Cognitive training in young and old adults

Transfer, long-term effects, and predictors of gain

Petra Sandberg

Department of Psychology
Umeå 2014

ISBN: 978-91-7601-176-8
Electronic version available at http://umu.diva-portal.org/
Printed by: Print & Media
Umeå, Sweden 2014
Cover illustration: Alia Sandberg, Petra Sandberg & Linus Andersson

To Karin Viktoria Lundgren
In bright memory

Acknowledgements

”I don’t know, Marge – trying is the first step towards failure”, Homer Simpson once said. Although there have been some times when that particular advice seemed to be perfectly right to follow, I am glad I did not. I owe several persons for keeping on trying in this line of work that I chose to start pursuing some seven years ago.

My heartfelt thanks go to you, Anna Stigsdotter Neely, my main supervisor. On the vast sea that is research, you have qualities of both a rowing drummer and a fellow rower – pushing me to my limits and beyond, while at the same time guiding my oars, lending me your knowledge, and providing pep in just the right time, as I sometimes went out of pace, and sometimes went with the flow.

Michael Rönnlund, trying to transfer some of your methodological expertise and scientific writing skills to me might not always have been easy, but it has been immensely valuable for me and I am grateful to you for keeping on trying.

To all participants, who took from your valuable time to volunteer in my studies, thank you! Without you, there would have been no thesis.

The Steven Nordin/Jonas Olofsson supervisor team for my master’s thesis. You welcomed me with enthusiasm, scientific rigour and curiosity, free coffee, and a subtle banana aroma into your lab corridor. That mix showed to be just right to make me stay in research, and I am very grateful to you for that.

Thanks to Susanne, Sandra, Nils, Elin and Caroline for help with data collection. I look forward to future collaborations!

Claire Murphy, thank you for inviting us to your lab in San Diego, and welcoming me, Linus and Alia into your research group. Even if Alia doesn’t remember the lab meetings she participated in, I surely do, and it was in San Diego I presented my research to colleagues for the first time.

The Nordin family – Mia, Steven, Hanna, Edvin. Without your help, the trip across the ocean and the stay in San Diego would have been much more difficult. Thanks for help with money orders, 100-pages contracts, furniture, and a lovely kitchen table to work, eat, and talk around.

I would also like to express thanks to the Research school of population dynamics and public policy, led by Johan Lundberg, which provided an environment in which diverse research traditions could come together, and which added great scientific and social values, as well as financing, throughout my PhD student years.

Thanks also to the Swedish Research Council for Health, Working Life and Welfare; the J C Kempe Memorial Foundation; the Knut and Alice Wallenberg Foundation for financing this research.

I owe both senior researchers and fellow PhD students at the Nordic centre of excellence in cognitive control thanks for welcoming me to the group. I learned a lot during the conferences, and I got to meet Endel Tulving (!), whom I also thank for showing how being a truly great person in research does not hinder one from also being so warm and understanding towards the more inexperienced lot.

Daniel Sörman, Steven Nordin, and Martin Lövdén – I am grateful to your extremely thorough reading of an earlier version of this thesis. Hopefully, this version is better, thanks to your suggestions.

My thanks go also to all the colleagues at the department of psychology at Umeå University, and especially everyone in the PhD students' group. Anna-Maria, in my heart you will always be my roommate. Eva, it's good to have someone with the same biological lunch-clock, sense of humor and worries about raising kids. Carola, thanks for all the pep-talk during these last months!

Dawid, Linus, Robert, Sabina, Simon, and Torbjörn – thank you for the hours spent in the darkness with candle lights at Osarcon's academy. I view my PhD period primarily as research about how to role-play Tishtrya's struggle to write an essay about the great Atra-Hasis. Holding on to escapism was what made me keep my sanity through the last period of writing. Hampus and Björn, you'll come to the next meeting, right?

Fanny and Johanna, my friends since forever. I am so grateful for your friendship, in research- as well as small and large real life-related matters.

Mom and dad. Being by your side and seeing how you keep on fighting in life makes me want to keep on trying. I know I can always come to Stugan and hang with you guys to cry or cheer. Thank you for your unconditional love and for reminding me what is important in life.

Pernilla, I know you know how nervous I am right now. It's good to have someone who understands exactly how I think and feel.

And of course, the gang at home. Linus, I couldn't have made it without you taking all the dagishämtningar and grocery shopping. Also, you helped with the layout a tiny bit. Alia and Mina, thank you for blessing my life with your presence. Special thanks also to you, Alia, for helping me design the cover illustration, and to you Mina, for reminding me when it is time to take a break and go dig in the sand.

Mormor. The lunches with you, the long talks over the phone, your help with testing out the training tasks, your firm advices, and open arms. I miss you. This thesis is for you.

Petra Sandberg
Umeå, 2014-11-12

Table of contents

Abstract

Aging, also in the absence of pathological conditions, is associated with cognitive decline, especially in so called fluid abilities, such as episodic memory and executive functions. Due to an ongoing demographic shift, a larger part of the population will reach higher ages, and more people will be affected by age-related cognitive decline. Finding ways of counteracting this development have the potential of having large benefits for both individuals and society. It has long been known that living in environments that are rich in terms of cognitive challenges can affect cognitive ability in old age. In this regard, intervention studies in which the amount of cognitive stimulation is manipulated can therefore generate insights to the causality of such effects in specific cognitive functions. Cognitive training as means to counteract negative effects of aging on cognition has received a lot of scientific interest in the last decades.

This focus of this thesis is cognitive training interventions, which is studied from several perspectives. In Study I, the aim was to investigate the extent to which executive functions can be strengthened by training in younger and older adults, and to which degree such training generalize to other measures of cognition. Although a large body of research has been investigating training of working memory and executive functions in recent years, the results are diverse, and few have been targeting executive functions broadly with training programs based on theoretical models of executive functions. Study I showed that despite a broad training program targeting three executive functions (updating, shifting and inhibition), it did not lead to transfer beyond the very near in old adults. The younger however showed transfer effects to measures of working memory.

In Study II, the focus was on studying how the effects survive across time. There is limited knowledge about long-term effects of process-based training and the results showed that the training effect was stable after 1.5 years, while only the nearest transfer effect was still significant in both younger and older adults.

Study III focused on individual factors affecting gain and maintenance thereof in a sample of older individuals. We used a strategy-based intervention focusing on episodic memory performance with a number-consonant mnemonic which is a mnemonic for memorizing digit-codes. A different set of predictors was observed for baseline episodic memory performance and training gain. Those that are better off in terms of episodic memory performance, also gain more in the episodic memory criterion task. Further, a higher rate of processing speed was also important. Lastly, better verbal knowledge also influence gain beyond the other factors. The results have both theoretical implications regarding how plastic cognitive functions are, and practical, in terms of how to best design training programs.

List of abbreviations

BDI	Beck's depression inventory
CFQ	Cognitive failures questionnaire
CPT	Continuous performance testCNS
CVS	Consonant-vowel-consonant
DLPFC	Dorsolateral prefrontal cortex
DS	Digit Span task
EF	Executive functions
EM	Epsisodic memory
fMRI	Functional magnetic resonance imaging
IADL	Instrumental activities of dayly living
MMSE	Mini-mental state examination
MTL	Medial temporal lobe
PASAT	Paced Auditory Serial Addition task
PFC	Prefrontal cortex
RBANS	Repeatable Battery for the Assessment of Neuropsychological Status
RAPM	Raven's Advanced Progressive Matrices
RSPM	Raven's Standard Progressive Matrices
STM	Short-term memory
TMT	Trail Making Test
TOVA	Tests of variables of attention
UFOV	Useful field of view
VSI	Verbal self-instructions
VSTM	Visual short-term memory
WM	Working memory
WMC	Working memory capcity

List of papers

1. Sandberg, P., Rönnlund, M., Nyberg, L., & Stigsdotter Neely, A. (2014). Executive process training in young and old adults. *Neuropsychology, Development, and Cognition. Section B, Aging, Neuropsychology and Cognition, 21(5),* 577–605. doi:10.1080/13825585.2013.839777

2. Sandberg, P., Stigsdotter Neely, A. (2014). Maintenance of training gains and near transfer effects in young and old adults: An 18 month follow-up of executive process training, *manuscript submitted to Neuropsychological Rehabilitation*

3. Sandberg, P., Rönnlund, M., Derwinger, A., & Stigsdotter Neely, A. (2014). Memory plasticity in older adults: cognitive predictors of training response and maintenance following learning of number-consonant mnemonic, *manuscript submitted to Neuropsychological Rehabilitation*

Study I is reproduced with permission from the copyright holder.

Sammanfattning

Över hela världen blir vi äldre. År 2050 kommer en femtedel av jordens befolkning vara 60 år eller äldre, att jämföra med en knapp tiondel år 1950. Det är förstås en positiv utveckling men en åldrande befolkning innebär också att vi står inför flera utmaningar. En sådan rör det kognitiva åldrandet. Vi vet att åldrande kan leda till nedgång i vissa kognitiva förmågor, såsom det episodiska minnet samt exekutiva funktioner. Episodiskt minne är vår förmåga att komma ihåg upplevda händelser knutna till tid och rum. Exekutiva funktioner är ett begrepp som inbegriper vår förmåga att hålla en plan aktiv medan vi utför den, utan att distraheras av tankar eller externa störningsmoment. Genom att studera effekter av träning hos yngre och äldre vuxna på sådana kognitiva funktioner kan vi få kunskap om till vilken grad de kan förbättras och om denna förbättringspotential är olika beroende på ålder. Vi vet sedan tidigare att människor som under sin livstid lever ett kognitivt stimulerande liv också till viss del är skyddade mot nedgång i kognition under åldrandet. Träningsstudier kan ge kunskap om kausaliteten i sådana fynd.

Studie I i denna avhandling behandlar träning av exekutiva funktioner för yngre och äldre vuxna. Träningsprogrammet konstruerades utefter en teoretisk modell som beskriver exekutiva funktioner som bestående av förmågan att inhibera störande stimuli eller överlärda responser, förmågan att uppdatera information i arbetsminnet, och förmågan att skifta mellan att utföra olika uppgifter. Resultaten visade att de yngre kunde generalisera träningseffekten också till otränade arbetsminnesuppgifter, medan de äldre endast visade förbättring på otränade uppgifter som hade stora likheter med de tränade.

I Studie II undersöktes hur mycket av träningseffekterna som kvarstod ett och ett halvt år efter träningen. Resultaten visade att både för yngre och äldre så kvarstod effekten på tränade uppgifter samt en av uppgifterna som hade stort överlapp med träningsuppgifterna, för både unga och äldre.

I Studie III studerades ett strategibaserat träningsprogram för episodiskt minne. Fokus låg på att undersöka vilka individuella kognitiva faktorer som påverkar förbättring som följd av träning. Resultaten visade att de med högre förmåga i kognitiv bearbetningshastighet samt verbal förmåga var de som hade bäst förutsättningar för förbättring.

Resultaten från dessa studier är av både teoretisk relevans i och med att de ökar förståelsen för träningsbarheten av exekutiva funktioner, samt har praktisk relevans för utformning av träningsprogram.

Introduction

Louis: Claudia, don't!
Claudia [Beginning to cut her hair]:
Why not? Can't I change, like everybody else?
[…]
Claudia: Why?! [did you turn me into a vampire]
Louis: You see that old woman? That will never happen to you.
You will never grow old, and you will never die.
Claudia: And it means something else too, doesn't it?
I shall never ever grow up. I hate him.

— Anne Rice, Interview with the vampire

When the young vampire Claudia cuts her hair, it grows back. When she gets a wound, it heals. Her body stays exactly the same as when she became a vampire. Claudia's realization that she will never change, and never grow old, but will stay a child forever, has a deep sadness and anger to it. She realizes that being a vampire means being conserved in time.

Fortunately, as opposed to vampires, humans do grow old – and in greater numbers now than ever before. All across the world, we live longer. In 2050, one fifth of the global population (22 %) will be over 60 years, as compared to 8 percent in 1950. (United Nations, 2010). An average 60-year-old in the beginning of the 21st century have many more years to live than a person of the same age 100 years ago (Lutz, Sanderson, & Scherbov, 2008). This is undoubtedly a positive development, but at the same time, we are faced with challenges associated with it.

Aging, also in the absence of pathological conditions such as Alzheimer's disease, is associated with cognitive decline (for reviews, see Buckner, Head, & Lustig, 2006; Hoyer & Verhaeghen, 2006; Nyberg, Lövdén, Riklund, Lindenberger, & Bäckman, 2012; Park & Reuter-Lorenz, 2009), especially in so called fluid abilities, such as episodic memory and executive functions. Crystallized, or knowledge-based, abilities decline less (Rönnlund, Nyberg, Bäckman, & Nilsson, 2005).

One challenge related to the demographic shift where a larger part of the population reaches higher ages, is thus that more people will be affected by age-related cognitive decline. Finding ways of counteracting this development have the potential of having large benefits for both individuals and society. It has long been known that living in environments that are rich in terms of cognitive challenges can affect an organism's cognitive ability in old age. An early example of this is a study by Hebb (1947), showing that old rats who had been raised in enriched environments were superior to their lab counterparts in cognitive performance as measured by navigating in a maze. It has since been shown that living in environments which are rich and varying in terms of cognitive demands also affects human cognition; and that people in particular environments show neuronal changes in response to the requirements on cognition. For example, London taxi drivers have a larger posterior hippocampus than non-taxi drivers, due to extensive training on navigating (Maguire et al., 2000). Such changes are usually called enrichment effects, since they are the result of "enriched" environment. The related concept of cognitive reserve (Stern, 2009) highlights the fact that some people seem to have built up a reserve capacity through cognitively stimulating lifestyle, which act protective against age-related cognitive decline or even dementia, so that even in the face of brain pathology, functional levels are above what should be expected (Barulli & Stern, 2013). The fact that the extent of cognitive activation throughout life affects cognition in old age may seem intuitive, but in fact the earlier view on aging was that it was essentially a period of universal decline. Since the studies of enrichment effects and cognitive reserve mostly are correlational in nature, little can be said about the direction about such effects. Cognitive training as means to counteract negative effects of aging on cognition has received a lot of scientific interest in the last decades and can also give insights into to which extent environmental factors play a role in strengthening specific cognitive functions through the life span.

Plasticity

Armand: The world changes, we do not, there lies the irony that finally kills us.

— Anne Rice, Interview with the vampire

To continue with the vampire analogy just a little longer – vampires are, since they lack the ability of bodily change, also hindered in terms of learning from experience. As has been mentioned above, humans, to the contrary, have highly flexible cognitive systems. We are dependent on learning great amounts of knowledge and skills and our brain and behavior constantly face new environmental demands and need to adapt accordingly. For humans, learning is not an option – it is mandatory. Plasticity is a term which is used to describe this property of mind and brain, and it can be described in both physiological and behavioral terms. Brain plasticity refers to reorganization of the brain in terms of, for example, changes in strength in synaptic activity, cortical reorganization, or metabolic changes between areas of the brain as measured by differences in blood flow. Behavioral plasticity describes changes in behavior – new knowledge or skills such as e.g. the mastering of handwriting; or a larger knowledge base about rivers in Sweden or German prepositions.

It should be noted that brain and behavior changes continuously, but that plasticity implies some degree of stability of that change. The changes in neural activity corresponding to performing routine tasks would not be considered brain plasticity, nor would reading a sentence in one's native language be an example of behavioral plasticity, despite the fact that they both requires some form of change of brain and behavior[1]. Day-to-day changes in performance on different tasks are also not enough to be defined as plastic change. Noack, Lövdén, Schmiedek, and Lindenberger (2009), highlights that performance on a specific task may fluctuate depending on factors such as mood, fatigue, or motivation, or on differences in strategies applied to solve a specific task. Such factors indeed affect cognition, but they are considered to be situated within a person's current range of performance. In a theoretical framework presented by the same group (Lövdén, Bäckman, Lindenberger, Schaefer, & Schmiedek, 2010), plasticity is contrasted to flexibility, where the latter describes the current range of performance, while plasticity means extending these limits. They point out that plasticity requires a prolonged mismatch between the available resources and requirements from the environment to occur.

Typically, plastic change is described to be reactive – and a result of changes in external or internal environment (Draganski & May, 2008), such as when brain and behavior adjusts after an injury, or as a result of a prolonged training period. It is the resulting change, which the system undergoes in response, which is the manifestation of plasticity. Thus, increased performance in juggling after training is a manifestation of plasticity, as is increase in grey matter in specific areas of the brain (Draganski et al., 2004).

Plasticity is most prominent during childhood, which can be exemplified with children's superior ability to learn a new language or motor skill compared to adults. However, older adults do retain the ability to learn. While an earlier view was that old age was considered a period of rigidity in terms of learning and plasticity, or that "you can't teach an old dog new tricks", this view has changed. The current view underlines that plasticity shapes a person throughout life. Within the field of life-span development, influence of social context and personal behavior on brain and cognitive development is stressed (Hertzog, Kramer, Wilson, & Lindenberger, 2009), so that a co-constructive interaction between environment and biology take place and affects cognition throughout the life-span (Baltes, 1987;

[1] This means, of course, that the fact that vampires manage to learn anything at all, is somewhat of a paradox.

S.-C. Li, 2009). It should also be highlighted that plastic changes are not unidirectional. Mahncke et al. (2006), points out that the aging process itself constitutes an interaction between environment and genetic factors leading to negative plasticity of brain and behavior resulting in age-related cognitive decline. Viewing cognitive aging as a plastic process also helps highlighting that such a process might be subject to positive reinforcement and plasticity as well, implying a possibility of slowing this process through focused training.

This thesis center around plasticity as studied with cognitive training interventions, which I will study from several perspectives. I will investigate the extent to which executive functions, (our ability to plan and execute complex actions without getting distracted by external events or internal thoughts), can be strengthened by training in younger and older adults, and to which degree such training generalize to other measures of cognition, and how the effects survive across time. Further, I will also study factors affecting gain and maintenance thereof in a strategy-based intervention focusing on episodic memory (a long-term memory system that allows conscious recollection of previously experienced episodes). These two aspects of cognition have shown to exhibit relatively large age-related decline, and are therefore interesting targets for cognitive training studies.

Memory

Remembering you, standing quiet in the rain, as I ran to your heart to be near.

— The Cure, 1989

Memory is without doubt a central aspect of being human and is a versatile construct. We can remember how the warmth of the sun or the chill of the rain feels; we can recall what we ate for breakfast this morning, or how to change the tires on the bike. We have a vast knowledge-base gained across our life-time; and previous experiences constantly influence how we react and adapt to our environment. Different aspects of memory have shown to be subject to decline during aging, and to give a background to this I will first give a brief overview of memory systems and processes.

Memory is typically defined as operations of the mind which includes encoding, storage, and retrieval of information (Hoyer & Verhaeghen, 2006). Encoding refers to the stage at which information first enter a memory system. During storage that information is maintained, and can later be retrieved from storage.

Since the early days of memory research, it has been recognized that memory is best understood by subdividing it into different systems, which can also be illustrated by the examples above. William James (1890), in his seminal work – The principles of psychology – suggested that memory consists of primary memory, which represents memory over the short term, while secondary memory are the memories which persists over time. Further, he also recognized that memory is distinct from habit, where the latter affects our behavior but does not necessarily involve conscious recollection.

The division of memory into systems which operates over short and long term persists into present day. Short-term/working memory is concerned with holding and/or manipulating information over a brief period, while long-term memory are memories which are largely stable over time. Long-term memory is in turn usually divided further into several subsystems. The empirical study of the division of long-term memory started with the observation that severely amnesic patients with damage to their medial temporal lobes, including the hippocampus, could learn a new complex procedural skill without having any conscious recollection of practicing the task[2] (Milner, Corkin, & Teuber, 1968). During the 1980s and 90s, a division of memory into declarative and non-declarative systems got widely accepted, and a taxonomy was proposed (Squire, 1987, 2004). According to this, the non-declarative memory systems are characterized by types of memory in which performance is affected by earlier events, but does not require conscious recollection of that event. Included in non-declarative memory are procedural memory, priming, classical conditioning, and nonassociative learning. Declarative memory, on the other hand, includes our conscious recollection of facts, or semantic memory, and encoding and retrieval of personally experienced episodes tied to a specific time and place, or episodic memory (Tulving, 1972).

Episodic memory is what makes us go back in time and re-live past experiences, or "mentally travel in time". It is a late developing memory system and it is sometimes argued that this memory system separates humans from other animals. Episodic memory is proposed to require semantic memory but going beyond it, since whereas semantic memory does not require recollection of where and when a particular event took place, episodic memory does (Tulving, 2002).

Episodic memory is usually studied by presenting lists of e.g words, numbers, sentences or other information to people, which they are later asked to recall. This can be tested both in terms of recognition and recall tasks. Recall tasks requires recalling the previously studied information without any cues, while recognition can be studied by presenting a second list with both new and old items, where the task is to recognize which items have been previously encountered.

The division of memory into different subsystem is relevant within the field

[2] Young patient H.M. got parts of his medial temporal lobes, including the hippocampus, surgically removed in order to treat epilepsy (Scoville & Milner, 1957), and was left amnesic. He was unable to form new episodic memories, and was severely hindered in learning new facts as well, with a few exceptions where he could learn new facts over a large amount of learning trials.

of cognitive aging, since not all types of memory are affected in the same way by the aging process. Non-declarative memory is usually considered to remain intact during aging (Fleischman, Wilson, Gabrieli, Bienias, & Bennett, 2004) while semantic memory is suggested to be stable up to ages around 60 years. Episodic memory is the system that most consistently over studies show age-related decline (Rönnlund, Nyberg, Bäckman, & Nilsson, 2005), and it will be further described in the chapter about Aging and cognition.

Executive functions

”Man kan ju inte tänka på allt”, sa jättemyrsloken tyst. ”Det får liksom bara plats ett visst antal tankar i taget. Kanske … två. Eller tre i bästa fall. Jo, tre tankar klarar jag nog ...”

(“One cannot think of everything”, the giant anteater said quietly. “There is like only room for a certain amount of thoughts at the same time. Perhaps … two. Or three at best. Yes, I can probably manage three thoughts … “). [My translation]

— Olsson, En annan resa (2012)

The term executive functions[3], unlike many other psychological constructs, such as for example memory or attention, does not have an obvious counterpart in common language, but is used extensively in psychological research and clinical practice. There is a quite broad set of definitions, but generally, it is used to describe how humans manage to select actions and thoughts in relation to internal goals, rather than to merely act on internal and external impulses. Humans are highly flexible in terms of how to react to a given situation, which makes such processes necessary (Miller & Cohen, 2001). Executive functions have been shown to be involved in episodic memory in tasks which requires elaborate rehearsal, remembering of source information, and when appropriate strategies for encoding and retrieval has to be generated. There are also well-established links between measures of executive functioning and working memory, intelligence (Salthouse, Atkinson, & Berish, 2003), and self-regulation (Hofmann, Schmeichel, & Baddeley, 2012).

Executive functions are vulnerable to both external and internal factors, and are usually affected by stress and periods of insomnia, and has been shown to decrease in a variety of ill-health conditions such as chronic pain (Glass et al., 2011), breast cancer (Kesler et al., 2013), and depression (Harvey et al., 2004). They are

[3] Sometimes other terms are used, such as cognitive control, or executive control processes. Although not completely synonymous they are highly similar in terms of how they are operationalized.

also affected during the course of normal aging (Royall, Palmer, Chiodo, & Polk, 2004). This state of affairs has motivated attempts to strengthen executive function through practice and this is also the focus of the first two studies of this thesis.

Empirical research on executive functions originates from the field of neuropsychology and the study of patients with frontal lobe damage (Stuss et al., 2002), which has been linked to a set of symptoms related to aspects of planning and regulating behavior (Daniels, Toth, & Jacoby, 2006). With the unfortunate case of Phineas Gage[4], the term executive functions became more widely used and studied (Daniels, Toth, & Jacoby, 2006). Luria (1966) who, after studying war veterans with brain injuries, proposed that the frontal lobes were at the highest level of cognitive organization, and the seat of a central executive, critical for planning, initiating and regulating behavior. Other frontal lobe patients have since been studied, and this has revealed a diverse pattern of symptoms which involve organization and planning of behavior, abstract thinking, setting a plan and keep to it, regulating emotions and impulses, monitoring behavior, and deal with novel situations (Daniels, Toth, & Jacoby, 2006).

Within the field of cognitive psychology, executive functions have been studied within frameworks of working memory models. Working memory can be described as our ability to briefly store and manipulate information. One influential model is that of Baddeley and Hitch, (1974). It stipulates that working memory consists of three storage systems: a phonological loop, which is concerned with auditory and language-based information; a visuospatial sketchpad, which allows us to see for our inner eye and rotate visual stimuli or mentally draw a map; and the episodic buffer which integrate information with long-term memory. The fourth component of this system is the central executive, which controls and directs attention to the two storage modules. Another model of working memory is one proposed by (Cowan, 1988; 2008), in which the central executive also have a prominent position, governing attention in a similar way, but where the information in working memory is viewed as long-term memories held in an activated form in the focus of attention. Cowan further stresses in the same article, that the central executive should be seen as an equivalent to limited capacity, control processes; or effortful processing as described by Shiffrin and Schneider (1977) and Kahneman (1973). Baddeley also stresses the linkage to other models and underlines that the

[4] Phineas Gage was a young foreman working at a railway construction site. One day, an accidental explosion caused a large iron bar to become a projectile which pierced right through Gage's head, entering in the cheek and exiting on the top of his head. He survived the violent event but a large portion of his frontal lobes had been destroyed by the rod. After miraculously surviving and recovering from the injury, Gage could no longer regulate his behavior, language, and emotions in the same way, which led his coworkers to even state that he was no longer the same person (Mesulam, 2002).

central executive of his model has large similarities with the Supervisory Attentional System (SAS) in the information processing model by Norman and Shallice (1986).

The central executive/executive functions have sometimes been accused of having properties resembling a homunculus, or a small person sitting in the brain guiding attention (Hazy, Frank, & O'Reilly, 2007). Computational modeling has been one approach to try to exclude the need of a homunculus, and testing hypotheses about how these functions might be implemented in the brain, based on neuroimaging findings of brain areas involved in executive functioning. In these models the basal ganglia serves as a gating mechanism into the prefrontal cortex, which in turn maintains task-relevant information (Botvinick, Braver, Barch, Carter, & Cohen, 2001; Braver & Barch, 2002; Cohen, Braver, & O'Reilly, 1996; Koechlin & Summerfield, 2007).

As is apparent from the above description, executive functions are present in several models of memory and information processing over the short term. All models have in common that the executive functions consist of a limited pool of resources which restricts how much information can be processed at any given moment. Sometimes other terms, such as cognitive control is used to describe

Subprocesses of executive functions

A debated issue in the literature is whether executive functions should be seen as a unitary construct or as composed of several distinct sub-functions (Teuber, 1972). Some underline the fact that all executive functions tasks are constricted by a common executive attention construct (Engle, 2002; Shenhav, Botvinick, & Cohen, 2013). Others have argued that executive functions are best described as a set of related but separable control processes (Chatham et al., 2011; Collette, Hogge, Salmon, & Van Der Linden, 2006; Friedman et al., 2006). The identification of such sub-processes is motivated by the diverse range of mental operations needed in order to perform tasks requiring planning, monitoring and execution of complex cognitive performance, often measured with tests such as Tower of Hanoi/London. Examples of proposed sub-processes are monitoring of behavior; updating of information in working memory/focus of attention; shifting between mental tasks or sets; and inhibiting automatic or prepotent responses; dual-tasking; interference control; cognitive flexibility; and some also view working memory as an executive function (Diamond, 2013). In studies focusing on individual differences in executive functions, it has been shown that it might be useful to view executive functions as both unitary and diverse in nature (Miyake et al., 2000).

In this thesis, a model of subprocesses of executive functioning proposed by Miyake and colleagues (2000), (see also Miyake & Friedman, 2012, for a review of the group's findings), serves as a theoretical basis. The authors stressed the need for developing a theory about the organization of executive functions and their role in complex cognition. They performed a latent variable analysis in order to study how three executive functions prominently described in the literature, related to each other, and how they contributed to complex clinical executive tasks. They used multiple tasks for each of three core components: Inhibition, shifting, and updating. The three factors in the model of best fit were shown to be moderately correlated with each other, but clearly separable, and further that they contributed somewhat differently to the more complex executive tasks. In conclusion, Miyake and colleagues suggested that the three executive functions should be viewed as part of the same underlying construct but that they are also clearly separate from one another, thus presenting a three-factor model of executive functions. This model serves as a theoretical basis for the training program used in the first two studies. This general pattern of unity and diversity among executive functions has since been replicated including both young (Friedman et al., 2006), and old (Fisk & Sharp, 2004). The three factors described in the model are as follows:

Inhibition refers to the suppression of information not relevant at the time, and of overlearned automatic responses (Hamilton & Martin, 2005). Inhibition is proposed to be involved in shutting out irrelevant environmental stimuli as well as internal thoughts, and when holding back responses which are automatically triggered. Inhibition is needed for example in order to block out a conversation from the corridor when trying to focus on work, as well as when avoiding scratching the mosquito bites or hindering the mind from wandering away from the task at hand. Inhibition is proposed to be important also in pain and emotion regulation (Clarke & Johnstone, 2013).

Shifting is involved when attention has to be alternated between different stimulus streams or task sets. Task sets are representations which guide performance of a specific stimulus response-mapping when there are many possible responses associated with a stimulus. Many complex tasks which we encounter requires holding several pieces of information in an active state and alternating between them, such as for example when an air traffic controller has to shift quickly between checking several different systems running at the same time, or when a driver has to switch attention between an ongoing conversation and the traffic situation. Shifting between different tasks is associated with a time cost each time a shift has to be performed. The switch cost probably represents the time which is needed in order to resolve interference from earlier conflicting task sets, represented in the brain by persistent neural firing in the prefrontal cortex related to the previous task set. Further, it is also thought of as the time to reconfigurate task sets, which includes retrieving information form long-term memory (Herd et al., 2014).

The third subprocess is *Updating* of current content in working memory/the focus of attention. Since we cannot hold an unlimited amount of information in the focus of attention at one time, there is a need to be able to update what should currently be held there. Updating can be thought of both as updating of working memory content and updating of goal representations or rules. Updating is thought to be involved whenever earlier representations in working memory have to be replaced with new information. This can be both in the form of specific memory content, but also goals or plans which has to be maintained or replaced. The basal ganglia and the dopamine system have been stressed as a gating mechanism into prefrontal cortex where representations are maintained (Chatham et al., 2011).

This general pattern of both unity and diversity of executive functions has been confirmed in several studies, although the pattern can vary between studies. In recent years, a new version of the model has been proposed, in which the focus is to study the biological and cognitive underpinnings of this unity and diversity (Miyake & Friedman, 2012), a framework which they name the unity/diversity framework. According to this model, the measures of shifting and updating reflects both a shifting-specific/updating-specific component, and a common EF component, while the common EF component captured all the variance in the inhibition tasks (Friedman et al., 2008; Miyake & Friedman, 2012).

Executive functions/cognitive control have been described thoroughly in the literature from several different theoretical perspectives, and are also being suggested to be involved in cognitive aging, which makes them an interesting target for cognitive training.

Aging and cognition

"Winter is coming."

– House Stark

It is widely accepted that aging is associated with changes in cognitive functioning, also in the absence of pathological conditions such as Alzheimer's disease, which also comports with subjective complaints of memory decline (Nilsson, 2003; Reid & Maclullich, 2006; Vestergren & Nilsson, 2011. For reviews, see Buckner, Head, & Lustig, 2006; Hoyer & Verhaeghen, 2006; Nyberg, Lövdén, Riklund, Lindenberger, & Bäckman, 2012; Park & Reuter-Lorenz, 2009). A decrease in functioning has been observed in several cognitive domains. However, not all aspects of cognition are affected by age to the same extent. Generally, so called fluid (or process-related) abilities deteriorate to a higher degree than crystallized (knowledge-based) abilities (Hertzog et al., 2008). The episodic memory system is disproportionally affected, as are speed of processing and attention-related constructs such as executive functions and working memory capacity. Implicit memory systems, such as priming and procedural memory, do not decline with age, and knowledge storage (stored semantic memories) if it does decline, seems to do so later than episodic memory (Park & Reuter-Lorenz, 2009; Rönnlund, Nyberg, Bäckman, & Nilsson, 2005). There are some discrepancy between studies, depending on the study design used, as to onset and slope of decline. Cross-sectional studies of episodic memory performance for example, have shown a linear pattern of decline with onset as early as in the 20s (S.-C. Li et al., 2004; Park et al., 1996), while longitudinal studies suggests that episodic memory is preserved until around 60-65 years of age, after which they show an accelerating decline (Rönnlund, Nyberg, Bäckman, & Nilsson, 2005; Schaie, 2005).

Several ways of explaining the cognitive decline in old adulthood have been proposed, and the following description will therefore be selective. Some of the theories have proposed that a decline in domain-general processing mechanisms can explain general cognitive decline, but also several domain-specific theories exist, such as for episodic memory.

One influential theory is the processing speed account for cognitive aging (Birren, 1974 & Salthouse, 1996). This theory states that during aging, the speed by which cognitive operations can be performed is decreased, and that this in turn is the most important limiting factor behind cognitive aging of fluid abilities. The decrease of processing speed limits the amount of operations that can be performed within a given time, and because earlier processing might be lost when later processing is completed. This limited time mechanism is particularly influencing performance when the time to perform a cognitive operation is limited, or when the available time has to be shared between several complex tasks, such as in executively demanding tasks. Salthouse argues that if performance in complex tasks is restricted by the ability to perform simpler operations, and those simpler operations take longer time to execute, this affects overall performance (Salthouse, 1996). Further, if products of earlier processing are lost before later processing is completed, this will also affect performance. Evidence in favor of the processing speed account for cognitive aging has been for example the finding that when speed of processing is controlled statistically, the amount of age-related variance in working memory measures is reduced (Salthouse & Babcock, 1991).

Criticism against the processing speed account has been raised, and it is pointed out that the empirical findings rely mostly on cross-sectional data (Lindenberger, von Oertzen, Ghisletta, & Hertzog, 2011). The influence of speed has been shown to be smaller in longitudinal desings (Robitaille, 2013). It has also been pointed out that the generalized slowing could be reflecting a balance between plasticity and deterioration rather than an explanation of that balance (Greenwood, 2007).

The inhibitory deficit theory of cognitive aging (Hasher & Zacks, 1988; Lustig, Hasher, & Zacks, 2007) states that in old age, inhibitory mechanisms decline, which leads to a decreased ability to suppress irrelevant information from entering the focus of attention. Older adults are for example disproportionally affected by distracting information when reading a text (Carlson, Hasher, Zacks, & Connelly, 1995). Decreased inhibitory skill also affects the ability to delete no longer relevant information from attention focus, as well as holding back responses which are inappropriate at the time (Lustig et al., 2007). A point to note regarding this is that inability to ignore distractors can also lead to better performance in old versus young, if the distracting information later turns out to be useful (Rowe, Valderrama, Hasher, & Lenartowicz, 2006). Further, this view has been criticized for focusing on only one aspect of processing (Greenwood, 2007).

Related to the inhibitory deficit theory are theories which state that the amount of attentional resources is the limiting factor in ageing. Evidence for this is provided by studies showing that under divided attention conditions, younger lower their performance to similar levels as older under single-task conditions. Anderson, Craik, and Naveh-Benjamin (1998) showed that older adults' reaction times and correct responses in a memory task were similar to when young performed the same task with divided attention. According to the long-standing Levels of processing theory, memory performance is better if the material to be remembered is elaborated on and processed in depth (Craik & Lockhart, 1972). In order to for such processing to be possible, there is a need for allocating attentional resources, and if they are not sufficiently available, the encoding and subsequent recall will be affected negatively.

Further, related to findings described above, episodic memory performance has been shown to be affected the most in conditions which puts large demands on processing resources at encoding or retrieval (Bouazzaoui et al., 2014). At encoding, older adults are disproportionally affected when there is little support, and during divided attention tasks. When support is given at encoding, for example through a descriptive phrase accompanying words to be remembered (Craik, Byrd, & Swanson, 1987), age deficits are less pronounced. During retrieval, as with encoding, episodic memory performance become more impaired in tasks that puts larger demands on executive functions (Daselaar, Dennis, & Cabeza, 2007). Thus, in the absence of environmental support or explicit instructions, older adults tend to engage less in controlled processes such as elaborative processing and binding operations as compared to young (Daniels et al., 2006).

The theories described above highlights the importance of deterioration of domain-general processing resources in aging. Other theories have focused specifically on episodic memory decline, such as the Associative deficit theory (Naveh-Benjamin, Guez, Kilb, & Reedy, 2004). Episodic memory is often dependent on the ability to associate pieces of information with one another into a coherent whole, such as the name of the new coworker, or the time and place of an upcoming birthday party, which is later remembered as belonging to the same unit. This process is usually called binding and it has also shown to decline in old age and this decrease has been suggested to reflect part of the reason for decline in episodic memory performance specifically. Older adults have been shown to be more punished in tasks which requires such binding of information as compared to when only remember one item. Naveh-Benjamin, Guez, Kilb, and Reedy (2004) tested younger and older adults in a face-name recognition task and compared it to recognition of face and name. The former generated much larger age-related differences, also over and beyond the effects of divided attention.

Based on observed age-related changes in structure and function of the prefrontal cortex, together with evidence of disproportionate performance decrement in more executively demanding tasks, a frontal/executive hypothesis of cognitive aging has been suggested, which underlines the inefficiency of executive functions as a key factor for decline (Raz, Gunning-Dixon, Head, Dupuis, & Acker, 1998; West, 1996). Executive functions can be viewed as supporting the generation of appropriate strategies, and support focusing and maintenance of abstract representations in other cognitive operations such as in episodic memory tasks (Bouazzaoui et al., 2014). Also in studies of working memory performance, it has been shown that age differences in working memory are enlarged when task difficulty is increased, which can be interpreted as a higher dependence on executive functions (Daselaar, Dennis, & Cabeza, 2007). While older adults perform similarly on simple span tasks such as digit span tasks, there are large age-difference on more complex tasks such as e.g. the n-back task (Dobbs & Rule, 1989), which is considered to measure the executive function updating.

Thus, it seems that a range of cognitive tasks require greater resources in the form of executive functions in older than in younger adults. A pattern which can seem rather contradictory in this regard is the fact that despite older adults limited executive resources, they need to rely more on them when performing challenging tasks (Bouazzaoui et al., 2014). The increase in reliance on executive functions has been suggested to act as a compensatory mechanism for other types of cognitive decline. Neuroimaging studies have further shown that older adults tend to show a more lateralized pattern of activation in prefrontal areas than younger adults do (Daselaar, Dennis, & Cabeza, 2007), but is complicated by findings of prefrontal under-recruitment (Logan et al., 2002). This is in line with a compensatory view, so that older adults over-activate these brain networks in order to compensate for declining efficiencies of them, or for reduced processing efficiency elsewhere in the brain, such as the medial temporal lobe (Reuter-Lorenz & Cappell, 2008). In contrast to the prefrontal cortex, the medial temporal lobe typically shows an activation decline in older compared to younger adults and this has been associated with decreased binding ability.

In sum, age-related cognitive decline may best be understood in terms of limited amount of resources in the form of processing speed, working memory capacity, inhibition, and executive functions, which all show decline to a varying degree with increasing age.

It should be noted also, that a factor which likely affect the amount of processing resources is the decline in sensory functioning. Sight and hearing are commonly affected in aging (Buckner, Head, & Lustig, 2006), which can make signal-to noise ratio higher, and stimuli harder to interpret. This probably affect several aspects of cognition – in episodic memory, it has been shown that if younger adults are presented with information in auditory noise, they perform at the same level as older adults under quiet conditions (Murphy, Craik, Li, & Schneider, 2000). Executive functions are vulnerable to several factors, including noisy environment, and this sensory processing decrement likely affect their functioning in old age as well. The decrease in sensory functioning may lead to a need for greater cognitive effort to uphold sensory functioning, thus leaving less available resources for cognitive operations. This view underlines that the increased noise in perceptual processing is a key factor for age-related memory reductions (Schnieder and Pichora-Fuller, 2000). Such findings are important to have in mind when studying cognitive functioning in old age.

When a larger proportion of the population reaches higher ages, more people will be affected by age-related cognitive changes. Because of this, it gets increasingly important to study the possibilities of slowing or reversing decline, so that more people can live independent lives also when reaching high ages. Not only is this a goal in and of itself, since it can enhance quality of life in old age, but it also have the potential to affect costs of long-term need of care (Hertzog, Kramer, Wilson, & Lindenberger, 2008). Cognitive training fits in to this broad research area since it can provide guidance about how to best support age-related cognitive decline, and generate knowledge about how cognition can be affected throughout life.

Cognitive training

"Get out. I need to go to my mind palace."

– Sherlock, S2E2

In recent decades, there has been a steady interest in research on enhancing cognitive functioning by means of cognitive training. Cognitive training refers to interventions which are aimed at enhancing specific cognitive processes or knowledge structures with plastic change as a goal.

This research has had both applied agendas such as finding optimal training regimens to support cognitive functioning in select populations such as children with ADHD (Klingberg et al., 2005), breast cancer survivors (Kesler et al., 2013), and people living with schizophrenia (Fisher, Holland, Subramaniam, & Vinogradov, 2010); as well as more theoretically driven agendas studying the plasticity of aspects of cognitive functioning across the life-span (Lövdén, Brehmer, Li, & Lindenberger, 2012).

Cognitive training can be situated within several theoretical frameworks such as the use-it-or-lose-it (Hultsch, Hertzog, Small, & Dixon, 1999; Salthouse, 2006) and enrichment effects hypotheses (Hertzog et al., 2008) as well as bio-cultural co-construction framework (Baltes & Singer, 2001; S.-C. Li, 2003) and cognitive reserve (Stern, 2009). These frameworks have in common that they emphasize the importance of the environment to shape cognition: people in particular environments rich in cognitive challenges display enhanced cognitive abilities compared to those that are not.

Two approaches to cognitive training: Strategy and process-based training

Within the cognitive training literature, two broad types of training interventions can be distinguished. In the strategy approach, the focus has been on optimizing cognitive performance through learning and practice with deliberate strategies. In the process-based approach, the focus is on strengthening cognitive processes central for complex cognition through practice without specific instruction about strategy.

Strategy training

A strategy in cognitive training can be defined as one of several methods to perform the same cognitive task (Salthouse, 1991). Most strategy training studies have focused on episodic memory, but other functions such as problem solving and reasoning have also been addressed (Pennequin, Sorel, & Mainguy, 2010). Knowledge of the effectiveness of memory or mnemonic strategies has a long history. In the millennia-old mnemonic the Method of Loci, a familiar environment is first visualized, and a specific path within that environment is then imagined. During encoding, the material to be remembered is placed at different locations (loci) along that path. At retrieval, the same path is mentally re-walked and the information picked up. This mnemonic was originally used with success by the ancient Romans to remember impressively long lists of keywords central to remembering dreadfully long speeches (Yates, 1966).

Mnemonic strategies support encoding and retrieval of to-be remembered information by providing structure and encourage elaborated processing. According to the influential levels-of-processing framework (Craik & Lockhart, 1972) information is better remembered if we engage in deep and elaborate processing of the material to-be-remembered, such as focusing on the meaning of words rather than their linguistic structure. The transfer-appropriate processing principle (Morris, Bransford, & Franks, 1977) underlines that if processing at the time of encoding matches or overlaps with the processing at retrieval, recall will be facilitated. Both these frameworks help explain the effectiveness of mnemonic strategies.

As mentioned above, older adults are disproportionally penalized under unsupported encoding and retrieval conditions compared to younger adults. Hence, a goal has been to teach older adults strategies to foster efficient processing of information. Within this field, both complex memory strategies (mnemonics) as well as basic processing skills such as imagery, organization, and association have been used in training.

In seminal work by Baltes and Kliegl, the above described method of loci was used to study episodic memory plasticity in young and old adults. The results from this research indicated impressive improvements in serial recall for both young and old adults (Baltes & Kliegl, 1992; Kliegl, Smith & Baltes, 1989, 1990). However, the older adults despite great improvement did not gain to the same extent from training as the young adults. Also several other studies have shown positive effects following instruction in the method of loci (Rebok & Balcerak, 1989; Stigsdotter & Bäckman, 1989; 1993, 1995) as well as the face name-mnemonic (Yesavage, 1990) and the number-mnemonic (Derwinger et al., 2003). The same goes for studies focusing on basic skills such as organization, visualization, or imagery (Hill et al., 1989; Yesavage, 1990; Zarit et al., 1981).

An impressive training endeavor is that of the ACTIVE study (The Advanced Cognitive Training for Independent and Vital Elderly study), with its 2832 participants. It is a multisite, randomized, controlled trial of the effectiveness of three forms of cognitive interventions (memory, reasoning, mental speed compared to a no contact group) on improving basic cognitive ability and performance of activities of daily living of normal older people (Ball et al., 2002, Ball, Edwards, & Ross, 2007; Willis et al., 2006; Rebok et al., 2013). Several studies have been published from this project and the main findings indicate that all groups improve performance in the targeted trained cognitive ability with very little evidence for transfer to other cognitive abilities. These task-specific effects are well maintained across a period of ten years for speed and reasoning whereas memory maintenance was seen over a five year period. Also, the participants reported less difficulty in everyday functioning compared to the control group at the 10 year follow-up.

Taken together, findings from the strategy-based approaches has been very successful in improving memory performance in criterion measures, with a longevity of gains for up to several years (Stigsdotter Neely & Bäckman, 1993), fewer studies points towards a generalized gain from training. Few have also had a focus of investigating individual differences of factors underlying training gain.

Process-based training

In the recent decade, there has been a steep rise in number of studies with the aim of finding ways of enhancing basic cognitive processes through extended practice on cognitively demanding tasks. The assumption has been that through strengthening such domain-general cognitive processes, such as working memory capacity and executive functions, which also typically decline with age, other cognitive abilities depending on them will benefit as well. Empirical findings from process-based training studies will be covered in Review of process-based training interventions, but first a note on transfer is warranted.

Transfer

Although studying the effect of training on the trained tasks themselves is informative about the trainability and enhancement of cognitively challenging tasks, such effects is of limited use outside the laboratory, and cannot be claimed to be a sign of enhancement of the underlying ability.

Transfer refers to the effects training or learning experiences have on other tasks, situations or processes which were not explicitly practiced. It seems reasonable to assume that learning can be generalized to similar situations and tasks, since the opposite would imply very limited learning. Despite this intuitive understanding of the concept, it has been hard to capture scientifically (Barnett & Ceci, 2002). In the beginning of the century, Judd (1908) proposed that "every learning experience has in it the possibilities of generalization". Thorndike and Woodworth (e.g. Thorndike & Woodworth, 1901; Woodworth & Thorndike, 1901) on the other hand put forward a restricted view on transfer. They proposed that in order for transfer to occur, a high degree of overlap between trained and transfer tasks is required, and thus stated that only near transfer is likely to occur. Since then, a large and growing body of studies has been published on the subject. Conclusions are diverse, and range from highly positive to very negative toward the existence of transfer (Barnett & Ceci, 2002). Often it is argued that transfer is uncommon, but when it occurs, it is mostly between highly similar situations (Detterman, 1993).

Transfer is commonly described along a near (and sometimes nearest) to far continuum (Barnett & Ceci, 2002). There is no golden standard for how to define tasks as measuring near or far transfer. In our studies, in line with most existing cognitive training literature, we define near transfer as transfer to tasks measuring the same abilities as those targeted in training, while far transfer refers to improvement on tasks which are used to measure other constructs. This assumption is based on previous suggestions that transfer depends on the degree of structural and procedural overlap between trained and transfer tasks – that processing demands during practice are similar to the ones required in transfer tests (Schmidt & Bjork, 1992). Cormier and Hagman (1987) stated that transfer occurs when earlier learned knowledge and/or skills affect the way in which new knowledge and skills are learned and performed. Thus, it could be expected that the larger the correlation between trained and transfer tasks, the greater transfer effects would occur (von Bastian & Oberauer, 2013b).

From a theoretical point of view, consistent near transfer effects (= transfer to the same ability, measured with other tests) would be an indication of enhancement of the trained construct on an ability level, while far transfer would imply that the training of one or several functions has also led to improvement in a clearly separate construct.

Long-term effects of training

Another crucial aspect when evaluating training programs regards stability of training and transfer effects (Schmidt & Bjork, 1992), since it can give insights of the longevity of such effects. Such findings are important in order to know how often training needs to be re-iterated in order to be sustained. In strategy-based studies, training effects have been shown to be sustained for several years. As alluded to above, research within the ACTIVE study have yielded impressive long-term effects of cognitive training. Such studies have shown that cognitive training indeed has the possibility to strengthen the cognitive system in a more fundamental way. Since the rise in interest of processed-based training approach, however, there is now a need for examining long-term effects also in such approaches.

Review of process-based training interventions

The field of process-based training across the life-span has gone through a large growth during the recent decade. Working memory and executive functions are considered important for age-related differences and underlying cognitive performance in general and will therefore be the focus of this review. The focus is on summarizing what knowledge has been gained so far with a focus on factors governing immediate, as well as long-term near and far transfer effects, and their relation with age.

This review is included to provide an empirical background to the studies in the thesis, but is not meant to be completely exhaustive. The criteria used for including relevant studies were as follows:

- Was published between January 2000 and June 2014
- Had a pre- posttest design with control group
- Sampled from a healthy younger and older population, or from a healthy older population only
- Included deliberate practice on tasks designed to be directly cognitively challenging, such as executive functions or working memory. Thus, computer game training in which the game has been chosen for its presumed high load on executive abilities/working memory capacity are included, while interventions focusing on cognition indirectly, such as for example meditation or exercise training, were not. Speed of processing and attention training paradigms are beyond the scope of this thesis, and were therefore not included
- Included transfer test(s), of which at least one was a measure of cognitive functioning. Cognitive training studies measuring transfer to only non-cognitive domains were not included
- Studies measuring also neural manifestations of plasticity were included in the review if they also included cognitive measures, but the neural findings are not reported.

The studies are presented in Table 1, and after that, I will summarize the main findings. The table is organized after targeted function/type of training, in the following order: executive functions; working memory; commercial brain training; multi-modal training; and computer/video games training. Transfer results are reported in two columns, in accordance with the authors' definitions of near and far transfer. Some of them also divided tasks into nearest (Borella et al., 2014), or intermediate (von Bastian & Oberauer, 2013a). Both are reported as near in such cases. In studies where the authors have not made any distinction between tasks, I have divided them based on if the tasks used measure the same or different constructs than the tasks used in training. In the cases where it is not clear as to whether the measures used are to be classified as near or far, they are reported in the table simply as transfer, across the two columns. In the interest of space, only the tests with a reported effect are presented in the table. Most studies focusing on process-based training have used large transfer batteries, which increases the sensitivity of measuring transfer effects. This however means that although many studies have shown positive transfer effects, the amount of tests not showing any transfer effect is much higher. When including several tests in the same study there is always the risk of finding spurious results. This should be kept in mind when reading the review.

Table 1

Cognitive training studies included in the review.

→

Authors (year)	Type of training	Training tasks	Population	Adaptive	Length (hrs)	Control group	Near transfer to	Far transfer to	Long-term effects
Bherer et al. (2005)	Dual-tasking, variable priority, fixed priority	Dual-tasks: auditory discrimination (tones) + visual identification (letters)	Young, old	No	5	No-contact	New dual tasks: within modality and Between modality Similar gains for young and old. Old larger improvement on accuracy. No difference between intervention groups	—	One month. Maintained training gain and transfer effects.
Bherer et al. (2008)	Dual-tasking	Dual-task: visual discrimination tasks (letter B or C, color yellow or green)	Young, old	No	5	No-contact	Task-set costs (cross-modality) more improvement for old in accuracy	—	Not investigated
Dahlin, Neely, Larsson, Bäckman, & Nyberg (2008)	Updating	Running span, letter, spatial, number, color. Keep track task.	Young, old	Yes, up, session based	11, 25	No-contact	N-back (young)	—	Not investigated
Dahlin, Nyberg, Bäckman, & Neely (2008)	Updating	Running span, letter, spatial, number, color. Keep track task.	Young, old	Yes, up, session based	11, 25	No-contact	N-back (young)	—	18 months, maintained n-back (young), & criterion measure (old)
Karbach & Kray, (2009)	Task-switching	Categorization dual-tasks (1 group with verbal self. Instructions,)	Children, young, old	No	~ 2,5	Active (same tasks, single blocks only)	Categorization dual-tasks with new stimuli	Stroop, verbal and spatial WM (reading and counting span, navigation and symmetry span), Gf (RAPM)	Not investigated
Karbach, Mang, & Kray (2010)	Task switching	Number/position switching (alternating runs, switch every two). Four different groups differing in use of verbal self-instructions (VSI) during training and/or posttest.	Old	No	Not reported. Two sessions.	No control group. Four intervention groups	Larger transfer to Number/digit shifting when VSI was used both at training and post-test	—	Not investigated
Wang, Chang, & Su (2011)	Executive functions (switching, updating, & planning)	The breakfast cooking task	Old	Yes, upwards, session-based	2.5 – 5	No-contact	Letter-number sequencing	Digit symbol coding	Not investigated

Authors (year)	Type of training	Training tasks	Population	Adaptive	Length (hrs)	Control group	Near transfer to	Far transfer to	Long-term effects
Lussier, Gagnon, & Bherer (2012)	Dual-tasking	Two visual discrimination tasks. Pure, dual-mixed or single-mixed	Young, old	No	5	No-contact	—	Reduced RT to stimulus-, response-, and stimulus+response modality transfer dual-tasks. Reduced dual-task costs to stimulus-, and response transfer dual tasks[2]	—
Wilkinson & Yang (2012)3	Inhibition	Stroop. Three training groups differing in amount of feedback.	Old	No	3	No-contact	—	—	Not investigated
Bürki, Ludwig, Chicherio, & de Ribaupierre (2014)	Updating	Verbal dual n-back tasks	Young, old	Adaptive, trial-based	5	Active (implicit sequence learning task), and a no-contact group	Spatial n-back, (more improvement for older)	—	Not investigated
Heinzel et al. (2014)	Updating	N-back	Young, old	Adaptive (up and down, list-based)	9	No-contact	STM: Digit span forward (old)	Verbal fluency, (young) CERAD delayed recall (old), speed: digit symbol substitution (young and old)	Not investigated
Stepankova et al. (2014)	Updating	Verbal single n-back (2 groups 10 or 20 sessions)	Old	Adaptive	3.3 – 4.2 / 7.5 – 8.3	No-contact	Compositee of WM (DS forward & backward, Letter-number sequencing)	Compositee of visuospatial skills (Block design & Matrix reasoning)	Not investigated
Xin, Lai, Li, & Maes (2014)	Updating	Letter, animal, & location running span	Old	Adaptive (trial based, within session, RT increase or decrease)	Up to 10 hours	Active (computer games)	Digit running span	Digit span backwards	Not investigated
Buschkuehl et al. (2008)	WM	Adaptive simple span (visou-spatial), adaptive span+ classification, RT task, CRT tasks	Old-old	Adaptive, up and down, trial based	18	Active: physical intervention (low metabolic load bicycle ergometer)	Block span	Visual free recall	12 months. no maintenance of effects

Authors (year)	Type of training	Training tasks	Population	Adaptive	Length (hrs)	Control group	Near transfer to	Far transfer to	Long-term effects
Li et al. (2008)	Spatial WM	Spatial 2-back Spatial 2-back+spatial shifting	Young, old	No	11, 25	No-contact	Spatial 3-back, accuracy numerical 3-back, RT numerical 2-back, RT	—	3 months, maintained gain and near transfer effects (more for young)
Borella, Carretti, Riboldi, & De Beni (2010)	Verbal WM	Categorization WM span tests (complex WM span)	Old	Adaptive in session one. Different manipulations in sess. 2-3	3	Active: Questionnaires of memory and well-being	Visuospatial WM task (same task, different modality and secondary task): dot matrix, Short-term memory tasks	Fluid intelligence: Catell test Inhibition: Stroop Speed: Pattern comparison	8 months, Criterion task, Cattell task, Pattern Comparison
Brehmer et al. (2011)	WM (Cogmed QM)	Different span-tasks (forward and backward, spatial and verbal)	Old	Adaptive	~ 10	Active (Fixed low-level practice)	Span-board backward	PASAT, trend for RAVLT	Not investigated
Richmond, Morrison, Chein, & Olson (2011)	WM	Complex span tasks (verbal & spatial)	Old	Yes, trial based, up- and downwards	10	Active (trivia quizzes)	Reading span	California verbal learning test – repetitions; self-reported improvement in everyday attention	Not investigated
Zinke, Zeintl, Eschen, Herzog, & Kliegel (2012)	Paper-and-pencil/face-to-face Verbal & visuospatial WM	Digit span forward & backward; Corsi block tapping forward & backward; K-ABC Icons.	Old-old	Adaptive List-based	~ 4 – 5	No-contact	—	—	Not investigated
Brehmer, Westerberg, & Bäckman (2012)	Spatial and verbal WM (Cogmed QM)	Visuo-spatial WM task, Digit span backwards, Letter span, Choice RT	Young, old	Adaptive	8.7 – 10.8	Active (low-level practice)	Span-board, Digit span forward (Larger transfer gains in young)	PASAT, CFQ	3 months, Span-board, Digit span forward, PASAT, CFQ (Equal gains in young and old
Borella, Carretti, Zanoni, Zavagnin, & De Beni (2013)	Verbal WM	Categorization WM span tests (Complex WM span)	Old-old	Adaptive in session one. Different manipulations in sess. 2-3	3	Active: Questionnaires of memory and well-being	Digit span forward	—	8 months, + digit span forward, Stroop incongruent errors

Authors (year)	Type of training	Training tasks	Population	Adaptive	Length (hrs)	Control group	Near transfer to	Far transfer to	Long-term effects
Carretti, Borella, Zavagnin, & de Beni (2013)	Verbal WM; WM updating during reading	Categorization WM span tasks; Updating information presented in texts	Old	Adaptive in session one. Different manipulations in sess. 2-3	3	Active: Questionnaires of memory and well-being	WM updating word span;	Listening comprehension (True/false & map drawing); marginal effect on Catell test	6 mon. + WM updating word span; Reading comprehension; Listening comprehension (True/false & map drawing); marginal effect on Catell test
McAvinue et al. (2013)	Updating, WM and strategy instruction	Span tasks (numbers, colors); Running span (faces, names); n-back (faces, moving squares, auditory presented names; dual with squares and aud. pres. names); a version of PASAT; Strategy instruction for everyday memory tasks	Old	Adaptive	~ 15	Active (non-adaptive training. Some of the tasks removed. No strategy instruction)	Digit span forward (STM), Immediate and delayed word recall (EM)	—	3 & 6 months digit span forward
Theill, Schumacher, Adelsberger, Martin, & Jäncke (2013)	Cardiovscular+WM, WM only	WM: n-back, serial position training (verbal). Cardiovascular: treadmill	Old	Adaptive (up and down, session based)	10	No-contact	Executive control task (WMC)	—	Not investigated
von Bastian, Langer, Jäncke, & Oberauer (2013)	WM (storage & processing, relational integration, supervision)	Numerical complex span, Tower of fame, figural task switching	Young, old	Adaptive (Session based)	10	Active (Quiz; visual search; counting and detecting missing digits)	Verbal complex span (equal across age)	Binding (marginal effect for young only)	Not investigated
von Bastian & Oberauer (2013)	WM (storage & processing, or relational integration, or supervision)	Complex span tasks (verbal, numerical, figural-spatial); Integration of elements and their relations (letter, kinship, pattern); categorization switching tasks (alternating runs)	Young, old	Adaptive (Session based)	10 – 13	Active (Face matching, digit matching, pattern matching)	Storage processing > WM (construct level); Supervision > shifting (construct level)	Relational integration > binding (task level)	Not investigated

Authors (year)	Type of training	Training tasks	Population	Adaptive	Length (hrs)	Control group	Near transfer to	Far transfer to	Long-term effects
Zinke et al. (2014)	Visouspatial, verbal, & executive working memory WM	Picture grid task; Subtract-2-span task; Tower of London task	Old	Adaptive within session	~ 4.5	No-contact	Verbal WM: Letter span plus	Reasoning: Raven's Standard Progressive Matrices	9 months + Training tasks and Letter span plus
Borella et al. (2014)	Visou-spatial WM	Remember positions of dots in matrices/pressing spacebar whenever dot appeared in shaded space	Young-old & old-old	Adaptive in session 1-2. Different manipulations in sess.[3]	3	Active (Questionnaires of memory and well-being)	Nearest: WM: Categorization WM span task (young-old & old-old) Near: STM: Forward & backward Corsi tests (young-old)	Speed: Pattern comparison (young-old)	8 months Criterion task, categorization WM span task (young-old & old-old)
Ackerman, Kanfer, & Calderwood (2010)	Nintendo Wii Big Brain Academy (different aspects of speed & WM)	Perceptual speed, Closure speed, Numerical estimation, Visual WM, Backw. memory span, Verbal & visual Categorical matching, Spatial visualization, Numerical computation, WM, Visual matching, Spatial orientation, Visual inspection (dynamic)	Young-old (m: 60.7)	No	20	Within-groups design. Reading assignment control condition (20 hrs)	—	—	Not investigated
Peretz et al. (2011)	1. Cognifit Personal Coach (Several cognitive domains) 2. Computer games which "significantly engage cognitive processing"	12 different task measuring (e.g. WM, aspects of EF, associative learning, speed, divided attention) 12 different computer games (e.g. Tetris, Tennis, Snake, Memory Simon, Labyrinth)	Old	Adaptive (the cognitive training, but not the computer games)	~ 12 – 18	No control group. Two intervention groups	Cognifit compared to Computer games: Visuospatial memory, visuospatial learning, & focused attention improved more	Cognifit compared to Computer games: Visuospatial memory, visuospatial learning, & focused attention improved more	
McDougall & House (2012)	Nintendo DS Brain Training Package	Math calculations (four games), Verbally based games (two games), Working memory (two games), Mental rotation	Old	Adaptive for some of the tasks	No exact info (2 – 3 times/ week for 6 weeks, large variation)	No-contact	Digit span backwards	—	Not investigated

Authors (year)	Type of training	Training tasks	Population	Adaptive	Length (hrs)	Control group	Near transfer to	Far transfer to	Long-term effects
Nouchi et al. (2012)	Nintendo Brain age	Calculation x 20, Reading aloud, syllable count, Low to high, Triangle math, Time lapse	Old	Adaptive	5	Active (Tetris)	Measures of executive functions (FAB and TMT B) and speed (Digit symbol and Symbol Search)	—	Not investigated
Boot et al. (2013)	Video game training (Mario Kart DS) and Brain fitness training (Nintendo Brain Age 2)	Abilities supposedly required in the game such as monitoring and divided attention; Activities emphasizing memory, reaction time, language, and mathematical ability	Old	Adaptive as part of game play	M = 22 for Mario Kart Group; 56 for Brain Age 2 group	No-contact	—	—	Not investigated
Bozoki, Radovanovic, Winn, Heeter, & Anthony (2013)	"games for learning" (including a broad range of brain-game-like tasks	E.g. visual attention, visual working memory, speeded processing, reasoning and visual-spatial skills, engage spatial executive processing and non-verbal reasoning	Old	Adaptive	M = 21	Active (reading, hearing and watching news)	—	—	Not investigated
Mayas, Parmentier, Andrés, & Ballesteros (2014)	Lumosity (Speed, Mental rotation, WM, Mental calculation)	Processing speed (Speed match;) Mental rotation (Rotation matrix); WM (Face memory, Memory match, Memory matrix, Moneycomb); Concentration (Lost in migration and Space junk); Mental calculation (Raindrops and Chalkboard)	Old	No information	60	Active (Group discussions)	Distraction (Ability to ignore irrelevant oddball sound in RT task to visual stimuli); Alertness (RT difference between silent and sound conditions)	Distraction (Ability to ignore irrelevant oddball sound in RT task to visual stimuli); Alertness (RT difference between silent and sound conditions)	Not investigated
van Muijden, Band, & Hommel (2012)	Tasks inspired by brain training games (select and integrate information, manipulate wm repr., switching)	Anagrams, Falling bricks, Telling time, Giving change, Firemen (keep track)	Old	Adaptive (session based)	M = 21.1	Active (documentaries + quizzes)	Training group: Stop-signal (inhibition), RSPM (reasoning); Control group: UFOV-3 (selective attention)	Training group: Stop-signal (inhibition), RSPM (reasoning); Control group: UFOV-3 (selective attention)	Not investigated

Authors (year)	Type of training	Training tasks	Population	Adaptive	Length (hrs)	Control group	Near transfer to	Far transfer to	Long-term effects
Owen et al. (2010)	1. Reasoning & planning. 2. Math, attention, memory Cambridge Brain Science tasks	1. Three reasoning tasks & three planning tasks. 2. Math sums; Find missing piece of puzzle; Click on moving target symbols; Counting memory task; Memory game	Young, middle-aged	Adaptive	Between 2 – 188 sessions (min 10 min). Average 24 sessions.	Active (answered obscure questions)	—	—	Not investigated
Schmiedek, Lövdén, & Lindenberger (2010)	Perc. speed, WM, EM	Choice reaction tasks (speed), comparison tasks (speed), Number-noun pairs (EM), Word lists (EM) Object position memory (EM), Alpha span (VWM), Memory updating numerical (WM), 3-Back spatial (WM)	Young, old	No (Fixed but individually tailored from pretest performan-ce)	100	No-contact[1]	—	Latent factor of WM ability (young and old), Latent factor Gf and EM (young) Several significant effects on individual tests, more for younger	Not investigated
Basak, Boot, Voss, & Kramer, (2008)	Rise of Nations (complex real-time strategy game)	Functions supposedly included in game performance: WM, EM	Old	Adaptive	23.5	No-contact	Task switching, n-back memory load cost (2-back vs 1-back RT), VSTM change detection 4 items vs 2 items; RAPM, Mental rotation	Task switching, n-back memory load cost (2-back vs 1-back RT), VSTM change detection 4 items vs 2 items; RAPM, Mental rotation	Not investigated
Stern et al. (2011)	Space Fortress (divided attention, multi-tasking, visual scanning, working memory and motor control)	Shoot missiles while protecting one's own ship from damage from missiles and mines, and monitor symbols appearing on the screen Intervention group: focus on either controlling ship or handling mines	Old	No information	36	Active (game play with standard instructions) and no-contact	WAIS-III letter–number sequencing, compared to both control groups	—	Not investigated
Whitlock, McLaughlin, & Allaire (2012)	Computer game (World of Warcraft)	Abilities required by game such as rapidly switching and attentional control. (CTA was performed, but result not provided.)	Old	Adaptive (built-in adaptivity in game)	14	No-contact	Stroop (attentional control)	Stroop (attentional control)	Not investigated

Authors (year)	Type of training	Training tasks	Population	Adaptive	Length (hrs)	Control group	Near transfer to	Far transfer to	Long-term effects
Belchior et al. (2013)	Video game training (first-person shooter – Medal of Honor) and Useful Field of View (UFOV) training program (speed, divided attention, selective attention)	Concluding missions in the MOH. UFOV training: tasks of speed, visual attention, and selective attention	Old	Adaptive	9	Active (Tetris); and no-contact	Selective visual attention, all three active groups including Tetris. No difference between the two game conditions. Marginally larger improvement in UFOV group.	Not investigated	Not investigated

Note. Unless stated, transfer effects were equal for young and old. Near/far transfer distinctions, and functions targeted by training follows authors' labeling. In absence of test labels, a short description is given instead.

[1] The authors emphasize that both training and control groups participate in 10 sessions of pre-and posttesting.

[2] Judged as far transfer by the authors

[3] The focus was on investigating effects of feedback.

Summary of findings

I will begin with a summary of the results from the different types of available training studies. Broadly, they can be divided by targeted function into executive functions, working memory, multimodal, computer game, and commercial brain training studies. This walkthrough will not cover all the studies; instead, I will try to identify important findings. After this summary, I will discuss factors affecting transfer (and to a lesser degree maintenance), and thereafter I will comment on some important design-related issues.

Executive functions training

Aspects of executive functions that have been studied are dual-tasking, updating, inhibition, and shifting. Most commonly, one function has been targeted in training, which allows for studying the malleability of specific aspects of executive functions. To avoid material-specific effects, some have used different task versions (Dahlin, Nyberg, et al., 2008), whereas others have trained with the same task throughout training (Wilkinson & Yang, 2012). Three studies focused on updating using the running span task (Dahlin, Neely, Larsson, Bäckman, & Nyberg, 2008; Dahlin, Nyberg, et al., 2008; Xin et al., 2014). Dahlin and colleagues found transfer to another updating task and to an episodic memory task in younger but not older, and the effect on updating was maintained after 18 months. The study by Xin and colleagues found transfer in older adults to measures of short term and working memory. Thus, all three studies revealed limited or nonexistent transfer effects in older and an indication of somewhat broader transfer in younger.

Some studies have also provided training with the n-back task which is also considered to a measure of updating ability. In a study by Li et al., near transfer effects to a more demanding version of the trained task, and to a version with new stimulus material, was found and these effects were age-invariant. They further showed maintenance of effects after three months. Heinzel et al. (2014) also compared young and old, and found near transfer to short-term memory together with far transfer to one measure of episodic memory in old, while the younger group improved in verbal fluency. Effects on a speed measure were age-invariant. Stepankovka et al. (2014) studied older adults, and compared two different training lengths – 10 and 20 hours. They showed near transfer to a working memory composite measure, and far transfer to composite measures of visuospatial and logical reasoning ability. Training length affected outcome so that those in the longer training improved more on far transfer tests. In a recent dual n-back training study by Bürki, Ludwig, Chicherio, and de Ribaupierre (2014), transfer was seen only to another n-back task with new material for the trained as compared to both active and no-contact controls. No other measures, including reasoning ability, was significant. Slightly larger transfer effects were seen for the younger.

Dual-task training has been assessed by Bherer et al., (2005, 2008) and Lussier et al. (2012). All three studies found transfer to other dual-tasks, modified to contain different stimulus material or response mode. The transfer effects were similar across age groups in all studies.

One study used a short intervention with a complex executive task (Wang et al., 2011), including several aspects of executive functions, such as goal maintenance, updating, task switching, and planning – the Breakfast Cooking Task. They found near and far transfer, but as in the case with computer game training, it is harder to disentangle which processes the training is targeting, and how this relates to the transfer effects.

Two studies investigated the effects of task-switching (Karbach & Kray, 2009; Karbach et al., 2010) and found that shifting training led to near transfer to versions of the trained tasks, and far transfer to inhibition, working memory, and reasoning ability which were similar for all age groups, but with slightly more near transfer for the older group compared to young adults. The shifting study by Karbach and Kray from 2010 focused on verbal-self instructions, and only measured near transfer to similar tasks, which was significantly enhanced. The inhibition study (Wilkinson & Yang, 2012) involved training with the Stroop task and did not produce any transfer effects.

In sum, training with executive functions has mostly been focusing on a specific ability. The results have, again, been varying, but a trend that n-back training seems to be generating more consistent transfer effects can be identified. Only one study took a broader stance to executive functions training, thus such training studies deserves future attention.

Working memory training

Complex working memory span tasks, such as the reading span task (Daneman & Carpenter, 1980) are widely used for measuring working memory capacity (Engle, 2002). In a series of studies (Borella et al., 2014, 2010, 2013; Carretti et al., 2013), a short training protocol consisting of three sessions of practice with a verbal complex span task were investigated. In the first (Borella et al., 2010), near transfer effects were seen to working memory, and far transfer to reasoning, inhibition, and speed. Enhancement on reasoning ability and speed was maintained after 8 months. When the same training regimen was tested again, this time with old-old adults (Borella et al., 2013), transfer and long-term effects were more limited. In a following study (Carretti et al., 2013), another training task was added, updating while reading, where participants were required to update information in WM and report 2 – 5 information pieces after reading a text. Measures of speed and inhibition was not included in this experiment, which limits the comparability to the other two studies, but it showed far transfer to reading comprehension along with a marginal effect to reasoning ability. Effects were maintained at eight months, and at this time, a listening comprehension was also significantly better than at pretest.

In the most recent study (Borella et al., 2014), the authors compared young-old and old-old adults on a visuospatial working memory span task, and again used the same transfer battery as in the first two studies. This training led to near and far transfer for the young-old group, while transfer in the old-old group was limited to a nearest transfer task. Maintenance effects after eight months were seen in both age groups for the criterion and nearest transfer task. These training studies have all used a relatively short intervention consisting of three hours of training, but the authors argues for the pivotal factor being that the training is varied to prevent strategy use and kept demanding throughout the training. In sum, this series of studies have shown that a short verbal complex span training regimen was successful in showing near and far transfer in older adults, and that age was a limiting factor for transfer in a visuospatial training program.

Complex WM span training has also been studied by Richmond, Morrison, Chein, and Olson (2011) who found near transfer to a reading span task and far transfer to a verbal learning task along with self-reported improvement in everyday attention after providing training with visuospatial and verbal tasks. However, they found no transfer to a reasoning measure (Raven's standard progressive matrices), despite longer training than the studies by Borella and colleagues. Buschkuehl et al. (2008) used a visual complex span task in combination with reaction time training and found near transfer to a visuospatial simple span task and far transfer to an episodic memory task in old-old adults. None of these effects was present at the one-year follow up assessment.

Working memory capacity has also been targeted by the commercially available training program Cogmed, originally developed for reducing symptoms in children with ADHD. The training includes several different tasks of verbal and spatial working memory/short term memory tasks. The program has primarily been studied within a younger population, but two studies have focused on older adults. In those studies near transfer to an untrained span task, and far transfer to a measure of attention was observed (Brehmer et al., 2011, 2012). Transfer to everyday tasks has rarely been included in process-based training studies, but in one of the aforementioned studies, trained participants also reported less cognitive failures in everyday life (Brehmer et al., 2012) as a function of training.

In two studies (von Bastian et al., 2013; von Bastian & Oberauer, 2013a) a training program based on a specific theoretical working memory model – the facet model of working memory capacity (Oberauer, Süß, Schulze, Wilhelm, & Wittmann, 2000) was designed and evaluated. In that model, WMC is classified into three functional categories (storage and processing; relational integration; and supervision). It highlights mostly the executive aspects of short term information processing and thus shares many similarities with the model of executive functions presented by Miyake et al. (2000). In the first study, they provided evidence for transfer effects after training with these subfunctions separately. In the second study, in which all aspects of the model were trained, they found that the broader training approach in fact resulted in less transfer. Hence, they concluded, broader training of working memory does not produce broader transfer effects.

Another working memory training (Zinke et al., 2014) study took a similar approach and based the training program on Baddeley's theoretical model of working memory (Baddeley & Hitch, 1974), and included visuospatial and verbal short-term and working memory updating tasks, along with a serial attention task. This training regimen led to transfer effect to a simple span task and an episodic memory task.

In sum, the studies reviewed above have all focused more specifically on working memory training, where three studies explicitly designed their training programs based on a theoretical model of working memory. Overall results suggested a mixed pattern of transfer effects ranging from slim to far transfer.

Multifactorial training

Some studies apply a larger multi-modal training approach, such as a study by Schmiedek, Lövdén, and Lindenberger, (2010), which provided training both on episodic memory, perceptual speed and working memory and showed broad near and far transfer effects to several tasks both for younger and older, but with slightly broader effect in the younger. Both age groups also showed transfer to a latent factor of working memory ability and the younger to latent factors of episodic memory and fluid intelligence. Thus, providing training in a broad range of abilities might be an important part of generating generalized gains, in line with the idea of functional and structural overlap between trained tasks.

Video/computer games training

Another method has been to provide training on off-the-shelf computer or video games that are not specifically designed for cognitive training. Earlier studies have shown that experienced computer game players are often superior to non-players on tests measuring task switching ability (Colzato, van Leeuwen, van den Wildenberg, & Hommel, 2010), attention (Green & Bavelier, 2003, 2006, but see Irons, Remington, & McLean, 2011 for contradictory findings), processing speed and visual short term memory (McDermott, Bavelier, & Green, 2014), and working memory (Colzato, van den Wildenberg, Zmigrod, & Hommel, 2013). Further, video game training studies with younger adults have indicated that game training is successful in generating transfer effects (Green & Bavelier, 2007; R. Li, Polat, Makous, & Bavelier, 2009).

The games used in training are often action games which requires "fast motion, require vigilant monitoring of the visual periphery, and often require the simultaneous tracking of multiple targets" (Green & Bavelier, 2006), chosen for supposedly being taxing on several cognitive abilities, such as focused attention, speed, executive functions, or working memory capacity. Computer games are usually built to be emotionally engaging, motivating, and with a rising difficulty level as the game proceeds, which makes them interesting as means of cognitive training. The results from available video game studies with older adults provide contradictory findings regarding the ability to enhance cognitive functioning in general. In one training study with older adults (Basak et al., 2008), positive transfer was found on a range of abilities. After practicing a 4-5 weeks training program, they could show transfer to a diverse set of tasks measuring executive functions, visual short term memory, and logical reasoning in older adults. While it is less straightforward to define transfer tasks as "near" or "far" in game training studies, the laboratory tasks appears to be quite different from the tasks encountered during game training, and the authors therefore argues for a far transfer effect.

A recent study by Boot et al. (2013) which compared a brain fitness program to a racing video game (Mario Kart 2) did not reveal any significant transfer effects. The only effect was that the control group in fact improved more in the composite measure of executive control. A drawback with computer game training programs is that it is harder to disentangle which aspects of the game that are driving the results. One computer game study included a cognitive task analysis (Militello & Hutton, 1998) prior to including World of Warcraft as an intervention (Whitlock et al., 2012). The analysis revealed several demanding cognitive processes that the players engaged in during game play, such as switching between sub-tasks, thus utilizing effortful attentional control. Such an analysis might be advised to include in order to ensure that the games used are sufficiently demanding. The study showed transfer effects to a Stroop task after around 14 hours of training over two weeks in older adults.

Another game-training study (Stern et al., 2011) used the Space Fortress game, which was originally constructed to target divided attention, multi-tasking, visual scanning, working memory and motor control, enables computing sub-scores reflecting the different task components. This gives more control over which processes are targeted in training compared to off-the shelf computer games.

In an action video game training study by Belchior et al. (2013), in which the active control group played another computer game – Tetris, both groups improved to the same degree which further illustrates the problem with knowing what is trained.

To conclude, although several game training studies have shown promising results, there is a diversity in terms of transfer effects. One reason for the variable results might be that the participants' motivation to play the game has varied between studies, which has sometimes lead to participants receiving different amount of training (Boot et al., 2013). Training studies performed in the laboratory has the advantage of larger control of participation as compared to online at-home training and this might affect whether participants stay on the program.

Commercial brain training

The recent growth in cognitive training research is paralleled with an industry of brain training/brain fitness software. The programs are often built upon ideas and results from research, and they include practice with similar tasks, but in a more "game-like" setting. Such game training studies have a potential advantage in that they include features from both computer games and laboratory tasks. Four studies have been investigating the effects of such programs. Nouchi et al. (2012) showed transfer effects to a relatively large range of executive and speed tasks when comparing Brain Age with Tetris. By contrast, a study by Boot et al. (2013), included training with Brain Age and a racing game (Mario Kart), but found no transfer in either condition as compared to a no-contact control group despite a much larger training dose than in the former study (56 vs. 5 hours). The Lumosity training program was shown by Mayas, Parmentier, Andrés, and Ballesteros (2014) to improve the ability to resist attention capture by an auditory distractor during a visual attention task. McDougall and House (2012) used Nintendo Brain Training package and showed transfer to one measure of working memory. None of the brain training studies have investigated long-term effects or included different age groups, and thus it is not known whether such training programs can produce lasting effects on cognition in old age, and if the effects of training are age-dependent. Further, a large-scale study with over 11 000 participants (Owen et al., 2010) needs to be mentioned here, although they included only participants ranging from young to young-old. They evaluated a training program with two conditions – one with tests of memory, attention, visuospatial processing, and mathematics, similar to commercial brain training programs; and one with tasks focusing on reasoning, planning, and problem solving. They did not show any increase in any of the transfer measures as compared to no-contact controls despite clear training task gains. In sum, again, the results from the brain training studies are also variable with transfer effects ranging from no effects at all to some evidence of far transfer effects. These results have important practical implications, since the claims from providers of commercial brain training studies often are that they can lead to very pronounced and far-ranging effects on cognition, and often are marketed towards an elderly audience.

Factors governing transfer

The aim of the following discussion is to summarize the knowledge gained from process-based training studies regarding factors governing transfer effects. I will further discuss individual factors, and design-related factors such as variations in task demand and different kind of control groups. Few studies have evaluated long-term effects of process-based training, but I will make some comments regarding this as well.

Training length

Training length has earlier been stressed as an important factor for eliciting transfer (Schmidt & Bjork, 1992). Studies in the current review vary greatly in amount of training provided, from 2.5 sessions (Karbach & Kray, 2009) to 100 (Schmiedek et al., 2010). The 100-days training program resulted in both near and far transfer effects to several latent factors in young, and one latent factor in old adults. This is the most robust transfer among the available studies which may allude to the fact that training length is important. Intriguingly, also studies with remarkably short durations have also shown impressive far transfer effects. Two very short training protocols in a study by Karbach and Kray (2009), and a series of studies by Borella all showed far transfer effects to a range of different tasks. Thus, drawing conclusions about training length between studies is complicated, to say the least.

Only one of the reviewed studies (Stepankova et al., 2014) has directly manipulated training length. They provided either 10 or 20 sessions of n-back training and the results suggested somewhat more transfer for the longer training intervention. Two studies, mentioned above, used the same training program (Nintendo Brain Age), but one provided a shorter and the other a longer training regimen. Quite contradictory, the longer training program (Boot et al., 2013) resulted in null effects while the other (Nouchi et al., 2012) led to near transfer.

The reasons for why very short training regimens can give rise to far transfer while longer programs fail to do so is not yet clear. Several factors might have affected the results, given the diversity among other factors such as type and number of different tasks, type of transfer measure, and type of control groups. In sum, there appears to be a need for a more systematic examination of the effects of training length while keeping the training type constant.

As to the question regarding factors governing maintenance effects after process-based training, the number of studies is still low and it is therefore hard to draw any conclusions of as to how training length affect long-term maintenance. But generally, the factors which govern transfer probably affect maintenance as well.

Who benefits from training?

Few studies have investigated how individual-related factors affect training outcome. One such predictor is gain in the trained tasks which was investigated in a study by Richmond, Morrison, Chein, and Olson (2011). When removing participants who did not improve during training from analysis, enhanced far transfer was observed. Similarly, Jaeggi, Buschkuehl, Jonides, and Shah (2011) showed that children who gained most from working memory training also benefitted the most in terms of transfer to Gf, and in a recent study by Zinke et al. (2014), larger training gain was related to larger transfer effects in older adults.

Another factor to consider besides the amount of gain, is the proficiency in the trained tasks. Older adults usually exit the training on a lower level than younger adults do. Therefore, the pivotal point for generating transfer might the performance level reached in the practiced tasks. In other words, older adults might need to reach a higher proficiency in the target skill in order to be able to exhibit transfer to new tasks. Future studies could thus tailor the training dosage for each participant and provide training until asymptote is reached, in a similar way as in the testing the limits-approaches (Baltes & Kliegl, 1992), and evaluating transfer effects.

Regarding age, some studies have shown equivalent transfer effects in young and old (Bherer et al., 2005, 2008; Bürki et al., 2014; Karbach & Kray, 2009), while other studies suggest that degree of transfer is modulated by age, thus indicating a decrease in plasticity from early to late adulthood (Dahlin, Neely, et al., 2008; Dahlin, Nyberg, et al., 2008; Schmiedek et al., 2010). Age as a predictor for transfer was also investigated in the study by Zinke et al. (2014) who showed that among older adults, younger age was associated with larger transfer effects.

Age-comparative studies investigating maintenance effects are few, but some of them show, in line with the results regarding transfer, that old age limits plasticity as evident by a higher degree of maintenance in the younger (Dahlin, Nyberg, et al., 2008; Li et al., 2008). There are however also evidence of age-equivalent maintenance effects induced by training (Borella et al., 2014; Brehmer, Westerberg, & Bäckman, 2012).

Taken together, studies investigating individual factors are to this date still comparably few. In the future, researchers should strive to include both younger and older samples into training studies. In regard to maintenance, there are very few studies comparing young and old, and only two of them have had a follow-up interval of longer than a year.

Design factors

Transfer batteries: Ideally, transfer should be measured on the level of latent ability, and this have been done in two studies (Schmiedek et al., 2010; Stepankova et al., 2014), but since training studies are time-consuming endeavors, the number of participants are normally too small to perform such analyses. Transfer batteries which include measures on a near to far continuum, preferably with several test of the same ability could however give a hint of how widespread the transfer effects are. Including several tests of each ability have been stressed in order to generate a more fine-grained picture of the transfer effects (Zinke et al., 2014).

Investigating long-term effects: Although many studies have investigated gain and transfer effects after process-based training, fewer have included long-term follow-up tests. Two studies have had a follow-up interval lasting a year or longer (Buschkuehl et al., 2008; Dahlin, Nyberg, et al., 2008). Shorter intervals have been more common, and those studies are generally positive regarding long-term effects, although near transfer effects are maintained to a greater degree. Three studies compared maintenance effects in younger and older adults (Brehmer et al., 2012; Dahlin, Nyberg, et al., 2008; S-C. Li et al., 2008), and revealed maintained performance in all tasks which were enhanced at post-test. Thus, both younger and older adult seem to be able to maintain performance gained in process-based training after several months, but there is still a pressing need for studying sustainability of gain and transfer effects over longer periods.

Measuring transfer to everyday life situations: The ultimate goal of cognitive training studies is to find ways of supporting people in their everyday life. If process-based training only manages to enhance performance on a set of laboratory tasks, it will be of limited use for people. Within the ACTIVE study, it was recently shown that those who participated in speed and reasoning training was to a lesser degree involved in at-fault motor vehicle accidents than those in the control and episodic memory training groups during six years after the training (Ball, Edwards, Ross, & McGwin, 2010). Only two studies in this review showed transfer to an everyday memory questionnaire (Brehmer et al., 2012; Richmond et al., 2011). Thus, the need for establishing whether process-based training might transfer to such measures remains highly important.

Control groups: Without a control group which does not receive the intervention, it is impossible to disentangle the effects of taking the tests twice (pre and post) from the true intervention effect. No-contact control groups participate in the pre- and posttest session with no intervention in between. Preferably, control groups should however receive a placebo intervention, to rule out effects not related to the particular training intervention. It is however a delicate task to construct such a control condition which "lacks the active ingredient", since it is not yet established how different types of training interventions might affect cognition. Some studies use low-level practice e.g. (Brehmer et al., 2011, 2012) on the same training tasks as the intervention group, but this might be problematic since it can be perceived as boring by the participants, and thus create differences in motivation between groups. Another alternative has been to provide low-level physical training to the control group (Buschkuehl et al., 2008). Most studies using active control groups did not find evidence for a motivational effect upon transfer (Brehmer et al., 2011; Bürki et al., 2014; Nouchi et al., 2012), while one study did (Belchior et al., 2013). This state of affairs is also supported in a recent meta-analysis of n-back training studies (Au et al., 2014), where it was concluded that type of control groups did not moderate the training effects, and the authors suggested that expectancy effects are unlikely to mediate the findings of transfer in the reviewed studies. This said, it is still to be recommended to include active control groups.

Adaptivity of training: Lövdén, Bäckman, Lindenberger, Schaefer, and Schmiedek (2010) underlined that in order for plasticity to occur, a prolonged mismatch between environmental demand and cognitive resources is needed. This has also been stressed by (Klingberg et al., 2005), and can be done by keeping the practice sufficiently challenging throughout the training by increasing (and decreasing) the difficulty level of the trained tasks. Most studies have included some form of adaptivity of difficulty level during the training progression. Some programs have varied the difficulty level individually to each participants performance on a trial-by trial basis (e.g. Buschkuehl et al., 2008; Bürki, Ludwig, Chicherio, & de Ribaupierre, 2014; Richmond, Morrison, Chein, & Olson, 2011) so that participants always practice on their peak level, which has been argued to promote transfer. Others have let participants remain on the same level of difficulty until they reach a criterion, after which they are raised one level (Dahlin, Nyberg, et al., 2008). Raising the difficulty in a more step-wise manner instead of adapting it continuously might have the advantage of letting the participants feel that they master the task before going up a level which could heighten motivation and training gain as well as transfer.

Although studies including a constant adaptation on a trial-by-trial basis have shown positive transfer (Buschkuehl et al., 2008), this has also been the case in studies where adjustment has been made with larger spacing, such as between lists

(Heinzel et al., 2014), or between sessions (Wang et al., 2011). One study which did not use an adaptive regimen was the hundred-days training study by Schmiedek et al. (2010). They kept the level stable across sessions but tailored this level individually from pretest performance.

Thus, although there is little doubt that adjusting difficulty level and keeping it challenging throughout training is an important aspect of training, there is little empirical evidence regarding the optimal way of doing this.

Concluding remarks

From the reviewed studies, it can be concluded that the field has seen some exciting progress. The results have yielded substantial training task improvements, often similar in magnitude, in both young and older adults after process-training. Several studies have also demonstrated impressive far transfer effects in young adults and in a lesser degree in older adults. Despite encouraging findings, several questions require more attention. First, it is still unclear as to which specific processes need to be addressed in training to foster reliable transfer effects. Von Bastian et al., 2013 have taken a step in this direction by comparing single process verses multi-processes training (see above), in which it was concluded that broad training did not lead to more transfer. This was done with a model of working memory, and it has not yet been investigated within the framework of executive functions specifically. Several studies have focused on executive functions, but only one has done so by addressing several different control functions in the same training intervention (Wang et al., 2011). This is surprising, given the importance of executive functions to other aspects of cognition and to aging, and it remains unclear whether focusing on executive functions more broadly give rise to transfer effects in young and old adulthood.

Few studies have to date investigated long-term effects of process-based training in age-comparative settings, and most of those which did focused on working memory training. Most studies have used follow-up intervals spanning between three and nine months. Only one study (Dahlin et al., 2008) focused on long-term effects of an executive functions training program (updating), and found maintained near transfer effects for the younger group. Thus, it is not well-understood how sustainable training and transfer effects of executive functions training are, and how this differs between young and old adulthood.

The empirical studies

Study I and Study II are based on the same training program and also use the same pre-and posttest batteries. Therefore, I will describe them together in the same section, and thereafter I will describe Study III.

Research questions and aims

The aim of this thesis is to study effects of cognitive training in younger and older adults, both with a process-based training program focusing on executive functions, and with a number mnemonic strategy training program. Three studies are included, and the following research questions were posed:

> Can a theoretically based training intervention for executive functions, focusing on executive functions broadly, give rise to transfer effects to untrained tasks in young and older adults?
>
> – Study I

> Are gains and transfer effects after executive functions training stable over time?
>
> – Study II

> Which individual difference factors predict baseline performance and gain from cognitive training?
>
> – Study I (age), III (age and cognitive factors)

> Which individual factors predict long-term maintenance of cognitive training?
>
> –Study II (age), and III (age and cognitive factors)

Study I and Study II

Sandberg, P., Rönnlund, M., Nyberg, L., & Stigsdotter Neely, A. (2014). Executive process training in young and old adults. *Neuropsychology, Development, and Cognition. Section B, Aging, Neuropsychology and Cognition, 21(5),* 577–605. doi:10.1080/13825585.2013.839777 ***(Study I)***

Sandberg, P., Stigsdotter Neely, A. (2014). Maintenance of training gains and near transfer effects in young and old adults: An 18 month follow-up of executive process training, *manuscript submitted to Neuropsychological Rehabilitation* ***(Study II)***

In Study I, the aim was to investigate immediate effects of a cognitive training intervention targeting executive functions broadly by taking departure from the theoretical model of executive functions proposed by Miyake et al. (2000). Since executive functions has been shown to decline with age, and also are important for other age-declining cognitive functions, such as episodic memory performance, according to the frontal hypothesis of cognitive aging, they constitute an interesting target for cognitive training across the life span.

In a series of previous training studies by this group (Dahlin, Neely, et al., 2008; Dahlin, Nyberg, et al., 2008) which were based on the Miyake model, updating was targeted in a training program lasting five weeks (15 sessions à 45 min), and transfer was observed to another updating task – n-back for the younger group. The focus of Study I and II was to investigate whether assessing the executive system as a whole (i.e. all of the three executive functions inhibition, shifting, and updating) would lead to broad benefits in terms of transfer and long-term maintenance thereof.

In Study I, the aims were to evaluate the direct training effects as well as transfer effects, and further, how they were affected by age.

Study II focused on long-term effects of executive functions training. While there has been a large increase in studies examining transfer effects across the life span after process based training, less is known about how sustainable such effects are and whether young and old differs in this aspect.

Method study I and II

Participants

For Study I, 66 adults (33 young, 33 older) were recruited through advertisement in newspapers and pensions organizations (older) and advertisements around Umeå University Campus (younger). They were screened for various conditions assumed to affect cognition before inclusion. Further exclusion criteria were low scores on Mini-Mental State Examination (MMSE) or high on Becks Depression Inventory (BDI). All participants spoke Swedish fluently. Dropouts after pretest were four from the younger group and one from the older group.

In Study II, the participants from Study I was contacted again via regular post or email and 24 persons (14 trained and 10 controls) from the older group and 19 from the younger group (11 trained and 8 controls) returned to a follow-up test session. The testing took place 18 months after the termination of training and included the same test battery as the pre- and posttest sessions. Background characteristics of the included participants in Study I and II are presented in Table 2 and 3.

Table 2
Background characteristics Study I

	Young trained	Young control	Older trained	Older control
Sex (w/m)	11/5	9/4	8/7	9/6
Age	26.25 (4.0)	24.62 (3.4)	69.73(5.0)	68.80 (4.8)
Education (years)	15.69 (2.5)	15.00 (2.5)	11.46 (4.6)	13.13 (4.5)
Verbal ability	23.31 (2.0)	23.46 (2.5)	24.07 (4.4)	25.73 (4.1)
Digit symbol	61.93 (14.2)	59.00 (12.0)	43.00 (9.3)	42.13 (10.3)
MMSE	29.13 (1.1)	29.00 (1.1)	28.67 (.8)	29.2 (.7)
Depressive symptoms	3.81 (5.2)	4.31 (2.2)	3.17 (3.0)	5.93 (3.6)

Table 3
Background characteristics Study II

	Young trained	Young control	Older trained	Older control
Age	27.5 (3.0)	25.1 (3.1)	71.6 (5.0)	71.2 (5.3)
Education (years)	16.3 (2.2)	14.3 (1.4)	11.4 (4.8)	12.2 (3.9)
Verbal ability	23.0 (1.9)	24.5 (2.2)	24.8 (3.6)	26.7 (1.8)
Digit symbol	65.9 (13.7)	63.8 (8.6)	43.9 (10.9)	46.2 (8.3)
MMSE	—	—	28.1 (1.4)	28.5 (1.0)
Depressive symptoms	3.3 (3.8)	4.8 (3.6)	3.3 (3.3)	6.9 (4.5)

Training program

The training intervention on which Study I and II are based consisted of five weeks (15 sessions à 45 min) of executive functions training. Training was performed individually in groups of four. In order to target the three executive functions inhibition, shifting, and updating in training, a computerized training program was developed with the theoretical model of executive functions presented by Miyake and colleagues (2000), as a point of departure. Each of the three subprocesses was targeted with two tasks each. The training tasks were chosen based both on tasks used in the Miyake (2000) paper and an additional literature review. Training tasks are described in Table 4 and depicted in Figure 1. In addition to this, a criterion task with fixed difficulty level was administered at the beginning of each training session to be able to measure performance across training trials. For this, a letter memory running span task was used, which is the same as the corresponding training task but with fixed length of the sequences (between 7 and 15 items).

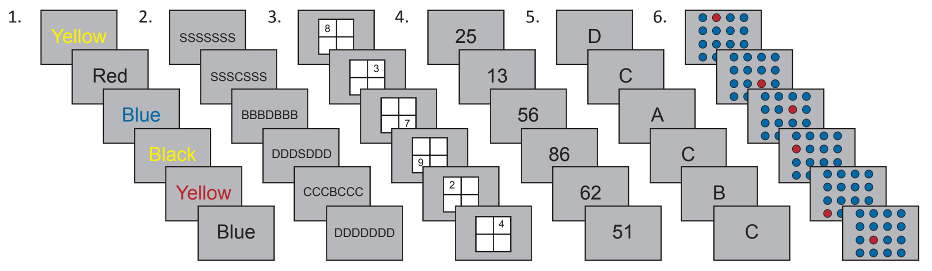

Figure 1. Schematic of the training program used in Study I and II. 1) Stroop. 2) Flanker. 3) Alternating runs. 4) Plus-Minus. 5) Letter memory running span. 6) Spatial locations running span.

Pre-, post-, and follow-up tests

Before training, all participants were tested individually across two sessions with a cognitive test battert chosen to test transfer ranging from near to far (see Table 5 and 6). The same tests were re-administered the week following training (Study I), as well as after 18 months (Study II). In some of the tests, alternative versions were used to avoid test-retest effects. The tests were administered in the same order for all participants at all test occations.

Table 4
Training tasks used in Study I and II

Training task	Executive function	Description	Difficulty level adjustment
Letter flanker	Inhibition	Make speeded right or left key press responses to the middle letter of five (e.g. DDDSDDD). Stimuli were either congruent (flankers mapping to same key), incongruent (flankers mapping to opposite key) or same letter strings	Shortening of the time to prepare for next item (200, 500, or 1000 ms)
Stroop	Inhibition	Make speeded key press responses to color words (black, red, blue, or yellow) written in same or another color, or to non-color words written in any color	Shortening of the time to prepare for next item (200, 500, or 1000 ms)
Alternating runs	Shifting	Shift between categorizing digits (1, 2, 3, 4, 6, 7, 8, or 9) as odd/even and lower/higher than five with left or right key presses every two trials depending on the position in a square	Shortening of the time to prepare for next item (200, 500, or 1000 ms)
Plus-minus	Shifting	1st run: add a number to two-digit numbers; 2nd run: subtract a number; and third run: Shift between adding and subtracting a number. Response with numeric keypad	Number to be added (2, 4 or 5)
Letter memory running span	Updating	Continuously monitor and update the four last items in sequences of serially presented letters (A, B, C, or C). Response at the end of each sequence by key press	Length of letter sequence (4 – 7, 6 – 11, 5 – 15)
Spatial locations Running span	Updating	Continously monitor and update the four last items of serially spatial locations in a 4 x 4 matrix of blue dots. Response as Letter memory	Length of dot sequence (4 – 7, 6 – 11, 5 – 15)

Table 5
Near transfer tests used in Study I and II

Test	Executive function	Description	Differences compared to corr. training task/s
Arrows flanker	Inhibition	Make speeded right or left key press responses to the middle arrow of five (>><>>)	Stimulus materials: arrows instead of letters
Verbal color Stroop	Inhibition	Name the color of squares; read aloud color word; or name the color of the text in which congruent or incongruent color words are written	Response mode: verbal instead of key press response
Alternating runs	Shifting	Shift between categorizing letters (A, B, D, E, U, X, Y, or Z) as vowel/consonant and beginning/end of alphabet with left or right key presses every three trials depending on the position in a circle	Stimulus material: letters instead of numbers; shifting task set every three instead of two trials
Plus-minus	Shifting	1st run: add 3 to two-digit numbers; 2nd run: subtract 3; and third run: Shift between adding and subtracting 3	Number to be added: 3 instead of 2, 4 or 5
Number memory running span	Updating	Continuously monitor and update the four last items in sequences of series of serially presented digits (1, 2, 3, or 4)	Stimulus material: digits instead of letters
n-back	Updating	To each of the serially presented digits decide if it matched the stimuli one, two, or three items before	Stimulus material: numbers instead of letters/positions in matrix; response mode: key press after every item instead of at the end of each sequence

Table 6
Intermediate and far transfer test used in Study I and II

Test	Cognitive domain	Description
Digit symbol	Processing speed	To copy as many symbols (each symbol associated to a digit as specified in a coding key) as possible in 90 s into empty boxes
Digit span forward and backward	Working memory	To repeat sequences of increasing length in the same (forward) or reverse (backward) order
Computation span	Working memory	To solve series of arithmetic problems, while holding the last digit of each problem in mind for later recall. Series increased in length over trials
FAS, letter and categories	Verbal fluency	To write down as many words as possible beginning on the letters F, A, or S; or belonging to the categories provisions, animals with first letter S, or professions with first letter B in 90 s
Recall of concrete nouns	Episodic memory	Free recall of 18 serially presented nouns (each word presented five seconds)
SRB I*	Verbal ability	Swedish word synonym test
Raven's advanced progressive matrices	Reasoning	Solve two-dimensional pattern matching matrices by finding the best fitting alternative to a missing section of each matrix

Note. *Included at pretest only.

Results Study I

The results from Study I showed that the training lead to substantial improvements in all trained tasks with exception of the flanker task, in both younger and older adults. The same pattern of equal gains was seen in the updating criterion task, which was administered in the beginning of each training session, and at pre- and posttest. Across training sessions, the gain in this task was parallel for young and old.

In most tasks, substantial age differences were observed and were often magnified under more cognitively demanding tasks conditions as evidenced by several reliable. In light of this observation, it is interesting to note that no age differences in the magnitude of training-related improvements in the criterion task as well as across training tasks were seen, with the exception of the plus-minus task. This finding is at odds with much earlier research showing that training more often amplifies preexisting age differences in performance (Brehmer, Li, Muller, von Oertzen, & Lindenberger, 2007; Schmiedek et al., 2010; Verhaeghen & Marcoen, 1996; but see S.-C. Li et al., 2008; Richmond et al., 2011 for equal age gains).

The results showed selective near transfer gains for both the young and the old trained participants in one updating transfer task (the number memory running span) and one inhibition transfer task (the Stroop task). Both these tasks differ from the trained tasks in terms of type of material for the updating task and in stimulus–response mappings for the Stroop-task. No effects on any of the included shifting near transfer tasks were observed despite substantial shift-cost reductions across training session.

In light of the sparse near transfer effects, it is interesting that the young adults showed intermediate transfer effects to digit span backwards and Computation span, although the latter finding did not survive a Bonferroni correction despite a strong effect size. In contrast to our earlier findings where we in two studies have shown transfer to an n-back task in young adults after 15 sessions of updating training, no such significant effects were seen in Study I.

Finally, no far transfer effects were seen for the young or the older adults. Our findings concur with those studies showing no effects on fluid intelligence measures or, for that matter, to any of the far transfer tests addressed in this study.
Of particular interest in the current study was to investigate if older adults would benefit more from a program focusing on several executive functions strengthening a declining executive system more thoroughly. This was not supported by our data and shows that training of multiple executive processes is not sufficient to support transfer beyond the very near in older adults.

Results Study II

The results from Study II indicated long-term maintenance in training task gain, as measured with the criterion test, Letter memory running span. This was revealed by stable performance levels from immediate posttest to follow-up, together with significantly better performance at follow-up compared to pretest, for both the young and older trained groups, but not for the controls.

Further, our findings also revealed long-term maintenance of immediate near transfer effects for both young and old trainees. For the Number memory updating task the same pattern of results were seen as for the above described Letter memory task, yielding stable performances for both young and old trained over the 18-month follow-up period. Performance in Stroop was not maintained over the studied period.

However, the follow-up analyses did not support maintenance of the intermediate transfer effects to working memory for the young adults. Thus, these findings of less permanent intermediate transfer effects suggest little evidence for that executive process training lead to more profound effects on the cognitive system. They also emphasize the importance of including long-term follow-up assessments in order to fully evaluate positive short-term effects on the cognitive system.

Study III

Sandberg, P., Rönnlund, M., Derwinger, A., & Stigsdotter Neely, A. (2014). Memory plasticity in older adults: cognitive predictors of training response and maintenance following learning of number-consonant mnemonic, *manuscript submitted to Neuropsychological Rehabilitation*

In Study I and II, age was shown to be an important factor behind the ability to gain from training, so that the younger showed more widespread effects of taking part in the training intervention as compared to the older. In those studies, we did however not evaluate how other individual factors affected the results. It has been suggested by earlier research that cognitive variables such as global cognitive functioning (Yesavage, Sheikh, Friedman, & Tanke, 1990), better initial ability on the targeted function (Verhaeghen & Marcoen, 1996), processing speed (Kliegl et al., 1990) and working memory capacity (Verhaeghen & Marcoen, 1996) affect the ability to gain from cognitive training. In Study III, we investigated the relationship between age as well as of three cognitive factors; working memory, processing speed, and verbal knowledge on training gains and maintainance thereof.

Method Study III

Participants

Participants in this study was 112 community dwelling older adults (M = 70.9; range 60-86) who were part of a larger sample receiving different types of memory training at the Stockholm Gerontology Research Center in Stockholm. They were recruited via advertisement in newspapers and screened for various conditions assumed to affect cognition. All participants spoke Swedish fluently. Background characteristics of the participants are presented in Table 7.

Table 7
M (SD) values of participant characteristics for returnees, dropouts and total sample in Study III

	Returnees (n = 94)	Dropouts (n = 18)	Total sample (n = 112)
Sex (w/m)	56/38	12/6	68/44
Age	70.9 (6.7)	70.9 (7.5)	70.9 (6.8)
Education (years)	11.9 (3.7)	11.2 (2.6)	11.8 (3.5)
Vocabulary	58.6 (7.3)	58.8 (4.1)	58.6 (8.9)
Depressive symptom	33.9 (6.2)	33.7 (6.4)	33.9 (6.2)

Training program

The training program in Study III consisted of individual computer-based memory training with a Swedish version of the number-consonant mnemonic (Higbee, 1988). Participants memorized lists of four-digit numbers which were randomly created and presented on the computer screen using a large font (Times 72). The mnemonic strategy was to convert each digit to a consonant, and creating words by adding vowels between the consonants. For further description of the mnemonic training, see Table 8. The difficulty level was adapted to the skill of the participants in a way which permitted them to control the number of four-digit sequences to be presented, the presentation time of them, and whether support in the form of writing down the generated word phrases should be provided. As the training proceeded, they were encouraged to add a time limit to the presentation time, and to work without support. The training was performed in groups of 6 participants with one test leader. Fourteen one-hour training sessions, (twice a week for seven weeks) weeks (14 sessions à 1 hour) were provided.

The four first session included strategy instruction and practice in order to ensure that the participants mastered the number-mnemonic. During the introduction, they were taught the four steps of the mnemonic. The training procedure is depicted in Table 8.

Table 8
Training procedure in Study III

Phase in training	Description
Introduction first step	Memorization of a series of number-consonant pairs. Each digit were to be transformed into one or two consonants: 1 = T or D 2 = N 3 = M 4 = R 5 = L 6 = J 7 = K or G 8 = F or V 9 = P or B 0 = S or Z
Introduction second step	Word-phrase generation by using the previously (over-)learned number-consonant pairs and inserting vowels between them. Four-digit codes which should be transformed into two words were used. From the four-digit number 4582 e.g. the words ReaL FuN could be generated
Introduction third step	Encoding of generated word phrases. Participants were instructed to create meaningful phrases and practiced imagery and association skills
Introduction fourth step	Retrieval of and translation of the encoded word phrases back to the number sequence ReaL FuN -> 4582
Training sessions 1-10	Practice with the number-mnemonic. Series of four-digit numbers were presented on a computer screen. Number of series; support in form of pre-generated word phrases or keywords; and presentation time could be adjusted by participant. As training proceeded, participants were encouraged to work without support and with a time limit.

Pre-, post-, and follow-up tests

At pre-, post-, and follow-up, multiple measures of each cognitive predictor (described in Table 9), along with the number recall criterion task measure was administered. The criterion task was the same as the one used during training and involved presentation of 10 four-digit numbers on a computer screen, at a rate of 45 sec per number, and tested with immediate recall test following the Buschke selective reminding procedure (Buschke, 1973). During post-test and follow up, two versions of the test were used – one with support and one without. The support condition allowed participants to enter the number-to-consonant transformation as well as the consonant-to-word generation information at encoding, and during recall, they could say the word-phrases they retrieved, which was then typed in by the test leader and displayed on the screen which they had learned during training.

Table 9
Cognitive predictor tests in Study III

Cognitive predictor test	Cognitive domain	Description
Number copying	Processing speed (motor)	Copy as many numbers as possible in 30 s into rows of empty boxes (10 boxes/row). Each empty box had a box above it, containing the number to be copied
Line marking	Processing speed (motor)	10 rows of squares that were missing one line were presented (10 squares/row). The task was to complete as many squares as possible in 30 s
Digit-symbol	Processing speed (perceptual)	To copy as many symbols (each symbol associated to a digit as specified in a coding key) as possible in 1 min into empty boxes
Pattern comparison and letter comparison	Processing speed (perceptual)	Judge whether 30 pairs of line-drawings (3, 6, or 9 lines)/letter strings (3, 6, or 9 letters) were same or different and write down the answer between each pair
Listening span	Working memory	Listen to sentences and respond to simple questions about each, while holding the last word of each sentence in memory for later recall. Number of sentences increased in length over trials

Cognitive predictor test	Cognitive domain	Description
Computation span	Working memory	Solve series of arithmetic problems, while holding the last digit of each problem in mind for later recall. Series increased in length over trials
Free recall of concrete nouns and Free recall of abstract nouns	Episodic memory	Recall as many as possible of 16 concrete/abstract nouns presented serially on a computer screen for 5 s each
Paried associates	Episodic memory	Recall as many as possible of 10 number-consonant pairs presented serially on a computer screen for 5 s each
Antonyms	Verbal knowledge	Two versions – 1 with 29 and one with 70 items. Select and mark the word opposite in meaning to a target word among four alternatives

Results Study III

The results from Study III suggest that several factors contribute to individual differences in memory plasticity. First, baseline episodic memory was a predictor of training-related gains in the criterion task, so that the older participants with better episodic memory functioning at pretest were those who benefitted the most from mnemonic training. Second, a higher rate of processing speed was associated with larger training gains, and third, more extensive verbal knowledge is conducive to gains from memory training, beyond the influence of the former factors.

When comparing predictors of gain to those of baseline performance, this study revealed that although working memory did not emerge as a significant predictor for gain, it predicted baseline performance, while the opposite was true for verbal knowledge and speed.

Most of the negative influence on training gain in number recall following training was mediated by the cognitive factors. Age remained a significant predictor of training gains only in the condition with support.

Further, the results demonstrated highly stable levels from posttest to the eight-month follow-up assessment, in particular for the condition in which support was provided. No relationship with age was found, suggesting that whereas older age is associated with a reduction in memory plasticity, it has little effect on maintenance. Basic processing resources in form of speed and working memory did not predict maintenance of mnemonic skills. Instead, verbal knowledge was as a significant predictor for maintenance.

General discussion

The overarching aim of this thesis was to study transfer, maintenance, and predictors of gain in cognitive training in young and old adults. Cognitive training studies can broadly be divided into strategy-training studies or process-based training studies. Both types of training interventions were incorporated in this thesis, and four main issues were investigated. I will center the following discussion on these issues.

Transfer effects after executive functions training in young and older adults

Few prior attempts to investigate training of executive functions broadly in both younger and older adults have been made (but see von Bastian, Langer, Jäncke, & Oberauer, 2013 for a similar setup with working memory training). In Study 1, the focus was on investigating training gain and transfer effects of a process-based training program constructed to target executive functions. The training was based on a theoretical model of executive functions presented by Miyake et al. (2000), and included training tasks designed to tap into inhibition, shifting and updating, in order to provide broad practice of the executive system. Inclusion of younger as well as older adults makes it possible to compare the modifiability of executive functions between age groups, which should be informative of life-span changes in plasticity.

In line with much previous research on process-based training (Jak, Seelye, & Jurick, 2013), we found significant training task gains, in both young and old, from pre- to post test in the criterion measure – the updating task letter memory running span, along with gain in all training tasks except the flanker task. The reason for the absence of a training effect in this task is not clear, but the costs of inhibiting incongruent flankers were relatively low already at session one, which made little room for improvement in this task.

Further, we also found transfer effects in both younger and older adults. The younger and older alike managed to generalize their practice to untrained measures of inhibition and updating. These tests were variations of the trained tasks but with different stimulus material, and different response modes. The differences between training and transfer tasks were arguably small, and this was also the purpose of including a larger set of near transfer task, since it can help paint a more fine-grained picture of the transfer effects. The differences between the tasks are, however, not trivial. In Stroop, for example, the transfer task involved giving a verbal response (e.g. saying "red" out loud when seeing the word "yellow" written in red). The training version required participants to make the responses with a button press on the appropriate color key. Thus, the observed transfer task involves a more difficult inhibition task since the verbal response is arguably more heavily overlearned than the button press response. This shows that the effect goes beyond mere strengthening of task-unrelated factors such as improving motoric responses. No near transfer to any of the shifting tasks was found which was contrary to our expectations, since the tasks included are highly similar to the ones trained, and despite a clear training effect in both shifting training tasks. It is intriguing to note that in a study by Karbach and Kray (2009), only 2.5 hours of shifting training led to impressive far transfer effects in young and old adults. One difference between that study and ours is that the shifting tasks were more predictive in our study, since we provided cues about which task to perform, which meant that participants did not have to keep track of which task to perform (Monsell, Sumner, & Waters, 2003).

As was alluded to in the background of this thesis, evaluating transfer effects after cognitive training might provide insights to the malleability of the hypothesized underlying ability. If training in one type of tasks also improves performance on untrained measures of the same ability, this would be a sign that the underlying ability has been strengthened (Lövdén et al. 2010). Our training program only led to transfer in two out of six near transfer tasks, and thus does not lend firm support to the notion that broad executive training give rise to broad and consistent near transfer effects neither in young nor in old adults.

We did however find transfer effects to two measures of working memory among the younger adults, which we classified as intermediate transfer (see also von Bastian et al., 2013). This fits with earlier research which provides well-established links between measures of working memory capacity and executive functions (Conway, Kane, & Engle, 2003). Varied training has been stressed as a key factor for giving rise to transfer (Schmidt & Bjork, 1992), and this notion is also supported by recent empirical findings (Schmiedek et al., 2010). It is however not quite clear why we found intermediate transfer in the absence of consistent near transfer effects. One explanation that comes to mind is that the training might not have been extensive enough in each targeted executive function to give rise to broad near transfer effects, but that it was varied enough to strengthen a common executive factor in younger adults.

Comparison to an earlier training study

The interest in investigating the effects of targeting all three executive functions in training rose after two earlier studies by this group (Dahlin, Neely, et al., 2008; Dahlin, Nyberg, et al., 2008) had shown that five weeks of practicing with a training program focusing on the updating component of executive functions had given rise to near transfer to another updating task in young, but no transfer in old. A key point made in this work was that transfer is driven by a specific overlap between trained and untrained tasks in terms of process (updating), and brain region (striatum). We therefore wanted to study if extending the training to target all three of the proposed functions would give rise to broader transfer, and to transfer also in older adults. We based this on the hypothesis that transfer is driven by an overlap in processing demands in trained and transfer tasks, and thus that strengthening the executive system as a whole might give rise to more robust and broad transfer effect. Specifically, a processing overlap between training and transfer tasks, according to Schmidt and Bjork (1992), is hypothesized to lead to transfer because processing demands encountered during practice, prepares the participants for upcoming demands in the transfer tests.

If transfer is driven by overlapping processing mechanisms, transfer effects could be expected to be broader when providing training on a larger set of functions as compared to a more limited training. This has previously been investigated within a working memory training framework by von Bastian and Oberauer (2013a), in which they found that broader training did not lead to broader transfer, but it has never specifically been studied within the context of executive functions.

Since Study 1 in this thesis and our two previous studies (Dahlin, Neely, et al., 2008; Dahlin, Nyberg, et al., 2008) used similar study designs, a comparison between them can be informative regarding this issue. The amount, length, and spacing of training was the same; many of the same transfer tasks was used; the same age ranges were investigated, and the same follow-up interval was used (Dahlin, Nyberg, et al., 2008). When comparing the studies, it can however not be concluded that training three subfunctions of the executive system instead of one leads to transfer beyond the very near in older adults. Even though we did find transfer to one updating task and one inhibition task in Study 1, a somewhat more sensitive transfer battery was used as compared to our earlier studies, which captured a near transfer effect to the updating and Stroop tasks. The n-back task which was used in all studies was not improved in Study I in either age group. The younger adults however showed a somewhat broader transfer effect which might suggest a strengthening of the core executive ability common for all the tasks.

It should be noted the design of Study 1 warrants for appropriate caution when drawing conclusions about whether it is more fruitful to apply training to one component as compared to three, since we only included the broader training program and not a second group receiving training in one function only. The inclusion of a control group receiving training in only one executive function – e.g. updating, in the same study, would have permitted us to draw more firm conclusions about whether training the executive system broadly also leads to broad transfer.

Proficiency in trained tasks as a predictor for transfer?

Based on our findings in Study I and the studies by Dahlin and colleagues, we could concluded that, although the older adults improved to an equal amount as the younger in training, they still performed at a lower level than their younger peers in the trained task at the end of practice.

To investigate the relation between level or performance and transfer further, we conducted a pilot study with older adults where the training length was not set, but where participant instead trained until they reached a set criterion of 70 % correct responses in the criterion measure (letter memory running span). We recruited 25 healthy older adults of which 18 participated in updating training and seven served as controls. The groups were equal in terms of age, MMSE score, processing speed (Digit Symbol Substitution), and vocabulary (SRB-I) at baseline. The training focused on updating with four running span tasks (Pollack, Johnson, & Knaff, 1959) and one keep track task (Yntema, 1963), and was adapted to performance. Sixteen of the participants reached the criterion, and mean number of sessions needed for reaching it was 23.4 (SD 8.6, range 15-43). The results showed that the trained group improved significantly in both of the transfer tasks – Number memory running span and 3-back, as compared to controls. When comparing a group who needed more than 24 sessions to reach the criterion to those who needed less, there were no differences in terms of transfer effects. This supports that the level of performance and not the training length was crucial for transfer. Thus, these preliminary results suggest that in order for transfer to occur, a certain degree of proficiency during training has to be reached. This has clinical implications, since cognitive training may need to be individually tailored in order to be effective. And further, the results show that the level of performance reached after training is relevant to consider in order to understand the nature of select transfer effect.

Transfer to measures of everyday-life cognition?

Studies of cognitive training have both theoretical and practical implications, and some of the theoretical issues have already been covered. However, clinical implications are also important to consider. The overarching clinical goal with training research is to find optimal ways of strengthening declining function in old age, in order to support cognition in people's everyday lives. Measuring transfer to other cognitive tasks is one way of investigating whether the training is beneficial in a broader sense, but they do not capture directly the effects on everyday life-situations. Transfer to real world situations have been investigated in studies within the ACTIVE program, which have shown that cognitive training resulted in transfer to self-reported instrumental activities of daily living (IADL; Willis et al., 2006), and less involvement in at-fault motor vehicle accidents (Ball, Edwards, Ross, & McGwin, 2010). In Study I we included the Prospective Retrospective Memory Questionnaire (PRMQ; Crawford, Smith, Maylor, Della Sala, & Logie, 2003), in which participants rate how often they have experiences of e.g. forgetting to buy something in the store, forget to do something which they just recently decided to do, or mislay things like glasses or magazine.

We did however not find any effect of the training on this questionnaire. It is possible that effects on everyday life performance might have gone unnoticed due to the nature of the measure, but it should be noted that prospective memory (which constitutes half of the questionnaire) refers to the ability of remembering to do things in the future, and this ability is closely related to executive functions. Capturing effects such as these with self-report scales is difficult, and it is possible that the training group as a result of participating in training started to pay closer attention to "failures" in their every-day lives.

We also administered a questionnaire in which we directly asked all participants whether they felt that participating in the study had led to any memory improvements, and if it had, we asked them to give examples. Of the 15 participants in the older training group, nine reported some or distinct improvements. Among the examples were "holding a telephone number in the head while dialing", and "remembering grocery lists when going shopping". Three of the younger stated that they experienced some improvement and gave examples of "remembering texts better", and "easier to shut out irrelevant sounds while studying". Among the controls, one in each age group reported some improvement. Such effects are positive to note, but a degree of caution should be applied when interpreting such data since they are possibly affected by expectancy effects. They are nonetheless encouraging and a motivation to keep doing research on the subject, and if used in combination with active controls, the influence of expectancy is likely to be lowered.

Stability of gain and transfer effects and their relations to age

It has been stressed (Schmidt & Bjork, 1992) that in order to fully evaluate the effectiveness of training, it is necessary to investigate not only immediate effects, but also to study the effects over time. Schmidt and Bjork (1992) distinguish between performance and learning, where the latter is reflected in enduring effects after practice, and investigating them is crucial when evaluating training.

Ball, Edwards, and Ross (2007), and Willis et al., (2006) have argued that the benefits of training may in fact be more relevant to maintenance than to immediate effects, so that untrained individuals over time experience a decline in cognitive functioning, while those who have received training show maintained or increase in ability.

Several studies with strategy-based training approaches have shown maintained performance over time periods for several years (Bottiroli, Cavallini, & Vecchi, 2008; Stigsdotter Neely & Bäckman, 1993; Rebok et al., 2013), and it has also been shown that strategy training can lead to long term effects of activities of daily living (Willis et al., 2006) after five years. However, the amount of process-based training studies investigating maintenance are few, and only two studies with follow-up intervals with a year or longer are available (Buschkuehl et al., 2008; Dahlin, Nyberg, et al., 2008). In Study II of this thesis, the focus was on investigating long-term effects of the executive functions training program from Study I, and if long-term maintenance is restricted by age.

The results from Study II showed that both (younger and older) training groups' gain in the letter memory criterion task was stable over the 18 months period. Thus, both younger and older performed at the same level in this task as directly after training, 1.5 years earlier. This result replicate the findings from Dahlin, Nyberg, et al. (2008) and give further support for stable maintenance of training gains in both younger and older adults, which is in line with much previous research (Anguera et al., 2013; Borella et al., 2014, 2010, 2013; Brehmer et al., 2012; Carretti, Borella, Zavagnin, & de Beni, 2013; McAvinue et al., 2013; Zinke et al., 2014).

Further, the same pattern of results were shown for an updating near transfer task which involved new stimulus material, and this is important since it shows that older and younger alike can maintain performance also in a untrained task for time periods longer than a year. This is noteworthy for the older adults, in light of lower performance levels at posttest compared to the younger, ongoing cognitive aging process, and the fact that no boosting activities was performed during the time interval between posttest and follow-up. They were also not given any information about an upcoming retest session. This is, to the best of my knowledge the first demonstration of maintained near transfer effects in older adults over a period longer than a year. As noted in the above section about training gain and transfer effects, an equally long follow-up interval was used in an earlier study (Dahlin, Nyberg, et al., 2008), but the transfer battery of Study II in this thesis was somewhat more sensitive than in that study, which allowed us to detect effects of tasks similar to the training tasks.

The gain in performance in the Stroop task which was evident for both age groups directly after training was not maintained over the studied period, and the intermediate transfer effects which were shown in the younger, had also decreased back to pretest level over the interval between posttest and follow-up. This might be interpreted as near transfer effects being more stable over time.

Thus, the results from Study II suggests that maintenance of transfer effects are slim, and only confined to one task, which was highly similar to one of the training tasks and the criterion measure. The larger part of the increase and maintenance of this task is probably rather task-specific (Schmiedek et al., 2010), since the only difference between the tasks were the stimulus material (numbers instead of letters). Thus our results does not suggest that a more broad and permanent plastic change in neither in young nor old, has been the result from training broadly on three executive functions.

In light of these results, it is important to point out that follow-up assessment should be included in training studies in order to fully evaluate the effects of training. Obviously, a training program which manage to enhance cognition in general, but where performance quickly drops back to baseline levels have little clinical significance. Such decline in improvement might be hindered if booster sessions are included after training has ended (Baldwin & Ford, 1988; Ball et al., 2002; Willis et al., 2006).

Predictors of gain and long-term effects after strategy-based training

Age-effects on gains, transfer and maintenance after process-based training have been discussed above, therefore the following section will focus on age and a range of cognitive predictors for training task gain and long-term effects after a strategy-based training program for episodic memory performance, which was examined in Study III.

In study III, the main focus was on investigating predictors of training gain upon an episodic memory task. The training involved learning and practicing a number-consonant mnemonic. The need for memorizing numerical information in the form of pin codes are getting increasingly common in a host of situations, such as paying bills, visiting friends, or borrowing books from the library. Therefore, such a mnemonic has an advantage of being highly ecologically valid (Derwinger, Neely, Persson, Hill, & Bäckman, 2003). Remembering random digits demands allocation of processing resources, and strategies can greatly remedy the amount of information to be remembered. Earlier studies have indicated that the amount of available cognitive resources in the form of for example, speed (Singer, Lindenberger, & Baltes, 2003), working memory capacity (Verhaeghen & Marcoen, 1996), and vocabulary (Bissig & Lustig, 2007) may be central in describing cognitive aging, and also affect training gain. No study has, to the best of our knowledge, investigated the influence of all these factors simultaneously upon mnemonic training gain.

In Study III an older sample with an age range of 60-86 years were included. The participants were thus both young-old and old-old participants. It has earlier been shown that decrease in cognitive abilities show decline after the age of 60, with relatively large differences within that age spectrum (Rönnlund et al., 2005), especially within the domain of episodic memory, which makes age, as well as cognitive abilities possible predictors of training gain. Further, age-related reductions in plasticity has been demonstrated both between samples of young and young-old adults, and within groups of older adults (Verhaeghen, Marcoen, & Goossens, 1992).

Previous studies involving strategy training have shown larger gains from training for younger adults, and a magnification/amplification model has been suggested from such studies (Kliegl, Smith, & Baltes, 1989, 1990; Verhaeghen & Marcoen, 1996). According to this model, age-related differences in training gain can be explained by differences in pretest performance, so that lower performance at pretest leads to lower gain. This in turn leads to, since older adults often perform at a lower level, age differences being magnified by training.

The results from Study III showed that baseline episodic memory performance predicted training gain in number recall. This is to be expected according to a magnification model, and shows that those participants who were initially more proficient in the targeted memory process were those that also benefited the most from training.

According to the processing speed account for age-related decline (Salthouse, 1996), the speed of which operations can be performed is the most limiting factor for cognitive functioning in old age. In the present study, speed did not explain any unique variance at pretest but did so at posttests as well as for training gains. The pattern of increased importance of speed in predicting gain are in line with previous findings showing an increase in predictive power of broad fluid ability measures as a function of skill learning (Kliegl et al., 1990; Singer et al., 2003).

The processing speed account of cognitive age-related decline is related to other theories about cognition in old age that underline that the decline in a range of cognitive functions might best be understood in terms of limitations in the total amount of available resources in old age. In this study, we did not investigate the importance of executive functions upon training gain directly, but some authors have argued for the possibility that processing speed predicts performance on other aspects of cognition, such as executive functions, because the tasks use to measure speed requires executive control. Cepeda, Blackwell, and Munakata (2013) points out that even the simplest tasks of processing speed requires maintenance of a task goal and filtering of background information, while the more complex measures also involves controlling attention when maintaining and manipulating task-related stimuli in working memory. In the future, it would be interesting to include explicit measures of executive functions in order to further shed light on their involvement in plasticity in old age.

We did however include measures of working memory, which did not predict training gain, contrary to our expectations, while it did predict baseline performance in the criterion task. According to 1) a magnification model, in which a matching set of predictors would be expected to predict both baseline recall and training gain, and 2) a limited processing account for age-related differences, it would be expected that also working memory proficiency played a part in this regard. The fact, again, that a reasonable amount of variance was shared between cognitive predictors for both baseline recall and training gains, might however be an indication of a more general cognitive factor for baseline recall and training gains.

Further, verbal knowledge (semantic memory) was predictive of training gain beyond the influence of speed and episodic memory. This is in line with earlier research showing that rate of verbal learning is predicted by earlier acquired verbal knowledge (Rast, 2011). One speculative interpretation of this might be that the life-long acquisition of verbal knowledge, which is also related to years of education (Rönnlund et al., 2005) also works compensatory for other types of decline.

Regarding age, the results showed that although the cognitive factors, which are discussed above, mediated most of the negative influence of gains in the number recall task, age predicted training outcome in the condition with support. In this condition, participants were allowed to write down the word phrases that they generated during encoding and retrieval of the number sequences. This procedure reduces the reliance on executive functions/working memory capacity during testing, and allows participants to concentrate on the crucial aspects of the strategy. The overall performance gain was significantly larger in the support condition, while in the unsupported condition, the training had a smaller impact on recall performance. This was contrary to our expectations, but might be explained in terms of the unsupported condition being to taxing for this age group. Thus, when support was given, more processing resources were freed, from which the younger-old benefitted more.

In this study, the extent to which individual differences in cognitive performance predict gain and maintenance in a strategy-based approach was examined. In the future, it would be interesting to extend this research question to the domain of process-based training also. This has been done by some researchers who have provided evidence for training improvement (Bürki et al., 2014; Richmond et al., 2011) and age (Bürki et al., 2014) being related to the outcome of training.

Predictors for long-term maintenance of training gains and transfer effects

In Study III we also investigated how age and initial cognitive performance was related to long-term maintenance of training gains over a follow-up interval of 8 months. The training gain in the target episodic memory task was maintained to a high degree, especially in the condition in which support was provided. The results showed that the only significant predictor for maintenance of gain in the criterion tasks, regardless of condition (with or without support) was verbal knowledge. None of the factors predicting training gain was related to maintained performance, neither any of the other cognitive variables (speed and working memory), nor age. Thus, verbal knowledge is acquired over the course of the life-time, and typically show less decline than other aspects of long-term memory, attention-related constructs such as executive functions and working memory. It is possible that this life-long learning works as a protective mechanism against cognitive decline in old age in other critical factors.

Limitations

General limitations related to studying older adults

An issue when studying an older population is that it is possible that older adults perform at a lower level due to other aspects than cognitive decline related to the normal aging process. Confounding factors such as depression; not yet detected early-stage dementia; mild cognitive impairment (MCI); impaired auditory, visual, and/or tactile sensory processing; weaker muscles; or less familiarity with computers could affect the older adults to perform in the training program and on the transfer tests. This could lead to an overestimation of the age-related differences in baseline performance, training gain, and transfer effects, as well as individual differences predicting gain. In our studies, we excluded people at risk of dementia with the MMSE test, and of depression as measured with BDI. To be included in the studies the participants could not have suffered trauma to the head or having problems with alcohol or other drugs. Sight and hearing were however not assessed, nor were muscle tonus, hypertension, diabetes, etc. Who to include in a sample representing an aging population is a delicate endeavor, since a stricter criteria for exclusion might yield a non-representative sample of only the highest functioning, or successfully aged individuals. Other problems with measuring age effects with cross-sectional studies are the possibility of cohort effect – such that later-born cohorts tend to perform better at cognitive tests than earlier-born cohorts (The Flynn effect; Flynn, 1987). Comparing aged individuals with their younger selves is to prefer, but was for the purpose of this thesis hard to implement. However, there are indications that education accounts for a large part of such effects (Rönnlund & Nilsson, 2009), and in Study I and II, the differences in education between younger and older were modest.

Another issue which is worth noting is that when recruiting participants to participate in psychological research, the people who sign up for participation might not be representative for the whole population, so that the study includes a sub-sample of successfully aged older adults.

Limitations of Study I and II

Study I and II have provided new insights about executive functions training. However, when interpreting the results from Study I and Study II, some limitations need to be considered. First, the sample size is arguably quite low which needs to be kept in mind when interpreting the results. Training studies are resource demanding, but in future studies, more participants is to prefer in order to increase power in the analyses.

The difficulty level in the training program was not individually tailored, but rather we used a stepwise increase in difficulty level which was adjusted only for age (so that the older participants received one more session on the first difficulty level). It is thus plausible that not all participant practiced under optimal conditions in terms of how challenging the training was. Individually tailored difficulty level has been stressed as important by e.g. Klingberg, (2010) and Lövdén et al. (2010). Post-training interviews confirmed however that the training was perceived as demanding for both young and old.

The fact that we included criterion measure only for updating needs to be considered. This was done in order to keep testing time within reasonable limits, and to be consistent with the earlier studies on updating training (Dahlin, Neely, et al., 2008; Dahlin, Nyberg, et al., 2008). This however led to slightly more training in updating compared to the other two executive functions, since the criterion task was administered both at pre- and posttest and at the beginning of each training session. This is unfortunate since it limits the interpretability of the result. This repeated testing might have affected the results. An active control group receiving only the criterion task could have been included to control for this. Further, the fact that the training sessions were kept at the same length as in the previous studies, led to less training in each targeted function.

In Study I and II, we used a no-contact control group. Such a control group makes it possible to rule out retest effects, but it does not control for placebo-like effects. Social contact and motivation might have affected our results and explain the training effects. Including an active control group with for example low-level training would have made possible more firm conclusions. However, studies were both an active and a passive control group have been used, did not show any difference between the two control groups performance, making a placebo effect less likely (Brehmer et al., 2011; Richmond et al., 2011). Further, in a meta-analysis of WM training studies by Melby-Lervåg and Hulme (2013), showed that the effect size of WM training did not differ whether the training group was compared with either an active or no-contact control. However, and it has been stressed before, researchers should strive to include active control conditions in order to rule out confounding effects of taking part of the training program.

Limitations of Study III

In Study III, we measured the predictors with composite scores based on several different tests of each ability which increases the reliability. However, using factor scores instead would have further strengthened the claim that they represent the same construct.

Further, a potential factor affecting the outcome of training is that the supported condition was administered before the unsupported condition at posttest and follow-up. This could have helped the participants to refamiliarize them with how to apply the strategy, and might particularly been important at the follow-up condtion.

Third, the generalization to other types of training situations is not straightforward. We used the number-consonant mnemonic, whereas most studies focusing on episodic memory have used the method of loci. The number-consonant is rather demanding, in terms of executive/working memory abilities, to master. It is possible that such resources thus have also been strengthened which might have affected the outcome.

Ethical considerations

All the studies in this thesis were based on voluntarily participation, and informed consents were collected from all participants. We had no direct cause of suspecting that the training programs themselves might be harmful to the participants, but still some ethical considerations needs to be mentioned. First, the control groups were excluded from taking part of the presumably beneficial training programs, which could be viewed as problematic in terms of ethics. However, all participants of all studies were invited to an information meeting (after the follow-up test sessions) where the purpose and results of the studies were presented, and demonstration of the tasks that were used.

For the control participants of Study I and II, we also provided information about where to find similar tasks online. Further, we do not know whether the act of telling people that they belong to a group that needs cognitive training in fact generating a stereotyped threat. However, the information for recruitment did not mention anything about memory problems in old age, and was the same to both young and old participants.

To sum up and look forward

There is no doubt that the view that was earlier dominating aging research, that aging is a period of universal decline, is being challenged. The life we live affects our cognitive abilities, and engaging in stimulating activities likely affect the life-span development of different aspects of cognitive functioning (Hertzog et al., 2008). Training studies are a promising way of studying such effects on cognition across the life span. With aging, the pool of available resources such as speed of processing, executive functions, or working memory for different reasons becomes limited. Two main roads have been taken in research in order to find ways of supporting such decline, which both have revealed the possibility for plastic change both in knowledge structures and in domain-general cognitive processes. There is a wealth of studies, which, although promising, have yielded rather mixed or even contradictory conclusions. Now the time has come to take this research one step further. Although training studies are resource demanding, both for researchers, funders, and participants, larger samples will need to be included in future studies. Effects of training upon cognition might be expected to be highly varying between people, especially in old age, and larger samples might be needed in order to detect an improvement. This would also be beneficial since it would permit other types of analyzes to be performed, such as measuring plasticity of cognitive functions on an ability level rather than on individual tests, which has successfully been done by (Schmiedek et al., 2010). In addition to larger samples, we should strive towards a more thorough investigation of the factors driving training gain and transfer.

Some final thoughts

During my years as a PhD student, I have had the pleasure to read, think, and talk about cognitive training during seven years (thank you Alia and Mina for giving me that extra time), and some reflections on this issue needs to get onto paper as well. When studying cognitive training in young and old adults, we assume that there is something with older people which needs to be fixed. When focusing research on issues that supposedly needs mending, we run the risk of cementing views of old age as a period of decline, although we thought we pointed out the opposite, that plasticity reaches into old age. Further, we might end up, also without the intention to do so, with communicating to people that perfect cognitive functioning is what counts in life. There is, however, arguably more to life than being "cognitively fit". We need to have such concerns in the back of our head, while continuing on this, I think, promising line of research.

References

Ackerman, P. L., Kanfer, R., & Calderwood, C. (2010). Use it or lose it? Wii brain exercise practice and reading for domain knowledge. *Psychology and Aging*, *25*, 753–66. doi:10.1037/a0019277

Anderson, N. D., Craik, F. I. M., & Naveh-Benjamin, M. (1998). The attentional demands of encoding and retrieval in younger and older adults: I. Evidence from divided attention costs. *Psychology and Aging, 13*, 405–423. doi:10.1037/0882-7974.13.3.405

Anguera, J. a, Boccanfuso, J., Rintoul, J. L., Al-Hashimi, O., Faraji, F., Janowich, J., … Gazzaley, a. (2013). Video game training enhances cognitive control in older adults. *Nature*, *501*, 97–101. doi:10.1038/nature12486

Au, J., Sheehan, E., Tsai, N., Duncan, G. J., Buschkuehl, M., & Jaeggi, S. M. (2014). Improving fluid intelligence with training on working memory: a meta-analysis. *Psychonomic Bulletin & Review*. Advance online publication doi:10.3758/s13423-014-0699-x

Baddeley, A. D., & Hitch, G. J. (1974). Working Memory. In G. A. Bower (Ed.), *Psychology of learning and motivation* (Vol. 8, pp. 47–89). New York: Academic Press. doi:10.1016/S0079-7421(08)60452-1

Baldwin, Ti., & Ford, J. K. (1988). Transfer of training: A review and directions for future research. *Personnel Psychology, 41,* 63–105. doi:10.1111/j.1744-6570.1988.tb00632.x

Ball, K., Berch, D. B., Helmers, K. F., Jobe, J. B., Leveck, M. D., Marsiske, M., … Willis, S. L. (2002). Effects of Cognitive Training Interventions With Older Adults. *JAMA, 288*, 2271. doi:10.1001/jama.288.18.2271

Ball, K., Edwards, J. D., & Ross, L. A. (2007). The impact of speed of processing training on cognitive and everyday functions. *The Journals of Gerontology. Series B, Psychological Sciences and Social Sciences*, *62,* 19–31. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/17565162

Ball, K., Edwards, J. D., Ross, L. A, & McGwin, G. (2010). Cognitive training decreases motor vehicle collision involvement of older drivers. *Journal of the American Geriatrics Society, 58,* 2107–2113. doi:10.1111/j.1532-5415.2010.03138.x

Baltes, P. B. (1987). Theoretical propositions of life-span developmental psychology: On the dynamics between growth and decline. *Developmental Psychology*, 23, 611–626. doi:10.1037//0012-1649.23.5.611

Baltes, P. B., & Kliegl, R. (1992). Further testing of limits of cognitive plasticity: Negative age differences in a mnemonic skill are robust. *Developmental Psychology, 28,* 121–125. doi:10.1037/0012-1649.28.1.121

Baltes, P. B., & Singer, T. (2001). Plasticity and the ageing mind: an exemplar of the bio-cultural orchestration of brain and behaviour. *European Review, 9,* 59–76. doi:10.1017/S1062798701000060

Barnett, S. M., & Ceci, S. J. (2002). When and where do we apply what we learn? A taxonomy for far transfer. *Psychological Bulletin, 128,* 612–637.

Barulli, D., & Stern, Y. (2013). Efficiency, capacity, compensation, maintenance, plasticity: emerging concepts in cognitive reserve. *Trends in Cognitive Sciences, 17,* 502–9. doi:10.1016/j.tics.2013.08.012

Basak, C., Boot, W. R., Voss, M. W., & Kramer, A. F. (2008). Can training in a real-time strategy video game attenuate cognitive decline in older adults? *Psychology and Aging, 23,* 765–777. doi:10.1037/a0013494

Belchior, P., Marsiske, M., Sisco, S. M., Yam, A., Bavelier, D., Ball, K., & Mann, W. C. (2013). Video game training to improve selective visual attention in older adults. *Computers in Human Behavior, 29,* 1318–1324. doi:10.1016/j.chb.2013.01.034

Bherer, L., Kramer, A. F., Peterson, M. S., Colcombe, S., Erickson, K., & Becic, E. (2005). Training effects on dual-task performance: are there age-related differences in plasticity of attentional control? *Psychology and Aging, 20,* 695–709. doi:10.1037/0882-7974.20.4.695

Bherer, L., Kramer, A. F., Peterson, M. S., Colcombe, S., Erickson, K., & Becic, E. (2008). Transfer effects in task-set cost and dual-task cost after dual-task training in older and younger adults: further evidence for cognitive plasticity in attentional control in late adulthood. *Experimental Aging Research, 34,* 188–219. doi:10.1080/03610730802070068

Birren, J. E. (1974). Translations in gerontology: From lab to life. Psychophysiology and speed of response. *American Psychologist, 29,* 808–815.

Bissig, D., & Lustig, C. (2007). Who benefits from memory training? *Psychological Science*, 18(8), 720–726. doi:10.1111/j.1467-9280.2007.01966.x

Boot, W. R., Champion, M., Blakely, D. P., Wright, T., Souders, D. J., & Charness, N. (2013). Video games as a means to reduce age-related cognitive decline: attitudes, compliance, and effectiveness. *Frontiers in Psychology*, *4*, 31. doi:10.3389/fpsyg.2013.00031

Borella, E., Carretti, B., Cantarella, A., Riboldi, F., Zavagnin, M., & De Beni, R. (2014). Benefits of training visuospatial working memory in young-old and old-old. *Developmental Psychology*, 50, 714–427. doi:10.1037/a0034293

Borella, E., Carretti, B., Riboldi, F., & De Beni, R. (2010). Working memory training in older adults: evidence of transfer and maintenance effects. *Psychology and Aging, 25,* 767–778. doi:10.1037/a0020683

Borella, E., Carretti, B., Zanoni, G., Zavagnin, M., & De Beni, R. (2013). Working memory training in old age: an examination of transfer and maintenance effects. *Archives of Clinical Neuropsychology*, *28,* 331–347. doi:10.1093/arclin/act020

Bottiroli, S., Cavallini, E., & Vecchi, T. (2008). Long-term effects of memory training in the elderly: a longitudinal study. *Archives of Gerontology and Geriatrics*, *47,* 277–289. doi:10.1016/j.archger.2007.08.010

Bouazzaoui, B., Angel, L., Fay, S., Taconnat, L., Charlotte, F., & Isingrini, M. (2014). Does the greater involvement of executive control in memory with age act as a compensatory mechanism? *Canadian Journal of Experimental Psychology*, *68,* 59–66. doi:10.1037/cep0000005

Botvinick, M. M., Braver, T. S., Barch, D. M., Carter, C. S., & Cohen, J. D. (2001). *Conflict Monitoring and Cognitive Control*, *108*, 624–652. doi:10.1037//0033-295X.I08.3.624

Bozoki, A., Radovanovic, M., Winn, B., Heeter, C., & Anthony, J. C. (2013). Effects of a computer-based cognitive exercise program on age-related cognitive decline. *Archives of Gerontology and Geriatrics*, *57,* 1–7. doi:10.1016/j.archger.2013.02.009

Brehmer, Y., Li, S.-C., Muller, V., von Oerzen, T., & Lindenberger, U, (2007). Memory plasticity across the life-span: Uncovering children's latent potential. *Developmental Psychology, 43,* 465-468. doi: 10.1037/0012-1649.43.2.465

Brehmer, Y., Rieckmann, A., Bellander, M., Westerberg, H., Fischer, H., & Bäckman, L. (2011). Neural correlates of training-related working-memory gains in old age. *NeuroImage*, *58,* 1110–1120. doi:10.1016/j.neuroimage.2011.06.079

Brehmer, Y., Westerberg, H., & Bäckman, L. (2012). Working-memory training in younger and older adults: training gains, transfer, and maintenance. *Frontiers in Human Neuroscience*, *6*. doi:10.3389/fnhum.2012.00063

Braver, T. S., & Barch, D. M. (2002). A theory of cognitive control, aging cognition, and neuromodulation. *Neuroscience & Biobehavioral Reviews*, *26*, 809–817. doi:10.1016/S0149-7634(02)00067-2

Buckner, R. L., Head, D., & Lustig, C. (2006). Brain changes in aging: A life-span perspective. In Bialystok, E., & Craik, F. I. M. (Eds.), *Lifespan cognition – Mechansims of change* (pp. 27-56). Oxford, (NY): Oxford University Press.

Buschke, H. (1973). Selective reminding analysis of memory and learning. J*ournal of Verbal Learning and Verbal Behavior, 12,* 543-550.

Buschkuehl, M., Jaeggi, S. M., Hutchison, S., Perrig-Chiello, P., Däpp, C., Müller, M., … Perrig, W. J. (2008). Impact of working memory training on memory performance in old-old adults. *Psychology and Aging*, *23,* 743–753. doi:10.1037/a0014342

Bürki, C. N., Ludwig, C., Chicherio, C., & de Ribaupierre, A. (2014). Individual differences in cognitive plasticity: an investigation of training curves in younger and older adults. *Psychological Research*. Advance online publication-doi:10.1007/s00426-014-0559-3

Carlson, M. C., Hasher, L., Zacks, R. T., & Connelly, S. L. (1995). Aging, distraction, and the benefits of predictable location. *Psychology and Aging*, *10*, 427–436. doi: 10.1037//0882-7974.10.3.427

Carretti, B., Borella, E., Zavagnin, M., & de Beni, R. (2013). Gains in language comprehension relating to working memory training in healthy older adults. *International Journal of Geriatric Psychiatry*, *28,* 539–546. doi:10.1002/gps.3859

Cepeda, N. J., Blackwell, K. a, & Munakata, Y. (2013). Speed isn't everything: complex processing speed measures mask individual differences and developmental changes in executive control. *Developmental Science*, *16,* 269–286. doi:10.1111/desc.12024

Chatham, C. H., Herd, S. A., Brant, A. M., Hazy, T. E., Miyake, A., Reilly, R. O., & Friedman, N. P. (2011). From an executive network to executive control: A computational model of the n -back task. *Journal of Cognitive Neuroscience, 23*, 3598–3619. doi: 10.1162/jocn_a_00047

Clarke, R., & Johnstone, T. (2013). Prefrontal inhibition of threat processing reduces working memory interference. *Frontiers in Human Neuroscience*, *7*, 228. doi:10.3389/fnhum.2013.00228

Cohen, J. D., Braver, T. S., & O'Reilly, R. C. (1996). A computational approach to prefrontal cortex, cognitive control and schizophrenia: recent developments and current challenges. *Philosophical Transactions of the Royal Society of London. Series B, Biological Sciences*, *351*, 1515–27. doi:10.1098/rstb.1996.0138

Collette, F., Hogge, M., Salmon, E., & Van Der Linden, M. (2006). Exploration of the neural substrates of executive functioning by functional neuroimaging. *Neuroscience*, *139*, 209–21. doi:10.1016/j.neuroscience.2005.05.035

Colzato, L. S., van den Wildenberg, W. P. M., Zmigrod, S., & Hommel, B. (2013). Action video gaming and cognitive control: playing first person shooter games is associated with improvement in working memory but not action inhibition. *Psychological Research*, *77*, 234–239. doi:10.1007/s00426-012-0415-2

Colzato, L. S., van Leeuwen, P. J. a, van den Wildenberg, W. P. M., & Hommel, B. (2010). DOOM'd to Switch: Superior Cognitive Flexibility in Players of First Person Shooter Games. *Frontiers in Psychology*, *1*. doi:10.3389/fpsyg.2010.00008

Conway, A. R. A., Kane, M. J., & Engle, R. W. (2003). Working memory capacity and its relation to general intelligence. *Trends in Cognitive Sciences*, *7,* 547–552. doi:10.1016/j.tics.2003.10.005

Cormier, S.M. & Hagman, J.D. Eds. (1987). *Transfer of learning: Contemporary research and applications*. San Diego, CA: Academic Press.

Cowan, N. (1988). Evolving conceptions of memory storage, selective attention, and their mutual constraints within the human information-processing system. *Psychological Bulletin*, *104*, 163–191. doi: 10.1037/0033-2909.104.2.163

Cowan, N. (2008). What are the differences between long-term, short-term, and working memory? *Progress in brain research* (Vol. 169, pp. 323–38). Elsevier. doi:10.1016/S0079-6123(07)00020-9

Craik, F. I. M., Byrd, M., & Swanson, J. M. (1987). Patterns of memory loss in three elderly samples. *Psychology and Aging, 2*, 79-86. doi: 10.1037/0882-7974.2.1.79

Craik, F. I. M., & Lockhart, R. S. (1972). Levels of processing: A framework for memory research. *Journal of Verbal Learning and Verbal Behavior*, *11,* 671–684. doi:10.1016/S0022-5371(72)80001-X

Craik, F. I. M., & Rose, N. S. (2012). Memory encoding and aging: a neurocognitive perspective. *Neuroscience and Biobehavioral Reviews*, *36,* 1729–1739. doi:10.1016/j.neubiorev.2011.11.007

Crawford, J. R., Smith, G., Maylor, E. A., Della Sala, S., & Logie, R. H. (2003). The Prospective and Retrospective Memory Questionnaire (PRMQ): Normative data and latent structure in a large non-clinical sample. *Memory*, *11,* 261–275. doi:10.1080/09658210244000027

Dahlin, E., Neely, A. S., Larsson, A., Bäckman, L., & Nyberg, L. (2008a). Transfer of learning after updating training mediated by the striatum. *Science*, *320*, 1510–1512. doi:10.1126/science.1155466

Dahlin, E., Nyberg, L., Bäckman, L., & Neely, A. S. (2008). Plasticity of executive functioning in young and older adults: immediate training gains, transfer, and long-term maintenance. *Psychology and Aging*, *23,* 720–730. doi:10.1037/a0014296

Daneman, M., & Carpenter, P. (1980). Individual differences in working memory and reading. *Journal of Verbal Learning and Verbal Behavior, 19,* 450-466. doi: 10.1016/S0022-5371(80)90312-6

Daniels, K., Toth, J., & Jacoby, L. (2006). The aging of executive functions. In Bialystok, E., & Craik, F. I. M. (Eds.), *Lifespan cognition – Mechansims of change* (pp. 96-111). Oxford, (NY): Oxford University Press.

Daselaar, S., Dennis, N., & Cabeza, R. (2007). Ageing: Age-related changes in episodic and working memory. In S. A. R. B. Rombouts, F. Barkhof, & P. Sheltens (Eds.), *Clinical applications of functional brain MRI* (pp. 115–148). New York (NY): Oxford University Press.

Derwinger, A., Neely, A. S., Persson, M., Hill, R. D., & Bäckman, L. (2003). Remembering Numbers in Old Age: Mnemonic Training Versus Self-Generated Strategy Training. *Aging, Neuropsychology, and Cognition*, *10,* 202–214. doi:10.1076/anec.10.3.202.16452

Detterman, D. K. (1993). The case for the prosecution: Transfer as an epiphenomenon. In D. K. Detterman & R. J. Sternberg (Eds.), *Transfer on trial: Intelligence, cognition, and instruction* (pp. 1–24). Wesport, CT, US: Ablex Publishing.

Diamond, A. (2013). Executive functions. *Annual Review of Psychology*, 64, 135–168. doi:10.1146/annurev-psych-113011-143750

Dobbs, a R., & Rule, B. G. (1989). Adult age differences in working memory. *Psychology and Aging*, *4,* 500–503. doi: 10.1037//0882-7974.4.4.500

Draganski, B., Gaser, C., Busch, V., Schuierer, G., Bogdahn, U., & May, A. (2004). Neuroplasticity: changes in grey matter induced by training. *Nature*, *427*, 311–312. doi:10.1038/427311a

Draganski, B., & May, A. (2008). Training-induced structural changes in the adult human brain. *Behavioural Brain Research*, *192,* 137–142. doi:10.1016/j.bbr.2008.02.015

Engle, R. W. (2002). Working Memory Capacity as Executive Attention. *Current Directions in Psychological Science*, *11,* 19–23. doi:10.1111/1467-8721.00160

Fisher, M., Holland, C., Subramaniam, K., & Vinogradov, S. (2010). Neuroplasticity-based cognitive training in schizophrenia: an interim report on the effects 6 months later. *Schizophrenia Bulletin*, *36,* 869–879. doi:10.1093/schbul/sbn170

Fisk, J. E., & Sharp, C. a. (2004). Age-related impairment in executive functioning: updating, inhibition, shifting, and access. *Journal of Clinical and Experimental Neuropsychology*, *26*, 874–90. doi:10.1080/13803390490510680

Fleischman, D. a, Wilson, R. S., Gabrieli, J. D. E., Bienias, J. L., & Bennett, D. a. (2004). A longitudinal study of implicit and explicit memory in old persons. *Psychology and Aging*, *19,* 617–625. doi:10.1037/0882-7974.19.4.617

Flynn, J. R. (1987). Massive IQ gains in 14 nations: What IQ tests really measure. *Psychological Bulletin*, *101,* 171–191. doi:10.1037/0033-2909.101.2.171

Friedman, N. P., Miyake, A., Corley, R. P., Young, S. E., Defries, J. C., & Hewitt, J. K. (2006). Not all executive functions are related to intelligence. *Psychological Science*, *17* doi:10.1111/j.1467-9280.2006.01681.x

Friedman, N. P., Miyake, A., Young, S. E., Defries, J. C., Corley, R. P., & Hewitt, J. K. (2008). Individual differences in executive functions are almost entirely genetic in origin. *Journal of Experimental Psychology. General*, *137*, 201–25. doi:10.1037/0096-3445.137.2.201

Glass, J. M., Williams, D. a, Fernandez-Sanchez, M.-L., Kairys, A., Barjola, P., Heitzeg, M. M., … Schmidt-Wilcke, T. (2011). Executive function in chronic pain patients and healthy controls: different cortical activation during response inhibition in fibromyalgia. *The Journal of Pain: Official Journal of the American Pain Society*, *12,* 1219–1229. doi:10.1016/j.jpain.2011.06.007

Green, C. S., & Bavelier, D. (2003). Action video game modifies visual selective attention. *Nature*, *423,* 534–537. doi:10.1038/nature01647

Green, C. S., & Bavelier, D. (2006). Effect of action video games on the spatial distribution of visuospatial attention. *Journal of Experimental Psychology – Human Perception and Performance*, *32,* 1465–1478. doi:10.1037/0096-1523.32.6.1465

Green, C. S., & Bavelier, D. (2007). Action-video-game experience alters the spatial resolution of vision. *Psychological Science*, 18, 88–94. doi:10.1111/j.1467-9280.2007.01853.x

Greenwood, P. M. (2007). Functional plasticity in cognitive aging: review and hypothesis. Neuropsychology, *21*, 657–73. doi:10.1037/0894-4105.21.6.657

Hamilton, A. C., & Martin, R. C. (2005). Dissociations among tasks involving inhibition : A single-case study. *Behavioral Neuroscience*, 5, 1–13.

Harvey, P. O., Le Bastard, G., Pochon, J. B., Levy, R., Allilaire, J. F., Dubois, B., & Fossati, P. (2004). Executive functions and updating of the contents of working memory in unipolar depression. *Journal of Psychiatric Research*, *38*, 567–576. doi:10.1016/j.jpsychires.2004.03.003

Hasher, L., & Zacks, R, T. (1988). Working memory, comprehension, and aging: A review and new view. In G. H. Bower (Ed.), *The psychology of learning and motivation: Advances in research and theory* (Vol. 22, pp. 193-225). New York: Academic Press.

Hazy, T. E., Frank, M. J., & O'reilly, R. C. (2007). Towards an executive without a homunculus: computational models of the prefrontal cortex/basal ganglia system. *Philosophical Transactions of the Royal Society of London. Series B, Biological Sciences*, *362*, 1601–1613. doi:10.1098/rstb.2007.2055

Hebb D.O. (1947). The effects of early experience on problem solving at maturity. *American Psychologist*, *2*, 306–307.

Heinzel, S., Schulte, S., Onken, J., Duong, Q.-L., Riemer, T. G., Heinz, A., … Rapp, M. a. (2014). Working memory training improvements and gains in non-trained cognitive tasks in young and older adults. *Neuropsychology, Development, and Cognition. Section B, Aging, Neuropsychology and Cognition*, *21*, 146–173. doi:10.1080/13825585.2013.790338

Herd, S. A, O'Reilly, R. C., Hazy, T. E., Chatham, C. H., Brant, A. M., & Friedman, N. P. (2014). A neural network model of individual differences in task switching abilities. *Neuropsychologia*, *62*, 375–389. doi:10.1016/j.neuropsychologia.2014.04.014

Hertzog, C., Kramer, A. F., Wilson, R. S., & Lindenberger, U. (2008). Enrichment Effects on Adult Cognitive Development: Can the Functional Capacity of Older Adults Be Preserved and Enhanced? *Psychological Science in the Public Interest*, *9,* 1–65. doi:10.1111/j.1539-6053.2009.01034.x

Higbee, K. L. (1988). *Your memory: How it works and how to improve it*. New York: Paragon House.

Hill, R. D., Sheikh, J. I. & Yesavage, J. A. (1989). Pretraining enhances mnemonic training in elderly adults. *Experimental Aging Research*, *14*, 207-211.

Hofmann, W., Schmeichel, B. J., & Baddeley, A. D. (2012). Executive functions and self-regulation. *Trends in Cognitive Sciences*, *16,* 174–180. doi:10.1016/j.tics.2012.01.006

Hoyer, W. J., & Verhaeghen, P. (2006). Memory Aging. In J. E. Birren & K. W. Schaie (Eds.), *Handbook of the Psychology of Aging* (6th ed., pp. 209–232). Academic Press.

Hultsch, D. F., Hertzog, C., Small, B. J., & Dixon, R. a. (1999). Use it or lose it: engaged lifestyle as a buffer of cognitive decline in aging? *Psychology and Aging*, *14,* 245–63. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/10403712

Irons, J. L., Remington, R. W., & McLean, J. P. (2011). Not so fast: Rethinking the effects of action video games on attentional capacity. *Australian Journal of Psychology*, *63,* 224–231. doi:10.1111/j.1742-9536.2011.00001.x

Jaeggi, S. M., Buschkuehl, M., Jonides, J., & Shah, P. (2011). Short- and long-term benefits of cognitive training. *Proceedings of the National Academy of Sciences of the United States of America*, *108,* 10081–10086. doi:10.1073/pnas.1103228108

Jak, A. J., Seelye, A. M., & Jurick, S. M. (2013). Crosswords to computers: a critical review of popular approaches to cognitive enhancement. *Neuropsychology Review*, *23,* 13–26. doi:10.1007/s11065-013-9226-5

Kahneman, D. (1973). *Attention and effort*. Englewood Cliffs, NJ: Prentice Hall.

Karbach, J., & Kray, J. (2009). How useful is executive control training? Age differences in near and far transfer of task-switching training. *Developmental Science*, 12, 978–990. doi:10.1111/j.1467-7687.2009.00846.x

Karbach, J., Mang, S., & Kray, J. (2010). Transfer of task-switching training in older age: the role of verbal processes. *Psychology and Aging*, *25,* 677–83. doi:10.1037/a0019845

Kesler, S., Hadi Hosseini, S. M., Heckler, C., Janelsins, M., Palesh, O., Mustian, K., & Morrow, G. (2013). Cognitive training for improving executive function in chemotherapy-treated breast cancer survivors. *Clinical Breast Cancer*, *13,* 299–306. doi:10.1016/j.clbc.2013.02.004

Kliegl, R., Smith, J., & Baltes, P. B. (1989). Testing-the-limits and the study of adult age differences in cognitive plasticity of a mnemonic skill. *Developmental Psychology*, *25,* 247–256. doi:10.1037/0012-1649.25.2.247

Kliegl, R., Smith, J., & Baltes, P. B. (1990). On the locus and process of magnification of age differences during mnemonic training. *Developmental Psychology*, *26,* 894–904. doi:10.1037//0012-1649.26.6.894

Klingberg, T. (2010). Training and plasticity of working memory. *Trends in Cognitive Sciences*, *14,* 317–324. doi:10.1016/j.tics.2010.05.002

Klingberg, T., Fernell, E., Olesen, P. J., Johnson, M., Gustafsson, P., Dahlström, K., … Westerberg, H. (2005). Computerized training of working memory in children with ADHD – a randomized, controlled trial. *Journal of the American Academy of Child and Adolescent Psychiatry*, *44,* 177–186. doi:10.1097/00004583-200502000-00010

Koechlin, E., & Summerfield, C. (2007). An information theoretical approach to prefrontal executive function. *Trends in Cognitive Sciences*, *11*, 229–35. doi:10.1016/j.tics.2007.04.005

Li, R., Polat, U., Makous, W., & Bavelier, D. (2009). Enhancing the contrast sensitivity function through action video game training. *Nature Neuroscience*, *12*, 549–51. doi:10.1038/nn.2296

Li, S-C., Schmiedek, F., Huxhold, O., Röcke, C., Smith, J., & Lindenberger, U. (2008). Working memory plasticity in old age: practice gain, transfer, and maintenance. *Psychology and Aging, 23,* 731–742. doi:10.1037/a0014343

Li, S.-C. (2003). Biocultural orchestration of developmental plasticity across levels: The interplay of biology and culture in shaping the mind and behavior across the life span. *Psychological Bulletin*, *129,* 171–194. doi:10.1037/0033-2909.129.2.171

Li, S.-C. (2009). Brain in macro experiential context: biocultural co-construction of lifespan neurocognitive development. *Progress in Brain Research*, *178,* 17–29. doi: 10.1016/S0079-6123(09)17802-0

Li, S.-C., Lindenberger, U., Hommel, B., Aschersleben, G., Prinz, W., & Baltes, P. B. (2004). Transformations in the couplings among intellectual abilities and constituent cognitive processes across the life span. *Psychological Science*, *15*, 155–163. doi: 10.1111/j.0956-7976.2004.01503003.x

Lindenberger, U., von Oertzen, T., Ghisletta, P., & Hertzog, C. (2011). Cross-sectional age variance extraction: what's change got to do with it? *Psychology and Aging*, *26*(1), 34–47. doi:10.1037/a0020525

Logan, J. M., Sanders, A. L., Snyder, A. Z., Morris, J. C., Buckner, R. L., Louis, S., … Louis, S. (2002). Under-Recruitment and Nonselective Recruitment : Dissociable Neural Mechanisms Associated with Aging, *Neuron*, *33,* 827–840.

Luria, A. R. (1966). *Human brain and psychological processes*. New York: Harper and Row.

Lussier, M., Gagnon, C., & Bherer, L. (2012). An investigation of response and stimulus modality transfer effects after dual-task training in younger and older. *Frontiers in Human Neuroscience*, *6*(129), 1–11. doi:10.3389/fnhum.2012.00129

Lustig, C., Hasher, L., & Zacks, R. (2007). Inhibitory deficit theory: Recent developments in a “New View”. In D. S. Gorfein & C. M. MacLeod (Eds.), *Inhibition in cognition* (pp. 145–162). Washington, DC, US: American Psychological Association. doi:10.1037/11587-008

Lutz, W., Sanderson, W., & Scherbov, S. (2008). The coming acceleration of global population ageing. *Nature*, *451,* 716–719. doi:10.1038/nature06516

Lövdén, M., Brehmer, Y., Li, S.-C., & Lindenberger, U. (2012). Training-induced compensation versus magnification of individual differences in memory performance. *Frontiers in Human Neuroscience*, *6*. doi:10.3389/fnhum.2012.00141

Lövdén, M., Bäckman, L., Lindenberger, U., Schaefer, S., & Schmiedek, F. (2010). A theoretical framework for the study of adult cognitive plasticity. *Psychological Bulletin*, *136,* 659–676. doi:10.1037/a0020080

Maguire, E. a, Gadian, D. G., Johnsrude, I. S., Good, C. D., Ashburner, J., Frackowiak, R. S., & Frith, C. D. (2000). Navigation-related structural change in the hippocampi of taxi drivers. *Proceedings of the National Academy of Sciences of the United States of America*, *97,* 4398–4403. doi:10.1073/pnas.070039597

Mahncke, H. W., Connor, B. B., Appelman, J., Ahsanuddin, O. N., Hardy, J. L., Wood, R. a, … Merzenich, M. M. (2006). Memory enhancement in healthy older adults using a brain plasticity-based training program: a randomized, controlled study. *Proceedings of the National Academy of Sciences of the United States of America*, *103,* 12523–12528. doi:10.1073/pnas.0605194103

Mayas, J., Parmentier, F. B. R., Andrés, P., & Ballesteros, S. (2014). Plasticity of attentional functions in older adults after non-action video game training: a randomized controlled trial. *PloS One*, *9*, e92269. doi:10.1371/journal.pone.0092269

McAvinue, L. P., Golemme, M., Castorina, M., Tatti, E., Pigni, F. M., Salomone, S., … Robertson, I. H. (2013). An evaluation of a working memory training scheme in older adults. *Frontiers in Aging Neuroscience*, *5*. doi:10.3389/fnagi.2013.00020

McDermott, A. F., Bavelier, D., & Green, C. S. (2014). Memory abilities in action video game players. *Computers in Human Behavior*, *34,* 69–78. doi:10.1016/j.chb.2014.01.018

McDougall, S., & House, B. (2012). Brain training in older adults: evidence of transfer to memory span performance and pseudo-Matthew effects. *Neuropsychology, Development, and Cognition. Section B, Aging, Neuropsychology and Cognition*, *19,* 195–221. doi:10.1080/13825585.2011.640656

Melby.Lervåg, M., & Hulme, C. (2013). Is working memory training effective? A meta-analytic review. *Developmental Psychology, 49,* 270–291. doi: 10.1037/a0028228

Mesulam, M. –M. (2002). The human frontal lobes: Transcending the default mode through contingent encoding. In Stuss, D. T., & Knight, R. T. (Eds.), *Principles of frontal lobe function* (pp. 8-30). New York (NY): Oxford University Press, Inc.

Militello, L. G., & Hutton, R. J. (1998). Applied cognitive task analysis (ACTA): a practitioner's toolkit for understanding cognitive task demands. *Ergonomics*, *41*, 1618–41. doi:10.1080/001401398186108

Miller, E. K., & Cohen, J. D. (2001). An integrative theory of prefrontal cortex function. *Annual Review of Neuroscience*, *24,* 167–202. doi:10.1146/annurev.neuro.24.1.167

Milner, B., Corkin, S., & Teuber, H. (1968). Further analysis of the hippocampal amnesic syndrome: 14-year follow-up study of H. M. Neuropsychologia, 6, 215–234. doi: 10.1016/0028-3932(68)90021-3

Miyake, A., & Friedman, N. P. (2012). The Nature and Organization of Individual Differences in Executive Functions: Four General Conclusions. *Current Directions in Psychological Science*, *21,* 8–14. doi:10.1177/0963721411429458

Miyake, A., Friedman, N. P., Emerson, M. J., Witzki, A. H., Howerter, A., & Wager, T. D. (2000). The unity and diversity of executive functions and their contributions to complex "Frontal Lobe" tasks: a latent variable analysis. *Cognitive Psychology, 41,* 49–100. doi:10.1006/cogp.1999.0734

Monsell, S., Sumner, P., & Waters, H. (2003). Task-set reconfiguration with predictable and unpredictable task switches. *Memory & Cognition*, *31,* 327–342. doi:10.3758/BF03194391

Morris, C. D., Bransford, J. D., & Franks, J. J. (1977). Levels of processing versus transfer appropriate processing. *Journal of Verbal Learning and Verbal Behavior*, *16,* 519–533. doi:10.1016/S0022-5371(77)80016-9

Murphy, D. R., Craik, F. I., Li, K. Z., & Schneider, B. a. (2000). Comparing the effects of aging and background noise on short-term memory performance. *Psychology and Aging*, *15*, 323–34. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/10879586

Naveh-Benjamin, M., Guez, J., Kilb, A., & Reedy, S. (2004). The associative memory deficit of older adults: further support using face-name associations. P*sychology and Aging*, *19*, 541–546. doi:10.1037/0882-7974.19.3.541

Nilsson, L.-G. (2003). Memory function in normal aging. *Acta Neurologica Scandinavica. Supplementum*, *179,* 7–13. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/12603244

Noack, H., Lövdén, M., Schmiedek, F., & Lindenberger, U. (2009). Cognitive plasticity in adulthood and old age: gauging the generality of cognitive intervention effects. *Restorative Neurology and Neuroscience*, *27,* 435–453. doi:10.3233/RNN-2009-0496

Nouchi, R., Taki, Y., Takeuchi, H., Hashizume, H., Akitsuki, Y., Shigemune, Y., … Kawashima, R. (2012). Brain training game improves executive functions and processing speed in the elderly: a randomized controlled trial. *PloS One*, *7*, e29676. doi:10.1371/journal.pone.0029676

Nyberg, L., Lövdén, M., Riklund, K., Lindenberger, U., & Bäckman, L. (2012). Memory aging and brain maintenance. *Trends in Cognitive Sciences*, *16,* 292–305. doi:10.1016/j.tics.2012.04.005

Oberauer, K., Süß, H.-M., Schulze, R., Wilhelm, O., & Wittman, W. W. (2000). Working memory capacity – facets of a cognitive ability construct. Personality and Individual Differences, *29*, 1017–1045. doi: 10.1016/S0191-8869(99)00251-2

Olsson, L., & Nilsson Thore, M. (2012). *En annan resa*. Stockholm: Bonnier Carlsson Bokförlag.

Owen, A. M., Hampshire, A., Grahn, J. a, Stenton, R., Dajani, S., Burns, A. S., … Ballard, C. G. (2010). Putting brain training to the test. *Nature*, *465,* 775–778. doi:10.1038/nature09042

Park, D. C., & Reuter-Lorenz, P. (2009). The adaptive brain: aging and neurocognitive scaffolding. *Annual Review of Psychology*, *60,* 173–96. doi:10.1146/annurev.psych.59.103006.093656

Park, D. C., Smith, a D., Lautenschlager, G., Earles, J. L., Frieske, D., Zwahr, M., & Gaines, C. L. (1996). Mediators of long-term memory performance across the life span. *Psychology and Aging*, *11,* 621–637. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/9000294

Pennequin, V., Sorel, O., & Mainguy, M. (2010). Metacognition, executive functions and aging: The effect of training in the use of metacognitive skills to solve mathematical word problems. *Journal of Adult Development*, *17,* 168–176. doi:10.1007/s10804-010-9098-3

Peretz, C., Korczyn, A. D., Shatil, E., Aharonson, V., Birnboim, S., & Giladi, N. (2011). Computer-based, personalized cognitive training versus classical computer games: a randomized double-blind prospective trial of cognitive stimulation. *Neuroepidemiology*, *36,* 91–99. doi:10.1159/000323950

Pollack, I., Johnson, L. ., & Knaff, P. . (1959). Running memory span. *Journal of Experimental Psychology*, *57,* 137–146. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/13641585

Rast, P. (2011). Verbal knowledge, working memory, and processing speed as predictors of verbal learning in older adults. *Developmental psychology, 47*, 1490-1498. doi:10.1037/A0023422

Raz, N., Gunning-Dixon, F. M., Head, D., Dupuis, J. H., & Acker, J. D. (1998). Neuroanatomical correlates of cognitive aging: evidence from structural magnetic resonance imaging. *Neuropsychology*, *12,* 95–114. doi: 10.1037/0894-4105.12.1.95

Rebok, G. W., & Balcerak, L. J. (1989). Memory self-efficacy and performance differences in young and old adults: The effect of mnemonic training. *Developmental Psychology, 25,* 714-721. doi: 10.1037/0012-1649.25.5.714

Rebok, G. W., Langbaum, J. B. S., Jones, R. N., Gross, A. L., Parisi, J. M., Spira, A. P., … Brandt, J. (2013). Memory training in the ACTIVE study: how much is needed and who benefits? *Journal of Aging and Health*, *2,* 21–42. doi:10.1177/0898264312461937

Reid, L. M., & Maclullich, A. M. J. (2006). Subjective memory complaints and cognitive impairment in older people. *Dementia and Geriatric Cognitive Disorders, 22,* 471–485. doi:10.1159/000096295

Reuter-Lorenz, P. a., & Cappell, K. a. (2008). Neurocognitive Aging and the Compensation Hypothesis. *Current Directions in Psychological Science*, *17,* 177–182. doi:10.1111/j.1467-8721.2008.00570.x

Richmond, L. L., Morrison, A. B., Chein, J. M., & Olson, I. R. (2011). Working memory training and transfer in older adults. *Psychology and Aging*, *26,* 813–822. doi:10.1037/a0023631

Robitaille, A., Piccinin, G., Muiz-Terrera, G., Hoffman, L. Johansson, B., Deeg, D., ... Hofer, S. M. (2013). Longitudinal mediation of processing speed on age-related change in memory and fluid intelligence. Psychology and aging, 28, 887-901. doi: 10.1037/a0033316

Rowe, G., Valderrama, S., Hasher, L., & Lenartowicz, A. (2006). Attentional disregulation: a benefit for implicit memory. *Psychology and Aging*, *21,* 826–830. doi:10.1037/0882-7974.21.4.826

Royall, D. R., Palmer, R., Chiodo, L. K., & Polk, M. J. (2004). Declining executive control in normal aging predicts change in functional status: the Freedom House Study. *Journal of the American Geriatrics Society*, *52,* 346–352. doi: 10.1111/j.1532-5415.2004.52104.x

Rönnlund, M., & Nilsson, L.-G. (2009). Flynn effects on sub-factors of episodic and semantic memory: parallel gains over time and the same set of determining factors. *Neuropsychologia*, *47,* 2174–2180. doi:10.1016/j.neuropsychologia.2008.11.007

Rönnlund, M., Nyberg, L., Bäckman, L., & Nilsson, L.-G. (2005). Stability, growth, and decline in adult life span development of declarative memory: cross-sectional and longitudinal data from a population-based study. *Psychology and Aging, 20,* 3–18. doi:10.1037/0882-7974.20.1.3

Salthouse, T. A. (1991). *Theoretical perspective on cognitive aging.* Hinsdale, N.J.: Erlbaum.

Salthouse, T. A. (1996). The processing-speed theory of adult age differences in cognition. *Psychological Review*, *103,* 403–428. doi:10.1037/0033-295X.103.3.403

Salthouse, T. A. (2006). Mental Exercise and Mental Aging. Evaluating the Validity of the "Use It or Lose It" Hypothesis. *Perspectives on Psychological Science*, *1,* 68–87. doi:10.1111/j.1745-6916.2006.00005.x

Salthouse, T. A., Atkinson, T. M., & Berish, D. E. (2003). Executive Functioning as a Potential Mediator of Age-Related Cognitive Decline in Normal Adults. *Memory, 132,* 566 –594. doi:10.1037/0096-3445.132.4.566

Salthouse, T. A., & Babcock, R. L. (1991). Decomposing adult age differences in working memory. *Developmental Psychology*, *27,* 763–776. doi:10.1037//0012-1649.27.5.763

Schaie, K. W. (2005). *Developmental influences on adult intelligence: The Seattle longitudinal study*, New York, (NY): Oxford University Press.

Schmidt, R. a., & Bjork, R. a. (1992). New Conceptualizations of Practice: Common Principles in Three Paradigms Suggest New Concepts for Training. *Psychological Science*, *3,* 207–217. doi:10.1111/j.1467-9280.1992.tb00029.x

Schmiedek, F., Lövdén, M., & Lindenberger, U. (2010). Hundred Days of Cognitive Training Enhance Broad Cognitive Abilities in Adulthood: Findings from the COGITO Study. *Frontiers in Aging Neuroscience*, *2*, 1–10. doi:10.3389/fnagi.2010.00027

Scoville, W. B., & Milner, B. (1957). Loss of recent memory after bilateral hippocampal lesions. *Journal of Neurology, Neurosurgery, and Psychiatry*, *20*(1), 11–21. Retrieved from http://www.pubmedcentral.nih.gov/articlerender.fcgi?artid=497229&tool=pmcentrez&rendertype=abstract

Shenhav, A., Botvinick, M. M., & Cohen, J. D. (2013). The expected value of control: an integrative theory of anterior cingulate cortex function. *Neuron*, *79,* 217–40. doi:10.1016/j.neuron.2013.07.007

Singer, T., Lindenberger, U., & Baltes, P. B. (2003). Plasticity of Memory for New Learning in Very Old Age : A Story of Major Loss ? *Psychology and Aging*, *18,* 306 –317. doi:10.1037/0882-7974.18.2.306

Stern, Y. (2009). Cognitive reserve. *Neuropsychologia*, *47*, 2015–28. doi:10.1016/j.neuropsychologia.2009.03.004

Squire, L. (1987). *Memory and brain*. New York (NY): Oxford University Press.

Squire, L. R. (2004). Memory systems of the brain: a brief history and current perspective. *Neurobiology of Learning and Memory*, *82,* 171–7. doi:10.1016/j.nlm.2004.06.005

Stepankova, H., Lukavsky, J., Buschkuehl, M., Kopecek, M., Ripova, D., & Jaeggi, S. M. (2014). The malleability of working memory and visuospatial skills: a randomized controlled study in older adults. *Developmental Psychology*, *50*, 1049–59. doi:10.1037/a0034913

Stern, Y., Blumen, H. M., Rich, L. W., Richards, A., Herzberg, G., & Gopher, D. (2011). Space Fortress game training and executive control in older adults: a pilot intervention. *Neuropsychology, Development, and Cognition. Section B, Aging, Neuropsychology and Cognition*, *18,* 653–77. doi:10.1080/13825585.2011.613450

Stigsdotter Neely, A., & Bäckman, L. (1993). Long-term maintenance of gains from memory training in older adults: two 3 1/2-year follow-up studies. *Journal of Gerontology*, *48,* 233–237. doi: 10.1093/geronj/48.5.P233

Stuss, D. T., Alexander, M. P., Floden, D., Binns, M. A., Levine, B., McIntosh, A. R., Raja, N., & Hevenor, S. J. (2002) Fractionation and locanlization of distinct frontal lobte processes: Evidence from forcal lesions in humans. In D. T. Stuss, & R. T. Knight (Eds.) *Principles of frontal lobe function* (pp. 392-407). New York: Oxford University Press.

Teuber, H. L. (1972). Unity and diversity of frontal lobe functions. *Acta Neurobiologiae Experimentalis*, *32,* 615–56. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/4627626

Theill, N., Schumacher, V., Adelsberger, R., Martin, M., & Jäncke, L. (2013). Effects of simultaneously performed cognitive and physical training in older adults. *BMC Neuroscience*, *14*, 103. doi:10.1186/1471-2202-14-103

Thorndike, E. L., & Woodworth, R. S. (1901). The influence of improvement in one mental function upon the efficiency of other functions. II. The estimation of magnitudes. *Psychological Review*, *8,* 384–395. doi:10.1037/h0071280

Tulving, E. (1972). Episodic and semantic memory. In E. Tulving & W. Donaldson (Eds.), *Organization of Memory* (pp. 381–402). New York (NY): Academic Press, Inc.

Tulving, E. (2002). Episodic memory: from mind to brain. *Annual Review of Psychology*, *53,* 1–25. doi:10.1146/annurev.psych.53.100901.135114

United Nations. (2010). *World Population Ageing* 2009. New York: United Nations. Retrieved from http://www.un.org/esa/population/publications/WPA2009/WPA2009-report.pdf

Van Muijden, J., Band, G. P. H., & Hommel, B. (2012). Online games training aging brains: limited transfer to cognitive control functions. *Frontiers in Human Neuroscience*, *6*, 221. Retrieved from http://www.pubmedcentral.nih.gov/articlerender.fcgi?artid=3421963&tool=pmcentrez&rendertype=abstract

Wang, M.-Y., Chang, C.-Y., & Su, S.-Y. (2011). What's Cooking? - Cognitive Training of Executive Function in the Elderly. *Frontiers in Psychology*, *2*, 228. doi:10.3389/fpsyg.2011.00228

Verhaeghen, P., & Marcoen, a. (1996). On the mechanisms of plasticity in young and older adults after instruction in the method of loci: evidence for an amplification model. *Psychology and Aging*, *11,* 164–78. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/8726382

Verhaeghen, P., Marcoen, A., & Goossens, L. (1992). Improving memory performance in the aged through mnemonic training: A meta-analytic study. *Psychology and Aging, 7,* 242–251. doi:10.1037//0882-7974.7.2.242

West, R. L. (1996). An application of prefrontal cortex function theory to cognitive aging. Psychological Bulletin, *120,* 272–92. doi: 10.1037/0033-2909.120.2.272

Vestergren, P., & Nilsson, L.-G. (2011). Perceived causes of everyday memory problems in a population-based sample aged 39-99. *Applied Cognitive Psychology*, *25,* 641–646. doi:10.1002/acp.1734

Whitlock, L. a., McLaughlin, A. C., & Allaire, J. C. (2012). Individual differences in response to cognitive training: Using a multi-modal, attentionally demanding game-based intervention for older adults. *Computers in Human Behavior*, *28,* 1091–1096. doi:10.1016/j.chb.2012.01.012

Wilkinson, A. J., & Yang, L. (2012). Plasticity of inhibition in older adults: retest practice and transfer effects. *Psychology and Aging*, *27,* 606–15. doi:10.1037/a0025926

Willis, S. L., Tennstedt, S. L., Marsiske, M., Ball, K., Elias, J., Koepke, K. M., … Wright, E. (2006). Long-term effects of cognitive training on everyday functional outcomes in older adults. JAMA : *The Journal of the American Medical Association*, *296,* 2805–14. doi:10.1001/jama.296.23.2805

Von Bastian, C. C., Langer, N., Jäncke, L., & Oberauer, K. (2013). Effects of working memory training in young and old adults. *Memory & Cognition, 41,* 611–24. doi:10.3758/s13421-012-0280-7

Von Bastian, C. C., & Oberauer, K. (2013a). Distinct transfer effects of training different facets of working memory capacity. *Journal of Memory and Language*, *69*, 36–58. doi:10.1016/j.jml.2013.02.002

Von Bastian, C. C., & Oberauer, K. (2013b). Effects and mechanisms of working memory training: a review. *Psychological Research.* doi:10.1007/s00426-013-0524-6

Woodworth, R. S., & Thorndike, E. L. (1901). The influence of improvement in one mental function upon the efficiency of other functions. (I). *Psychological Review, 8,* 247–261. doi:10.1037/h0074898

Xin, Z., Lai, Z., Li, F. U., & Maes, J. H. R. (2014). Near- and far-transfer effects of working memory updating training in elderly adults, *Applied Cognitive Psychology, 28,* 403–408. doi: 10.1002/acp.3011

Yates, F. A. (1966). *The art of memory*. United Kingdom: Routledge and Kegan Paul.

Yesavage, J. a, Sheikh, J. I., Friedman, L., & Tanke, E. (1990). Learning mnemonics: roles of aging and subtle cognitive impairment. *Psychology and Aging, 5*, 133–7. doi: 10.1037//0882-7974.5.1.133

Yesavage, J. A. (1990). Age-associated memory impairment: Conceptual background and treatment approaches. In: M. Bergener, M. Ermini, H.B. Stahelin (Eds.), *Challenges in aging* (pp. 53-72). London: Academic Press.

Yntema, D. B. (1963). Keeping track of several things at once. *Human Factors, 5*, 7–17.

Zelinski, E. M., Spina, L. M., Yaffe, K., Ruff, R., Kennison, R. F., Mahncke, H. W., & Smith, G. E. (2011). Improvement in memory with plasticity-based adaptive cognitive training: results of the 3-month follow-up. Journal of the *American Geriatrics Society, 59,* 258–65. doi:10.1111/j.1532-5415.2010.03277.x

Zinke, K., Zeintl, M., Eschen, A., Herzog, C., & Kliegel, M. (2012). Potentials and limits of plasticity induced by working memory training in old-old age. *Gerontology, 58,* 79–87. doi:10.1159/000324240

Zinke, K., Zeintl, M., Rose, N. S., Putzmann, J., Pydde, A., & Kliegel, M. (2014). Working memory training and transfer in older adults: effects of age, baseline performance, and training gains. *Developmental Psychology, 50,* 304–315. doi:10.1037/a0032982