks have in common linking “… attenuated neuromodulation to increased neural noise and less distinctive cortical representations in the aging brain, and finally on to cognitive aging deficits" (Li and Lindenberger, 2001). Given the role of dopamine in the frontal cortex, these models of (dopaminergic) neuromodulation provide important insights in the nature of aging at both the biological and cognitive level and could lead to a refinement of the frontal lobe hypothesis.

1.2.4 Aging and goal activation

Age effects in executive control tasks might reflect intrinsic limitations in executive control capabilities or failures to fully or consistently utilizing such capabilities or a combination of these factors (De Jong et al., 1999). Intention activation in relation to cognitive control has been discussed above. This perspective is strongly related to the concept of goal-neglect, put forward by Duncan et al. (1996, 1997). Goal neglect is defined as a disregard of a task requirement even when it has been understood and remembered (De Jong, et al. 1999, Duncan et al. 1996).

Goal selection and goal maintenance under conditions of novelty or weak environmental support is seen as a primary function of the frontal lobe (De Jong, 2001). Research into the relation between intention or goal activation and cognitive aging have focused primarily on three experimental paradigms, prospective memory tasks (i.e. Maylor, 1996; Einstein & McDaniel, 1990; Duncan et al. 1996; West & Craik,1999), switch-task (i.e. De Jong, 2001) and cue-tasks (Nieuwenhuis et al. 2000, 2004). These paradigms require subjects to be proactive and anticipate for performance in future trials. More specifically these tasks have in common that for performance to be optimal subjects need to consistently endogenously initiate a preparatory action or process.

1.3 Outline of thesis

In this thesis three studies are reported that explicitly study cognitive control function in relation to aging.

From the perspective of the frontal lobe hypothesis of cognitive aging, prospective memory tasks are particularly interesting and relevant, because prospective memory requires planning and keeping a prospective intention activated during performance on another task. Both functions are generally believed to involve the frontal lobes. Thus, according to the frontal lobe hypothesis of cognitive aging, robust age-related performance differences on prospective memory tasks should be expected. However, the evidence on age effects on prospective memory abilities is not entirely consistent. Older adults have been found to perform as well as younger adults in every day tasks such as making telephone calls or taking medicine at particular times of the day (see Maylor, 1996, for a review). It is possible that this age-invariance is due to older adults adopting efficient strategies (for example strategic use of retrieval cues). In prospective memory tasks developed for use in laboratory settings, the use of external memory aids and other strategies can be better controlled. Several studies using laboratory prospective memory tasks have found age effects on performance (Einstein, McDaniel, Richardson, Guynn & Cunfer, 1995; Park, Hertzog, Kidder, Morrell & Mayhorn, 1997; Cherry & LeCompte, 1998; Duncan et al. 1996; Maylor, 1998; West & Craik, 1999, but see Einstein & McDaniel, 1990). Moreover, prospective memory tasks are especially sensitive for demonstrating goal neglect (Duncan et al., 1996; see also Nieuwenhuis et al., 2004). In chapter 2, a study is presented testing the sensitivity and reliability of four different prospective memory tasks for assessing effects of normal aging. Based on previous evidence, the tasks were differentiated on various dimensions such as perceptual saliency of prospective target events, frequency of occurrence of prospective target events, complexity of prospective-memory instructions, and provision of feedback after prospective-memory errors. The role of goal maintenance (or maintaining prospective intentions) and basic mental speed as mediators for age effects on prospective memory performance are discussed.

Chapter 3 reports a study on age-related differences in task-switching. Switching between tasks requires the application of cognitive control function (Allport & Wyllie, 2000)). In switch tasks, usually three types of trials can be distinguished. On fixed-task trials, that constitute control blocks, the task remains the same throughout a block of trials. On non-switch trials the task to be performed is the same as on the previous trial. On a switch trial the task to be performed is different than the task on the previous trial. The differences in performance between switch trials and non-switch trials are referred to as local switch costs. The differences in performance between blocks with fixed-task trials and blocks in which non-switch trials and switch trials are intermixed, are referred to as global switch costs. Local switch costs have been found to decrease, but mostly not diminished when subjects are given ample time to prepare in advance for the task switch (preparation interval) resulting in, what is referred to as, residual switch-costs. Several studies on the relation between task-switching and cognitive aging have been conducted (i.e. Eenshuistra, Wagenmakers & De Jong, 2000; Kray (2005); Kray and Lindenberger (2000); Kramer, Hahn & Gopher, 1999; Meiran et al., 2001). Age-related differences in global switch-costs are found in most studies. This finding seems to be restricted, though, to paradigms in which response sets of the different tasks overlap, and it appears to be mediated by strategical aspects. Age-related differences in local switch costs are found in most but not in all studies. It appears that when taking into account baseline performance and practice, these age-related effects become modest or diminished. With respect to residual switch costs in old adults, it remains unclear whether these can be attributed solely to intermittent failures to engage in advance preparation when ample time is provided, as has been found with young adults by De Jong (2000) and by Nieuwenhuis and Monsell (2002), or to intrinsic limitations to prepare in advance by endogenous means only. In chapter 3, a study on global, local and residual switch costs in relation to age, is reported. Specifically, the study was aimed at clarifying possible differential contributions to residual switch costs between young and old adults. To accomplish this, a RT distribution modeling approach developed by De Jong (2000) was used.

As reviewed above some theories posit that age-related differences can be accounted for solely by one general aspect of cognition (e.g. Birren, 1956; Cerella, 1985; Eearles et al., 1997; Salthouse, 1996), while other theories hold that that effects of age on cognition are more specifically limited to executive control functions (e.g. Bryan & Luszcz, 2001; Mayr, Spieler & Kliegl, 2001; Wecker, Kramer, Wisniewski, Delis & Kaplan, 2000). In chapter 4, a study is reported that focuses on performance on several executive control functions in relation to aging. The study is part of a larger research project in which the relationships between age on executive control and on memory functions are investigated, using an extensive battery of retrospective and prospective memory tasks and executive control tasks. In chapter 4 patterns of performance of older and younger adults on measures of executive control, fluid intelligence and performance on standard neuropsychological indices are reported. Age-related effects on executive control functions are discussed by focusing on the results regarding age-related within-task variability of the different tasks. The relation between different executive control measures and the effect of aging on this relation are discussed by focusing on the results regarding age-related between-task variability and these results are modeled using structural equation modeling.