Bachelor Degree Project

UNIVERSITY
OF SKÖVDE

INVESTIGATING TRAINING AND TRANSFER IN COMPLEX TASKS WITH DUAL N-BACK

Bachelor Degree Project in Cognitive Neuroscience
30 ECTS
Spring term 2011

Lars Jonasson

Supervisor:Daniel Broman
Examiner:Judith Annett

Investigating Training and Transfer in Complex Tasks with Dual N-Back

Submitted by Lars Jonasson to the University of Skövde as a final year project towards the degree of B.Sc. in the School of Humanities and Informatics. The project has been supervised by Daniel Broman.

2011 – 06 - 05

I hereby certify that all material in this final year project which is not my own work has been identified and that no work is included for which a degree has already been conferred on me.

Signature: ____

Abstract

No clear consensus exists in the scientific community of what constitutes efficient dual-tasking abilities. Moreover, the training of executive components has been given increased attention in the literature in recent years. Investigating transferability of cognitive training in a complex task setting, thirty subjects practiced for five days on a Name-Tag task (controls) or a Dual N-Back task (experimental), subsequently being tested on two transfer tasks; the Automated Operation Span and a dual task (Trail Making task + Mathematical Addition task). Dual N-Back training previously transferred to unrelated intelligence tests and in this study is assumed to rely primarily on executive attention. Executive attention, functioning to resolve interference and maintaining task-relevant information in working memory, has previously been linked to fluid intelligence and to dual-tasking. However, no transfer effects were revealed. The length of training may have been too short to reveal any such effects. However, the three complex tasks correlated significantly, suggesting common resources, and therefore having potentials as transfer tasks. Notably, subjects with the highest task-specific improvements performed worse on the transfer tasks than subjects improving less, suggesting that task-specific gains do not directly correlate with any transfer effect. At present, if transfer exists in these settings, data implies that five days of training is insufficient for a transfer to occur. Important questions for future research relates to the necessary conditions for transfer to occur, such as the amount of training, neural correlates, attention, and motivation.

Key words: dual task, transfer, executive attention, working memory, dual n-back, automated operation span

Table of Contents

Introduction

In our everyday activities we often encounter multitask situations, or dual task and time-sharing situations as it is often referred to in the literature. Common examples include driving while talking on the phone, preparing dinner while involved in a conversation, or listening while reading, to name a few. In order to be successful in such situations behavior must be coordinated. Normally there are substantial sacrifices when performing two tasks simultaneously regardless of the complexity of the task (Dux et al., 2009), such as a slowing of response time or an increased rate of errors. Depending on the particular tasks involved in a situation, various cognitive processes are required, e.g., switching of attention, inhibition, planning, rule following, *working memory* (WM), or prospective memory (Thoma, Koch, Heyder, Schwarz, & Daum, 2008). Now, a useful distinction between an *executive component* and an *executive function* should be made. While an executive component has some specialized function, e.g. updating information in WM, an executive function is a broader concept, being goal-directed and guiding behavior, and may be regarded as more general as it may draw upon several underlying components (Hedden & Yoon, 2006). Multitasking could be considered an executive function essential for the successful execution of behavior in situations where two or more tasks must be coordinated in either a simultaneous or sequential fashion (Thoma et al., 2008).

Investigating training and transfer in complex tasks is important for several reasons. First, as mentioned in the opening lines of this paper, dual-tasking is common in everyday life, hitherto it is not clear what constitutes efficient performance in such situations. Secondly, understanding cognitive training may benefit such diverse groups as children and neurological patients. Thirdly, there is no clear consensus under what conditions successful training and transfer occur.

In order to understand human cognition in complex tasks, such as dual-tasking, it is crucial to understand the concept of WM and its relation to attention; hence this is a logical starting point for reviewing the relevant literature.

Theories of Working Memory

Central executive. One of the most influential theories of WM is the Baddeley and Hitch model of WM (Baddeley, 2000). Originally, the model included the phonological loop for storing auditory and verbal information, and the visuo-spatial sketchpad for storing visual and spatial information, and the *central executive* (CE) serving as an attentional control system. The phonological loop may further be divided into two subcomponents (Repovs & Baddeley, 2006). The first part is a limited-capacity phonological store, keeping active acoustic or phonological memory traces over a few seconds before the traces decay. The other part involves rehearsal processes necessary to keep active any memory trace in the phonological store over a longer time-span. The phonological store in turn, is limited to the number of items that can be articulated and rehearsed before the actual trace decays. Similarly, the visuospatial sketchpad may be divided into subcomponents, one visual and one spatial subsystem, both having their respective stores and rehearsal processes (Repovs & Baddeley, 2006). Worth mentioning is that the theory of WM focuses on visual and auditory information only, making no specific notion of other sensory modalities, such as smell, taste, or touch. The last component to be added to the model was the episodic buffer (Baddeley, 2000), being a limited-resource temporary storage able to integrate information from several sources into a multi-dimensional code, and is controlled by the CE. The role of the CE is to retrieve information open to conscious awareness and also monitoring and modifying that information (Baddeley, 2000). In recent years however, several distinct components of the CE have been well established, including the shifting, updating, and inhibition components (Colette & Van der Linden, 2002).

Extensive research has investigated the neural correlates of WM. Findings suggest the same regions in the parietal cortex processing perceptual information as being the sites for storing information in WM. Normally, perceptual information quickly decays without rehearsal, hence, rehearsal processes of WM recruit selective attention networks in frontal and parietal areas to maintain activation (Jondies, Lacey, & Nee, 2005).

Executive attention. Engle and Kane (2004) presented their theory of WM based on investigations of individual differences in *working memory capacity* (WMC). They viewed their approach as being similar to Baddeley's model, although the latter emphasizes the structure of the WM system whereas they themselves emphasize its function (however, see Repovs & Baddeley, 2006, for a functional approach of the original WM model). Engle and Kane's model of WM contains three main components: (a) Short-term memory (STM) consists of activated long-term memory (LTM) traces, (b) individual rehearsal processes and strategies for maintaining STM activation, and (c) *executive attention*. Executive attention, previously named controlled attention, is responsible for the maintenance of goals, stimulus and contextual information, when there is conflict or interference, and is the most crucial element of high WMC. "Thus, we assume that individual differences in WMC are not really about memory storage per se, but about executive control in maintaining goal-relevant information in a highly active, accessible state under conditions of interference or competition." (Engle & Kane, 2004, p. 149). In other words, willful maintenance of attention while avoiding distraction is a crucial element of the theory, hence executive or controlled attention. Moreover, WMC is being looked upon by Engle and Kane (2004) as domain general and important for complex tasks across different modalities and processes. On the one hand there are simple span tasks assumed to rely primarily on domain-specific STM rehearsal processes while, according to the authors, to a lesser degree on attention. Complex span tasks, on the other hand, are assumed to primarily rely on executive attention more than on domain-specific STM considering that the information must be maintained when secondary tasks, shifting attention, or proactive interference are involved. Thus, WMC is essential in cognitive tasks where controlled attention is required and has been found to predict abilities involving numerous higher-order functions and is moreover assumed to relate to general fluid intelligence (Gf) (Engle & Kane, 2004).

Using structural equation modeling, Engle, Tuholski, Laughlin, and Conway (1999) found correlations between certain tests and WM, and others with STM. Furthermore, WM correlated with STM and with Gf. They argued that the relationship between WM and Gf is primarily through controlled attention.

Several studies have supported the view that high-span subjects differ qualitatively in certain respects. By dividing participants into high and low-span groups according to performance on the Operation Span Task (OSPAN) involving mathematical calculations and word memory recall, Kane and Engle (2003) found individual differences in Stroop task performance. In Stroop tasks, preprogrammed response tendencies of reading printed words must be inhibited in favor of naming the printed color of words, hence requiring conflict resolution. More specifically, low spans exhibited goal neglect, making more errors in trials where 80% of words were congruent, an indication of unsuccessful maintenance of appropriate task goals in WM. Moreover, low spans had higher response-time interference on trials with 0-20% congruent items.

In addition, brain-imaging has provided evidence for *anterior cingulate cortex* (ACC) and *dorsolateral prefrontal cortex* (DLPFC) involvement in Stroop tasks. An event-related potential (ERP) peaking 800 ms before stimulus onset in fronto-polar to fronto-central regions predict correct trials and is probably related to successful maintenance of task goals in the DLPFC (West & Alain, 2000). Another ERP originating in fronto-polar regions peaks at around 500 ms after stimulus onset (West & Alain, 1999) and is assumed to reflect conflict resolution in the ACC (Kane & Engle, 2003). A recent imaging study by Kim, Kroger, and Kim (2011) found differences within the ACC depending on the presence of perceptual or response conflict, proposing that the caudal dorsal ACC detects perceptual conflicts whereas the rostral part of the dorsal ACC detects response conflicts. Moreover, activation in the rostral dorsal ACC in conflict trials was accompanied by activation in the DLPFC, presumably due to the control of response conflict resolution by the DLPFC. In other words, the data indicates that the dorsal ACC detects conflicts while the DLPFC monitors and resolves conflicts (Kim et al., 2011).

Further evidence supporting the Engle and Kane (2004) view of WM is found in research by Bunting, Conway, and Heitz (2004) suggesting that low spans are more susceptible to proactive interference than are high spans. Proactive interference occurs when old representations interfere with retrieval of newly learned representations (Persson, Welsh, Jonides, & Reuter-Lorenz, 2007). Lows had difficulties learning new sets of to-be-remembered person-locations when old sets interfered with the new, such that some person-locations were used as targets in both (Bunting et al., 2004). This was interpreted as a failure of the attention component of WM resolving such interference. Highs on the other hand were able to resolve the conflict, maintaining the correct activation.

Vogel, McCollough, and Machizawa (2005) divided participants into highs and lows depending on their visual item storage capacity and found the highs being able to filter out distractors whilst the lows had difficulties in doing so. Measured by electroencephalogram (EEG), lows were eliciting ERPs of equivalent amplitudes for two target/two distractor trials and four target trials whereas highs were filtering out the distractors, thereby eliciting lower amplitude ERPs for the two target/two distractor trials. Furthermore, the authors believed that the *prefrontal cortex* (PFC) sends a bias signal towards the parietal and occipital cortices which consequently keeps the irrelevant information away from storage. These results were replicated and expanded upon with *functional magnetic resonance imaging* (fMRI) by McNab and Klingberg (2008). In addition to the higher activity in the parietal cortex storage region, they found activity in prefrontal and basal ganglia regions predicting successful filtering of distractors. The researchers suggested that activities in the middle frontal gyrus (MFG) and the basal ganglia were the neural correlates of the controlled attention mechanism biasing the selection of relevant information for encoding.

Moreover, lesions to the lateral PFC in macaques disrupted their ability to flexibly switch top-down attention between cued targets (Rossi, Pessoa, Desimone, & Ungerleider, 2009). A subsequent fMRI study showed that the specific regions for top-down attentional control involved the intraparietal sulcus, frontal eye field, MFG, and inferior frontal gyrus. Braver, Reynolds, and Donaldson (2003) demonstrated sustained activity in the anterior PFC when *cognitive control* was exerted over a prolonged period for successful alternation between multiple tasks, whereas the lateral PFC involved maintenance of task-set information. The superior parietal cortex on the other hand was implicated when the task-set information was updated after a switch between tasks, results in line with the other neuroimaging data presented so far.

What does this model of WM predict for dual-task situations? In complex cognitive tasks controlled attention is assumed to be essential since several task-relevant goals must be actively maintained at the same time, tasks compete for response and conflicts must be resolved, and where monitoring and modification are controlled and effortful (Engle et al., 1999). Engle and Kane (2004) proposed that low span subjects may encounter problems in some dual-task situations because of depleted controlled attention capacity, hence rather than being memory specific, successful dual-tasking is seen primarily as an attentional phenomenon. In addition, Miyake et al. (2000) found no correlations between dual-task performance and the inhibition, updating, or shifting executive components suggesting that dual-tasking involves a different component, such as controlled attention as proposed by the authors. In the subsequent paragraphs dual-task literature will be reviewed.

Brain Imaging and Dual-Tasking

D’Esposito et al. (1995) conducted one of the first fMRI studies investigating dual-tasking. A difference in activation between dual-task and single-task conditions was observed only in the DLPFC and in the ACC in five out of six subjects. Based on Baddeley’s model of WM, the additional activation was interpreted as a result of the CE allocating and coordinating attentional resources, assimilating the view of Engle and Kane. In another dual-task investigation participants showed increased activity in the inferior frontal sulcus and the MFG, i.e. areas in the DLPFC, due to which the authors reached a similar conclusion as D’Esposito and colleagues (Szameitat, Schubert, Müller, & Von Cramon, 2002). Furthermore, slight differences in activation during various dual task studies are likely due to variations in the particular tasks involved. Likewise, Wu and Hallet (2008) found increased activity in dual-task conditions as compared to single-task conditions, but after practicing dual tasks, activation decreased, being interpreted as improved efficiency in performing them. In their review of a number of studies, Smith and Jonides (1999) concluded that tasks requiring executive processes plus storage involve additional activation in the PFC. They believed that the ACC was primarily being involved in the resolution of response-conflict for preprogrammed responses whereas the DLPFC was being involved in attention for monitoring and non-preprogrammed conflict resolution. This view is supported by recent imaging data (Kim et al., 2011).

The majority of studies however, have not found any additional area of activation during dual-tasking conditions (Adcock, Constable, Gore, & Goldman-Rakic, 2000; Dux et al., 2009; Klingberg, 1998). Therefore, Adcock et al. (2000) questioned any additional region of activation during dual-tasking. Results from Adcock et al. (2000) should be interpreted with caution as only about one third of participants had interference during dual-task performance. A too simplistic task, putting minimal load on the executive system, might explain these findings. Nonetheless, despite the fact that no additional area of activation was seen there was a slight increase in activation in the DLPFC, ACC and left MFG in the dual condition. Klingberg (1998) used auditory and visual WM tasks requiring the detection of changes in pitch or luminance. Importantly, activities in sensory specific areas were lower in dual conditions in both studies. When attention must be shared among tasks a decrease in activity is likely due to reduced allocation of attention, considering attention as a modulator of activity in early sensory areas (Raz & Buhle, 2006). Similarly, Just, Keller, and Cynkar (2008) investigated concurrent driving performance and sentence comprehension using fMRI, showing that participants made more errors when driving while listening than when driving alone. Nonetheless, no additional area of activation was found. However, visual areas in the parietal cortex necessary for driving decreased in activation, assumedly attributable to less attentional resources being directed to the driving task according to the authors. Furthermore, regardless of differences in single-task and dual-task conditions, the DLPFC was active during dual-task conditions in all studies reviewed above. In sum, the review of brain-imaging studies suggests that alterations in activity do occur during dual-tasking as compared to the component single-task conditions, even though no additional area of activation is implicated. Further, the majority of alterations occur in the DLPFC, ACC, and parietal cortices.

Theories of Dual-Task Interference

In dual-task situations, due to *interference*, performance is often compromised as compared to situations where the tasks can be completed one at a time. Hence, one important area of investigation in relation to dual-task studies relates to the sources of that interference.

There are two prominent theories of interference; the multiple resource theory (Wickens, 1980, 2002, 2008) and the central bottleneck theory (Pashler, 1994).

Multiple resource theory. When two tasks share the same resources grave interference is known to occur (Wickens, 1980, 2002, 2008). According to the multiple resource theory, interference in dual-task situations may occur for several reasons. First, the term resource stands for certain capacities, such as attention or WM. These may be allocated differently between tasks and are often under cognitive control. Consequently, more difficult resource-demanding tasks create greater interference. The multiple aspect of the theory connotes greater interference when tasks share the same resource. Originally, the model included three dimensions, with corresponding levels, along which interference occurs if two tasks compete for resources on the same level of any given dimension (Wickens, 1980). A fourth dimension was added at a later point (Wickens, 2002, 2008). The first dimension, stages, includes the perceptual, cognitive, and response levels. The second, modalities, includes the auditory and visual levels. The third, codes, can be either spatial or verbal. The fourth dimension involves focal or ambient vision. While focal vision is necessary for pattern recognition and fine detail, ambient vision detects motion and orientation. Finally, the levels of the dimensions vary along each other, e.g., responses may be manual spatial or vocal verbal, and perception and cognition may be spatial or verbal. Unfortunately, even though providing detailed descriptions of sources of interference, the specific role of attention in the model is not clear, as pointed out by Wickens (2002).

Consider two situations with high and low levels of interference. When participants had to perform a spatial visual search, higher interference was seen only when coupled with simultaneous manipulation and storage of spatial and not verbal information in WM (Liu & Wickens, 1992). In addition, participant performance during a manual tracking task decreased substantially when paired with a manual-response choice-task and not with a vocal-response choice-task (McLeod, 1977).

The multiple resource theory may possibly be incorporated into Baddeley's theory of WM, where Baddeley distinguished between a spatial system, a verbal system, the CE allocating resources and resolving conflicts, and the episodic buffer integrating various codes. The multiple resource theory adds to Baddeley's model important knowledge about sources of interference within WM.

Central bottleneck theory. Another prominent theory is the central bottleneck theory proposed by Pashler (1994). He argued for the existence of *processing bottlenecks* in the human brain, implicating that central operations proceed rather in serial processing than in parallel processing. To investigate processing bottlenecks, theorists make use of the psychological refractory period (PRP), i.e., a slowing of the reaction time (RT) when two tasks must be performed simultaneously (Pashler, 1994; Pashler, Johnston, & Ruthruff, 2001). By variation of the stimulus onset asynchrony (SOA) a response selection bottleneck, also referred to as a central bottleneck, has commonly been investigated. When the SOA is shortened, RT on the second task normally increases and is often interpreted as being due to a central bottleneck. Additionally, by variation of SOAs, participants' grouping of responses is avoided (Pashler, 1994).

The inferior frontal junction (IFJ) is a region involved in the central stage of response selection. It represented the only region with greater activity in a dual task prior to training as compared to its component single tasks, but as performance improved the activity decreased to the same level as during the single-task conditions (Dux et al., 2009). One analysis of particular importance revealed that improved performance was not due to the rerouting of information away from areas in the PFC towards automatic sensory-motor networks. This is important as automatic responses do not require attention. Another analysis was made to see if there could have been a neuronal segregation in the IFJ, allowing for more efficient parallel processing. On the contrary, the opposite was found. The data were interpreted as a shortening of the processing time in the limited-capacity central stage of response selection and decision-making (Dux et al., 2009). Again, the tasks here are very simple, requiring one of two different responses in an auditory discrimination task and a face discrimination task. The fact that neurons within the IFJ became less task-specific with practice might suggest that the two tasks were treated as one since the stimuli were presented simultaneously. However, a study by Ruthruff, Van Selst, Johnston, and Remington (2006) showed no indication of task integration. There are at least two possible reasons why tasks have not been integrated in this study in contrast to the study by Dux et al. (2009). Firstly, although similar, tasks in the former study were more difficult than in the latter. Secondly, and most importantly, Ruthruff and colleagues presented their tasks with a varying SOA, while the latter presented their tasks with a SOA of 0 ms. Hence, grouping responses would delay RT for the first task. There is no clear agreement on whether there is a serial processing central bottleneck or whether central processes may run in parallel. Both may actually be valid as will be covered in subsequent paragraphs.

Cognitive Training and Transfer Effects

The present study set out to investigate the transferability of cognitive training in a dual-task setting; as will be discussed exploring existent literature on the subject. A famous dual-task experiment was conducted by Spelke, Hirst, and Neisser (1976). After extensive practice their two subjects learned how to read and comprehend stories while taking dictation and categorizing words without any form of interference. However, it was argued that attention may have been directed away from dictating, such that dictating was done automatically without being given attention. If dictating was done automatically, the subjects would not comprehend what they had been dictating, but unfortunately no such test was taken. In addition, the stories used-for reading might have allowed participants to alternate between the tasks, not performing them concurrently. To address these two issues Hirst, Spelke, Reaves, Caharack, and Neisser (1980) conducted two additional experiments. During these experiments, the subjects were trained to take dictation while reading. They were also tested on their comprehension of the dictated material, revealing no sign of automaticity. Secondly, half the participants read a less redundant encyclopedia text, requiring constant attention for comprehension, while the other half read stories like those in the experiment by Spelke et al. (1976). There appeared to be no difference between the two conditions, therefore, the alternating hypothesis was not given support. Finally, there was evidence of a *transfer effect* as three out of four subjects performed equally well when tested on the non-trained reading material. The authors argued that attention may be improved by practice and not necessarily being limited in capacity (Hirst et al., 1980).

Transfer effects have been observed previously in other dual-tasking settings as well (Bherer et al., 2005, 2008). On the other hand, these studies may not have revealed a particular component involved in dual-tasking. First of all, the practice tasks were discrimination tasks and the transfer tasks were also discrimination tasks, leaving open the possibility that improvement was actually due to enhancement in discrimination tasks rather than to an improvement of a more general component. Secondly, one of the transfer tasks was the same as one of the training tasks, allowing for greater opportunity of automaticity for one of the tasks. To avoid automaticity it is especially important to use novel transfer tasks. Hazeltine, Teague, and Ivry (2002) also demonstrated transfer effects in a series of experiments. However, these results were even more limited as the transfer condition merely consisted of adding three additional responses to the transfer tasks. Even so, the results demonstrated that responses are not wholly automatic. As there was no dual-task interference following training, Hazeltine et al. (2002) claimed that the processes seemed to run parallel and that the central bottleneck may be overcome by practice, such that the two tasks may be processed simultaneously.

Training on a STM task and a classification task was transferred to a dual tracking task already after one day of practice (Damos & Wickens, 1980). The authors suggested that the actual time-sharing skill being transferred promoted a shift towards parallel processing. In addition, they found that participants adopting a parallel response strategy for the first set of tasks outperformed the other participants not only on that set but also on the tracking set.

Another issue to consider is the instructions given to participants, as strategy has showed to affect dual task performance. A better transfer for subjects training with a variable strategy over subjects training with a fixed strategy was observed (Kramer, Larish, & Strayer, 1995). Nevertheless, depending on the particular dual task this is not always the case (Bherer et al., 2005).

Interestingly, cognitive dual-task training has transferred to such far domains as standing balance. More specifically, it led to improved standing balance in older adults (Li et al., 2010). At first glance this might seem puzzling. However, according to the authors, due to the central processing of postural tasks, attention is an important factor in balance performance. Considering that attention is highly implicated in dual-tasking, it is possible that training attention in a dual-task setting positively influenced balance performance.

The question then, is whether training participants performing one cognitive dual-task can be generalized to other cognitive dual-tasks after selecting rather different component tasks. Successful transfer could indicate an executive function such as executive attention being involved in dual tasking, being domain general and rather independent of the particular tasks involved.

In fact, there seems to be a certain component or function involved in dual-tasking but it is not yet clear what it is exactly and how general it may be. Oberauer and Kliegl (2004) believed the actual coordination of multiple tasks is critical for successful improvements. In their study, participants' dual-task interference was eliminated after them practicing the dual task and not by them practicing the single tasks alone.

As mentioned previously, a link between executive attention and Gf has been suggested (Engle et al., 1999). Jaeggi, Buschkuehl, Jonides, and Perrig (2008) trained participants on a Dual N-Back task for 8 to 19 days, followed by performance measures on several tests of Gf. Participants receiving 17 and 19 days of Dual N-Back training scored higher on Gf following training as compared to controls and participants receiving 8 or 12 days of training. Intriguingly, the final level reached on the Dual N-Back did not predict improvement of Gf scores, nor did increases in simple WM measures. The authors proposed that successful transfer actually depended on participants working at their maximum capacity on the Dual N-Back. To ensure participants working at their limit, the level of n was increased or decreased after each block depending on performance. Moreover, both Dual N-Back and Gf assumedly involve the same underlying processes in form of binding processes and attentional control (Jaeggi et al., 2008).

Transfer of training has also been investigated in children (Klingberg et al., 2005; Rueda, Rothbart, McCandliss, Saccomanno, & Posner, 2005). Rueda et al. (2005) trained four to six-year old children for five days on various tasks assumed to tap into executive attention abilities. Training was later transferred to an untrained and unrelated intelligence test and the Attention Network Test. Furthermore, DNA samples were collected and certain dopamine coding genes predicted performance. Children with the most beneficial genes benefited less from training than did children with less beneficial make-up. Furthermore, electrophysiological recordings revealed that training and genetic setup altered activity in the lateral PFC and ACC. Dopaminergic cells project from the midbrain to the PFC and ACC (Haber & Knutson, 2010) and are assumedly implicated in executive attention (Rueda et al., 2005). In the Klingberg et al. (2005) investigation, children at around 10 years of age diagnosed with attention-deficit/hyperactivity disorder (ADHD) underwent visuo-spatial WM training for more than twenty days. Training successfully improved measures of WM span, inhibition, and reasoning abilities, as well as improving observer ratings of head movements during the completion of tasks. Decreased head movements were interpreted as a sign of keeping attention on the task.

On the other hand, not all studies have been able to find transfer effects (Boot, Kramer, Simons, Fabiani, & Gratton, 2008; Owen et al., 2010), suggesting rather limited transferability from training cognitive tasks (Slagter, Davidson, & Lutz, 2011). A controversial internet-based brain training study by Owen et al. (2010) revealed no transfer from computerized brain training tasks to untrained tasks. The paradigm adopted by Owen et al. (2010) is quite controversial and may be subjected to several critiques. First of all, training took place solely over the internet, therefore, relatively little control over the subjects was involved. Secondly, participants were allowed to train various tasks and the amount of training for each task varied considerably amongst participants. Additionally, the minimum training-time required to be included in the final analysis was little. It might be that some transfer effects disappeared because frequent trainers were not analyzed separately.

Opposing results are also demonstrated in video game training literature (Boot et al., 2008; Green & Bavelier, 2003). Green and Bavelier (2003) found striking differences between expert video game players and non-video game players on several tests measuring visual attention, more specifically on a flanker compatibility task, an enumeration task and an attentional blink task. To make sure that some people did not become video game players because of better inherent attentional abilities they had non-video game players practice two different video games for 10 days. Subjects training on an action video game, requiring disperse visual attention skills, outperformed subjects training on *Tetris*, where in contrast the focus of attention is very narrow, on the enumeration task, attentional blink task, and a useful field of view task (Green & Bavelier, 2003). In contrast, Boot et al. (2008) found no significant differences between experts and non-gamers on the three tasks reported above. However, experts were significantly better on a STM visual task, on task switching, on tracking targets at high speed, and in judging rotations. Furthermore, non-gamers were allowed to train on one of three video games for 20 hours, the results showing no significant effects on any transfer task, even though participants improved significantly on the games. It may be that transfer effects disappeared due to the groups performing the transfer task before training commenced, halfway through, and post-training. The reason for these discrepancies is not clear; however, inclusion criteria for experts versus non-experts seemed to differ between the studies, where criteria in the Boot et al. (2008) study were more lax than in the Green and Bavelier (2003) study. Similarly, non-experts were allowed to have played more video games in the Boot et al. (2008) study as compared to Green and Bavelier (2003).

What may be the cause of successful transfer versus non-successful transfer? It has previously been shown that practice effects may be transferred to untrained tasks if tasks share overlapping neural resources (Dahlin, Stigsdotter Neely, Larsson, Bäckman, & Nyberg, 2008; Klingberg et al., 2005; Olesen, Westerberg, & Klingberg, 2004; Persson & Reuter-Lorenz, 2008). More specifically, successful transfer was seen for the updating executive component (Dahlin et al., 2008) and for a tentative proactive interference resolution component (Persson & Reuter-Lorenz, 2008). Dahlin and colleagues scanned participants before and after training while performing letter memory, n-back, and Stroop tasks. All tasks shared the same fronto-parietal networks but the letter memory and n-back tasks had significant activity in the striatum and transfer occurred only from letter memory to n-back. The authors argued that having some overlapping regions may not be sufficient for transfer;

instead what is necessary is the sharing of the same processing component and related brain regions (Dahlin et al., 2008).

Five-week training on a visuo-spatial WM task, a backward digit span task, and a letter span task have been transferred to the untrained Raven’s Advanced Progressive Matrices (RAPM), the Span Board task, and the Stroop task (Olesen et al., 2004; Westerberg & Klingberg, 2007). This was related to increased activation in the MFG and the superior and inferior parietal cortices. Training was still significant if only slightly diminished for the two participants tested on the RAPM and Span Board Task eight months after training (Westerberg & Klingberg, 2007). Moreover, a follow-up session three months after training ended, revealed that the children from the Klingberg et al. (2005) investigation still benefited markedly. Thus, it seems as if cognitive training can prove to be rather long lasting.

In sum, the training literature does not always seem to converge, finding rather similar designs showing opposing results. Even though not all studies have been able to reveal transfer effects there is still an extensive body doing so. Interestingly, skills on specific tasks are crucial for high performance, but general executive components may also play important roles in various multitask scenarios as is evident from neuropsychological investigations (Burgess, Veitch, de Lacy Costello, & Shallice, 2000; Dreher, Koechlin, Tierney, & Grafman, 2008; Thoma et al., 2008; Wu & Hallet, 2008).

Hypotheses

No clear consensus has yet been reached regarding what function or component being essential for successful dual-tasking. Depending on the type of tasks implicated in a dual-task situation various cognitive processes are required. The present study aims to investigate whether a rather general function, namely executive attention may be trained and then transferred to two different complex tasks. Five days of Dual N-Back training paired with later transfer tasks allow for testing two hypotheses. The first prediction is that Dual N-Back training will transfer to unrelated tasks if executive attention is domain general and implicated in both Dual N-Back and the transfer tasks. The two tasks within the Dual N-Back task are highly similar in that both require the active maintenance of stimulus order, likely constituting a high level of interference, hence requiring executive attention. The automated operation span (AOSPAN) was found to correlate with WMC (Unsworth, Heitz, Schrock, & Engle, 2005), and WMC has been suggested to strongly correlate with executive attention. If five days of training would improve AOSPAN measures, it would indicate that executive attention training is transferable to another task. The second prediction is that training executive attention will help resolve dual-task interference in a high interference situation. Hence, if there will be a transfer only to dual tasks with a high degree of interference, executive attention needs to be more thoroughly considered in the multiple resource model. Accordingly, since the transfer dual task (Trail Making task + Addition Task) involves a high degree of interference it may be an appropriate task for testing the second hypothesis.

Methods

Participants were divided at random into experimental and control groups, differing in the type of training tasks. Repeated measures analysis was used for the Dual N-Back task whereas the AOSPAN and a dual task (Trail Making task + Addition Task) acted as transfer tasks to investigate whether Dual N-Back training would affect other complex tasks.

Participants

Thirty participants, 21 males and 9 females, ranging from 20 to 35 years of age, were recruited in and around the campus at the University of Skövde. The experimental group consisted of 11 males and 4 females, mean (M) age (25.3), and the control group of 10 males and 5 females, M age (24.8).

Stimuli and Apparatus

All tasks in the lab, the addition task excluded, were performed on an HP EliteBook 6930p, Intel®Core™2 Duo CPU, T9400 @ 2.53Ghz, 4gb RAM, Windows 7 Enterprise, DirectX 11. The Face N-Back and Dual N-Back tasks used on the first and last day of the experiment were created with E-Prime Studio 2.0 and run with E-Run 2.0. The AOSPAN task was run with E-Run 2.0. Finally, the Trail Making task was run with the PEBL psychological software tool.

Procedure

On day one, the pre-training session, all participants performed the same tasks. First, participants completed a Face N-Back task followed by a Dual N-Back task. Participants in the experimental group were then provided instructions to practice a Dual N-Back task once a day for six days, whereas participants in the control group were provided instructions to practice Name Tag once a day for six days. One week after the pre-training session participants returned and made Dual N-Back, AOSPAN, and a dual task consisting of a Trail Making task and an Addition Task. Participants practicing for less than five days were excluded from the final analyses, as indicated by logs on www.lumosity.com.

Pre-Training Session

Face N-Back. First, in order to acquaint participants with n-back tasks they performed an n-back task using faces as stimuli. The faces were presented for 500ms in the middle of the screen followed by a fixation cross for 2500ms. When the face was a target participants were instructed to press the *f* key on a standard keyboard. In absence of a target no key was to be pressed. A target is identified by comparing the newly presented face to the one presented n presentations back. Hence, on the 1-back level they were to press the f key when the same face was presented two times in a row, on the 2-back level when the newly presented face was the same as the one presented two times back, and finally, on the 3-back level when the face matched the one presented three times back. They were first given a 1-back practice round before they moved on to a 2-back practice session followed by two 2-back test sessions from which data was collected. The same procedure was applied for the 3-back level. Each block included 16 faces, of which five or six were targets, and all participants received identical lists of stimuli. The number of hits, misses, false alarms, and correct rejections were measured.

Dual N-Back. The Dual N-Back task followed the same principle as the Face N-Back task. However, in the Dual N-Back task, participants were to keep track on two separate streams of stimuli appearing for 500ms followed by a fixation cross for 2500ms. One task was to focus on a blue square that appeared randomly in one of eight positions around a fixation cross. When the last presented square was a target, participants were to press the *s* key. With each presentation of a square one of eight letters was presented through headphones (A, C, G, K, Q, R, T, V), and when the letter was a target participants were to press the *l* key. When no target was present no key was to be pressed. Each block consisted of 21 square locations and 21 letters, including six targets in each modality. Twice in each block, both the square and the letter were targets simultaneously thus requiring participants to press both the *s* key and the *l* key for a correct answer. Before each new level, participants were presented with written instructions and if anything was unclear they were allowed to ask questions. First, participants performed one practice session on the 1-back level before they moved on to the real test-phase. Subsequently, they executed one practice session followed by two proper tests per level from which data was collected on the 2-back, 3-back, and 4-back levels. Following each practice and test session accuracy feedback was presented. The number of hits corresponded to correctly identified targets, the number of misses to missed targets and false alarms to faulty keyboard presses. Finally the number of correct rejections was recorded. This score was based on the number of times no key press was detected when there correctly should have been no key press.

Training

Following the pre-test session participants were given instructions to practice a particular task through the internet at www.lumosity.com - for a total of six days. Participants in the control group were practicing Name Tag whereas participants in the experimental group were practicing a version of the Dual N-Back task.

Name Tag. In the beginning of each level, a card with a face on it is presented together with a name of that face. One session consists of ten rounds and it is possible to reach a maximum level of nine. On the first level of each session, two faces are presented together with the corresponding name. Four cards turned upside down are then presented on the screen, with either a face or a name on the side that is turned down. When clicking on a card it is turned over, revealing either a face or a name. The participant is then to identify which card still remaining on the screen is the corresponding face or name. If the correct card is clicked both cards disappear from the screen. If the incorrect card is clicked the content on the back of that card is revealed followed by both cards being turned over again. Successful performance on a level leads to one additional face with corresponding name, to a maximum of ten. Depending on the number of turns required to identify a pair, a score is added to the total score.

Dual N-Back. In this version of the Dual N-Back, the level of n varies depending on the performance of the participant. The only difference between this task and the one used by Jaeggi et al. (2008) is that all letters and positions of the squares may appear in any one round at www.lumosity.com whereas Jaeggi and colleagues allowed only six of each in any single round. Following the same rules as the Dual N-Back task used in our lab, a square and a letter were presented every 3000ms, each round consisting of 21 presentations, of which six in each modality were targets, and twice the targets appeared simultaneously. Starting on the 1-back level, two mistakes or less in each modality is considered as a successful attempt and allows the participant to the next level. With between two and five errors in any modality, the participant will stay on the same level. If more than five mistakes are made in any one modality the participant will drop one level. In this way the participant is always presented with a challenging level. After one full training session consisting of 15 rounds, results are stored and displayed in a graph showing the mean n-back level for each session. One additional difference between this task and the pre- and post-session Dual N-Back-tasks was that the letters (C, D, G, K, P, Q, T, V) were presented in English at www.lumosity.com whereas the letters (A, C, G, K, Q, R, T, V) were presented in Swedish in the pre-training session. Some letters from the English version had to be changed due sounding to similar when pronounced in Swedish

Post-Training Session

One week after the pre-training session participants returned to complete three post-training tasks. AOSPAN and the dual task acted as transfer tasks and were counterbalanced across participants such that half the participants started with the AOSPAN and the other half with the dual task. The Dual N-Back task was used as a control measure to see if participants had been practicing. The Dual N-Back task was performed in the end to minimize any fatigue effects affecting the transfer tasks. Especially since there is a possibility that participants in the control group would find it more demanding than participants in the experimental group to perform the Dual N-Back task as they had not been practicing the task.

Automated Operation Span. AOSPAN was first used by Unsworth et al. (2005). In this version of the Operation Span, participants were encountered with mathematical operations which they were to mark as either true or false by clicking the mouse on the corresponding box. After each mathematical judgment a letter is flashed on the screen for

800ms. After completion of a full set, varying from three to seven letters, participants are presented with a four by three matrix showing twelve letters. Participants are then to click the letters in the order presented during the last set. Set sizes vary from three to seven letters and each set size is presented thrice totaling 75 mathematical problems and letters respectively. First, a letter span session is performed, where participants are presented with two to three letters and are instructed to click the letters in the order presented. Feedback is then provided indicating the number of correctly recalled letters. Secondly, a math practice session is given. A number of math operations is then presented, (e.g. (8/4) + 2 = ?), and the task is to solve the operation as quickly as possible before clicking the mouse button. Following the click, a number is presented at the top of the screen, either corresponding to a correct or incorrect answer to the operation. When correct, participants are instructed to click “true” and when incorrect “false”, and after each math operation accuracy feedback is provided. Unknown to the participant, during the math training session, the time taken to solve each operation is measured. Subsequently, when performing the real test, participants have no more time to solve any operation than the mean time from the practice session plus 2.5 standard deviations (SD). This information is only presented to the participants after completing math practice. The third training session consisted of three sets of two math operations and letters performed together.

Following the three training sessions, the real test was initiated. When participants failed to solve a math operation in time this was counted as a speed error and was added to the total math error score. Making calculation errors counted as accuracy errors and were added to the total math error score. The participants are also instructed to keep their total math accuracy rate above 85% to ensure they are solving the math problems and not merely rehearsing letters. During the recall phase, the error percentage is shown in red in the upper right-hand corner of the screen. After each set size has been performed thrice the participant is presented with feedback on five different measures. The size of any completely remembered set is added to the absolute operation span score. The number of correctly recalled letters from each set is added to the operation span score, regardless of the set being completely or partly recalled. As for the math operation feedback, speed and accuracy errors were first presented separately, and together added up to form the math error score.

Dual task. In the dual task, participants had four minutes to respond to a simple Addition Task while simultaneously completing as many maps as possible on a Trail Making task.

Addition Task. The Addition Task consisted of an opening statement, (9 + 8 = 17), followed by a number between one and nine presented every five seconds through speakers, the numbers being generated using a random numbers table. Participants were instructed to add the last number to the total accumulated number of previous presentations. E.g., when nine was to be added after five seconds, the participant was to say 26 aloud to the experimenter (9 + 17 = 26). Next, when the number three was added, the participant was to say 29 and so on. Moreover, if exceeding 100 counting started from zero again (e.g., 97 + 5 = 2). When an incorrect answer was given, the experimenter corrected the participant stating the correct number. Such an error was considered an accuracy error. If no response was given in time, the experimenter stated the correct number and the error was considered a no-response error. The two types of errors then added up to form the total error measure. The experimenter kept track of numbers and errors on paper.

Trail Making task. The PEBL version of the Trail Making task was used. The first type of map consisted of 26 filled blue circles with a white number in the middle, ranging from 1 to 26, spread out randomly across the screen. The task was to click the numbers in order, starting with 1 and finishing with 26. When the first map was completed a second type of map appeared, again with 26 blue circles. This time the letters A until M and the numbers 1 until 13 appeared inside the circles. The task was to click 1 followed by A, 2 followed by B, and so on. If the participant finished the second map the first type would appear again. For analysis, the number of correct clicks was measured, such that the completion of the first map and completing circles until letter B would correspond to 30, (i.e., 26 + 4 = 30). Before the start of the dual task participants were allowed to click their way through the first map to see both types.

Dual N-Back. The post-training Dual N-Back task consisted of two test sessions on each level starting at 2-back and ending at 4-back. Due to time constraints and the familiarity of the task no practice sessions were included.

Results

Five subjects were excluded from the final analysis. Three subjects, two in the experimental group and one in the control group, aborted their participation, and two additional subjects in the experimental group were excluded because they did not reach the inclusion criteria of five training-sessions.

Performance measures on the Face N-Back and Dual N-Back were recalculated into A' values for each participant using equation 1 (Donaldson, 1996), where H is equal to the proportion of correct hits and FA to the proportion of false alarms:

$$A' = ½ + \frac{(H-FA)\ x\ (1-H-FA)}{(4\ x\ H) x\ (1-FA)} \tag{1}$$

Similarly, performance measures on the dual task subtests were recalculated into Z values for each participant using equation 2, where X is the mean of each subject, M is the sample mean and SD the sample standard deviation:

$$Z = \frac{X-M}{SD} \tag{2}$$

The combined score (Z_{Total}) for the dual task was calculated using equation 3, where Z_{Trails} and Z_{Addition} are Z-values for the Trail-Making task and Addition Task respectively.

$$ZTotal = \frac{ZTrails + ZAddition}{2} \quad (3)$$

Pre-Training

See Table 1 for M and standard deviations (SD) on Face N-Back and pre-training Dual N-Back performance. For the Face N-Back task, one-way analysis of variance (ANOVA) revealed no significant effect of group, neither on the 2-back level, $F(1, 23) = .002$, $p = .97$, nor on the 3-back level, $F(1, 23) = .13$, $p = .73$.

For the Dual N-Back, on the 2-back level, differences approached significance [$F(1, 23) = 3.70$, $p = .07$], where the control group had higher performance than the experimental group. In addition, the control group performed significantly better on the 3-back level [$F(1, 23) = 6.21$, $p = .02$]. On the 4-back level, no significant differences between groups were revealed [$F(1, 23) = .91$, $p = .35$].

Table 1
Means (and standard deviations) for the pre-training session Face N-Back and Dual N-Back

	Experimental Group[a]	Control Group[b]
Face 2-back	.86 (.05)	.86 (.09)
Face 3-back	.78 (.12)	.76 (.09)
A'_{Pre} 2-back	.77 (.11)	.83 (.06)
A'_{Pre} 3-back	.72 (.06)	.78 (.05)
A'_{Pre} 4-back	.64 (.09)	.70 (.09)

[a] *n* = 11 . [b] *n* = 14.

Pre-Post Training

Only one subject completed six days of Dual N-Back training, 10 subjects completing five days. See Table 2 for M and SD for post-training Dual N-Back performance and pre- to post-training improvements.

A 2x2 repeated measures ANOVA was used for pre- to post-training measurements. See Figure 1 for pre- and post-training performance on the Dual N-Back task. The analyses revealed a significant interaction effect [$F(1, 23) = 16.06$, $p < .001$] for the 2-back level, and an effect of session [$F(1, 23) = 16.82$, $p < .001$], but no effect of group [$F(1, 23) = .62$, $p =$

Table 2

Means (and standard deviations) for the post-session Dual N-Back and pre- to post-training improvement

	Experimental Group^{a}	Control Group^{b}
A’$_{\text{Post}}$ 2-back	.95 (.03)	.83 (.12)
A’$_{\text{Post}}$ 3-back	.85 (.06)	.77 (.07)
A’$_{\text{Post}}$ 4-back^{b}	.75 (.08)	.68 (.09)^{c}
A’$_{\text{Improvement}}$ 2-back	-.18 (.12)	-.00 (.11)
A’$_{\text{Improvement}}$ 3-back	-.12 (.07)	.01 (.06)
A’$_{\text{Improvement}}$ 4-back	-.12 (.10)	.02 (.11)^{c}

^{a}*n* = 11. ^{b}*n* = 14 .^{c}*n* = 13.

.44]. For further understanding of pre- and post-session results, within-group analyses using paired samples t-tests revealed no improvement from pre- to post-training for the control group [*t*(13) = -.07, *p* = .94], whereas the experimental group improved significantly [*t*(10) = -5.14, *p* < .001].

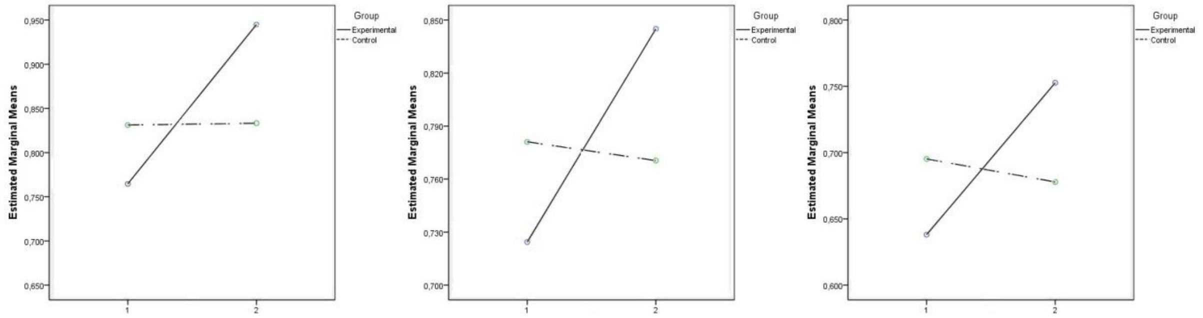

Figure 1. Pre- versus post-session means per group on Dual N-Back. The 2-back, 3-back and 4-back levels are displayed in separate graphs, from left to right. Means are displayed on the y axis and pre- (1) and post-session (2) on the x axis. The filled and dashed lines represent the experimental group and control group respectively.

Another 2x2 ANOVA revealed an interaction effect also on the 3-back level [*F*(*1*, 23) = 24.85, *p* < .001], and an effect of session [*F*(*1*, 23) = 17.45, *p* < .001], but no effect of group, [*F*(*1*,23) = .17, *p* = .69]. Further analyses revealed improvement for the experimental group [*t*(10) = -5.51, *p* < .001], but not for the control group [*t*(13) = .67, *p* = .51].

One subject from the control group was excluded from analysis on the 4-back level as no responses were recorded. Again, a 2x2 ANOVA revealed a significant interaction effect

[$F(1, 22) = 9.022$, $p = .007$], and an effect of session [$F(1, 23) = 4.902$, $p = .04$], but no effect of group [$F(1, 23) = .09$, $p = .77$], and sub-analyses demonstrated that the experimental group improved significantly [$t(10) = -3.80$, $p = .004$], whereas the control group did not [$t(12) = .55$, $p = .59$].

Post-Training

For the transfer task performance on the dual task and AOSPAN see Table 3 for M and SD. For the total operation span score (TotOSPAN) no significant effect of group was revealed, $F(1, 23) = .12$, $p = .73$ in a one-way ANOVA. Similarly, no significant effect was found for the absolute operation span score (AbsOSPAN) [$F(1, 23) = .02$, $p = .90$].

In the same way, on the dual task subtests, no significant differences were found on the Trail Making task [$F(1, 23) = 2.30$, $p = .14$], the Addition Task [$F(1, 23) = .01$, $p = .93$], or the combined dual task performance measure [$F(1, 23) = .62$, $p = .44$].

Table 3

Means (and standard deviations) for the Automated Operation Span and dual task

	Experimental Group^a	Control Group^b
TotOSPAN	55.18(13.09)	57.00(13.10)
AbsOSPAN	38.91(18.35)	39.86(18.64)
Z_{Addition}	.04(.72)	.00(1.20)
Z_{Trails}	-.28(.35)	.32(1.28)
Z_{Total}	-.12(.34)	.16(1.16)

$^a n = 11$. $^b n = 14$.

Additional Analyses

Correlations were calculated in order to further explore the data. Firstly, transfer tasks performance and Dual N-Back performance in the pre-training session were compared using Pearson bi-variate correlation analysis (see Table 4). The general trend demonstrates that performance on one task correlates with performance on all other tasks. Dual N-Back performance on the first day predicted performance on the transfer tasks, and additionally, AOSPAN compared to the dual task showed significant correlations.

Table 4

Pearson bi-variate correlations for all subjects' pre-training Dual N-Back and transfer task performances^{a}

	A'_{pre} 2-back	A'_{pre} 3-back	A'_{pre} 4-back	TotOSPAN	AbsOSPAN	Z_{Trails}	$Z_{Addition}$	Z_{Total}
A'_{pre} 2-back		,62**	,31	,63**	,58**	,43*	,20	,36
A'_{pre} 3-back	,62**		,23	,46*	,33	,48*	,47*	,53**
A'_{pre} 4-back	,31	,23		,33	,29	,19	,22	,23
TotOSPAN	,63**	,46*	,33		,91**	,41*	,47*	,50*
AbsOSPAN	,58**	,33	,29	,91**		,45*	,48*	,52**
Z_{Trails}	,43*	,48*	,19	,41*	,45*		,57**	,89**
$Z_{Addition}$	,20	,47*	,22	,47*	,48*	,57**		,88**
Z_{Total}	,36	,53**	,23	,50	,52**	,89**	,88**	

$^{a}n = 25$.

$^{*}p < .05$. $^{**}p < .001$

To investigate whether participants that improved more from Dual N-Back training would differ on transfer tasks in comparison to those that improved less, a split-half procedure was used on the experimental group; thereby dividing participant into highs and lows according to improvement from pre- to post-training on the 3-back level of Dual N-Back. Comparison of TotOSPAN yielded M = 47.00 (11.45) for the high improvers (highs) ($n = 6$), and M = 65.00 (6.60) for the low improvers (lows) ($n = 5$) and a one-way ANOVA revealed significant differences [$F(1, 9) = 9.58$, $p = .01$]. A similar pattern was revealed for the AbsOSPAN; M = 24.50 (9.67) for the highs, and M = 56.20 (6.30) for the lows [$F(1, 9) = 39.38$, $p < .001$]. On the Trail Making task and Addition Task, Z-values were first recalculated to be compared within the experimental group; Trail Making task, M = -.54 (.49) for the highs and M = .64 (1.12) for the lows [$F(1, 9) = 5.53$, $p = .04$]. Similar analyses demonstrated no significant effects in the Addition task, M = .11(1.21) for the highs and M = -.14 (.79) for the lows [$F(1, 9)=.16$, $p = .70$], nor in the total score, M = -.21 (.71) for highs and M = .25 (.20) for lows, [$F(1, 9) = 1.99$, $p = .19$].

In order for the data not to be driven by the most extreme improver, she was excluded from the analysis, yielding split-half groups of equal sizes (n = 5).However, performance on AOSPAN was still significant. TotOSPAN, M = 49.80 (10.26) for the highs, and M = 65.00 (6.60) for the lows [$F(1, 8) = 7.77$, $p = .02$], AbsOSPAN, M = 26.00 (10.00) for highs, and M = 56.20 (6.30) for lows [$F(1, 8) = 32.64$, $p < .001$]. Performance on the Trail Making task was also significant, M = -.62 (.50) for highs, and M = .64 (1.11) for lows [$F(1, 8) = 5.34$, $p = .05$].

Analyzing the experimental group separately, significant correlations (see Table 5) were found between A'$_{pre}$ 2-back performance and TotOSPAN and AbsOSPAN. In contrast, pre-training A'$_{pre}$ 3-back, did not significantly correlate with TotOSPAN or AbsOSPAN. Intriguingly, correlations were negative between AOSPAN scores and Dual N-Back improvement for both the 2-back and 3-back levels. Moreover, 3-back improvement correlated significantly with the Trail Making task.

Table 5

Experimental group's pre-training performance and improvement on Dual N-Back correlated to transfer tasks.[a]

	TotOSPAN	AbsOSPAN	$Z_{Addition}$	Z_{Trails}	Z_{Total}
A'$_{pre}$ 2-back	,94***	,87***	-,01	,20	,16
A'$_{pre}$ 3-back	,58	,43	,21	-,06	,14
2-Back Improvement	-,94***	-,84**	-,02	-,14	-,14
3-Back Improvement	-,74**	-,77**	,14	-,66*	-,46

[a] n = 11.

*p < .05. **p < .01. ***p < .001

Discussion

First, some reflections about the tasks used in the present study. The AOSPAN has been found to correlate with WMC (Unsworth et al., 2005). The task involves remembering a sequence of letters while simultaneously solving mathematical operations, hence putting a load on WM. First of all, letter sequences must be actively maintained for later recall. The mathematical operations also put a load on WM in form of calculations. However, whilst the letters must be maintained, information related to the mathematical operation can be discarded after responding to the true or false statement. Now, the mathematical operation constitutes a source of interference for the letter part. Hence, according to the Engle and Kane (2004) model, executive attention should be crucial here. The story is similar for the Trail Making task and Addition Task performed concurrently, though this dual task likely constitutes even greater interference in WM. Optimal performance in the Trail Making task requires constant attention, scanning for the next object to click, and maintaining information about the last correctly clicked object. Likewise, the Addition Task requires active maintenance of an accumulated number while solving simple additions, thus involving updating and modification of WM content. Both these tasks may strongly interfere with one another. Hence, a high degree of executive attention should be required for successful performance.

Consequently, these tasks share some of the characteristics with the Dual N-Back task where two separate streams of information must be actively maintained and responded to, correctly updated and modified. The two streams may interfere with one another in at least two ways. First of all, maintaining the order of presented stimuli places a high demand on WM storage resources. Secondly, when finding and responding to a target, or believed to be target, it is crucial not dropping the goal-state of maintaining the sequence of presented stimuli, such that information important for subsequent presentations is lost.

Turning now to a discussion of the present results; training of Dual N-Back for five days over the internet led to better performance on the lab-version of Dual N-Back, regardless of the tasks slightly differing in that the auditory part was presented in Swedish instead of English and that some letters were different. Therefore, task-specific training must be considered successful. However, there were no signs of transfer effects from Dual N-Back training to the transfer tasks, indicated by no differences in performance being present between the groups on the AOSPAN or dual-task subtests.

A problem with interpreting the data in relation to transfer effects arose from the groups differing in the pre-session, the control group performed significantly better on the 3-back level of the Dual N-Back task, with tendencies for the same results on the 2-back level. This may be an indication of the control group being higher WMC subjects already from the start. This could have led to any transfer effects failing to appear in our final analyses as the control group could have performed better also on the transfer tasks if they were taken at the pre-training session. Consequently, there is a risk of making a Type II error here. Nonetheless, groups did not differ on the Face N-Back and it may be that differences merely existed for the Dual N-Back. However, the Face N-Back task is a simpler task than the Dual N-Back, and both the AOSPAN and the dual task are more complex than Face N-Back. Having used the same tasks in the pre- and post-training sessions would have allowed for repeated measures analyses and transfer effects may have been revealed in significantly higher improvement for the experimental group. However, the present data suggested no transfer effects from five days of Dual N-Back training to other tasks.

Additional analyses were made to better interpret the present results. Splitting participants into high and low improvers based on Dual N-Back performance, it was possible to test whether high improvers would differ on the transfer tasks as compared to lows. Significant differences between high and low improvers were revealed, in that highs performed significantly worse than lows on AOSPAN and to a lesser degree on the Trail Making subtask. Moreover, the pre-training Dual 2-Back scores correlated positively with AOSPAN, whereas the pre- to post-training improvement correlated negatively with AOSPAN. This provides further indications that training did not transfer to other tasks. Taken together, these differences imply that low improvers were performing closer to their maximum already the first time they performed Dual N-Back, whereas high improvers increased Dual N-Back specific scores from training, but the high gain did not seem to transfer to other tasks. However, considering the small sample size for the ANOVA analyses (*n* = 5 respectively 6) these should only be viewed as an additional sign for no transfer effects and interpreted with caution.

The full sample analysis suggests that Dual N-Back, AOSPAN and dual task performance are correlated, such that being good on Dual N-Back at the pre-training session would later correlate with good performance on the transfer tasks. Considering, AOSPAN correlating with WMC (Unsworth et al., 2005), Dual N-Back training previously transferring to tests of IQ (Jaeggi et al., 2008), and high performers on tests of WMC having been hypothesized to outperform low performers on dual tasks (Kane & Engle, 2004), this suggests a rather general cognitive ability, such as executive attention, necessary for successful completion of the tasks, not being easily enhanced after five days of training.

Dual-task performance has been found to correlate with general cognitive ability previously. Interestingly, a general cognitive ability test correlated with performance on two dual tasks only the first time the two tasks were administered, but not the second time (Ben-Shakhar & Sheffer, 2001). The authors believed this being due to a more efficient allocation of attention for the high ability subjects, but this advantage disappeared the second time the tasks were performed. Moreover, the component single-tasks did not correlate with the general cognitive ability test, and neither were they good predictors of dual-task performance, fitting our results from the Face N-Back task, where no significant effects were present. Therefore, in the present study, the fact that controls may have been better equipped prior to training could mean their scores would have been higher on the AOSPAN and the dual task if the experimental group had not been practicing Dual N-Back. However, one main difference between this study and the Ben-Shakhar and Sheffer (2001) investigation is that they used RT measures for the tasks, something they argued would be more sensitive to resource allocation, while the AOSPAN and the dual task used relied more on accuracy, even though speed is a factor, and especially for the Trail Making task.

This study may be subject to several critiques. First, allowing participants to practice from home is controversial (Owen et al., 2010). Having subjects' complete tasks in a lab involves a high level of control, whereas home-practice does not. E.g., participants were, after the first session, explicitly asked to practice once a day, starting from the day following the pre-training session until the day before the post-training session. Still, the majority of subjects completed merely five days. Furthermore, even if graphs of performance are available to the experimenter they do not give information about each separate round. Thus, in theory, it is possible that participants focused for ten rounds and then let the last five rounds finish without participants' actually performing them, and consequently reducing the amount of real practice. Moreover, participants may have let someone else try the task not completing the task themselves. Home-practice may also be less motivating when no one is there to monitor the results. This may be important as Jaeggi et al. (2008) claimed that an important reason for participants showing a transfer to Gf was their working at maximum capacity. Possible effects of motivation will be discussed in subsequent paragraphs.

As mentioned previously, motivation may be an important factor when performing cognitively demanding tasks. The fact that subjects completed five days of training instead of six may be an indication of poor motivation. Duckworth, Quinn, Lynam, Loeber, and Stouthamer-Loeber (2011) conducted a meta-analysis of 46 samples involving intelligence testing where incentives were involved. Several findings may be of importance. First, incentives increased intelligence scores. However, the effect of incentives was high for persons with below-average IQ while low for those with above-average IQ. Secondly, Duckworth and colleagues, observing 251 boys taking a low-stake intelligence test, rated the below-average scorers as having lower test motivation. What is more, even if not directly related to the present study, is evidence for a memory-enhancing effect of monetary incentives (Murayama & Kuhbandner, 2011), their subjects better remembering uninteresting material after a one-week delay when given monetary incentives. The effect was not seen with interesting material suggesting that monetary incentives have greater impact when the material itself did not contain any intrinsic motivational factor. The home-practice tasks in the present study are not likely motivating in themselves, hence training efficiency potentially suffers decrements due to low motivation. An obvious question is whether motivated subjects benefit more from cognitive training than others. In the present study, low motivation may have caused participants not “trying their best”, thus not benefiting maximally from training. However, there may be a qualitative difference between memory consolidation over time and executive component or function training over time.

As a complement to the behavioral data reported above, Adcock, Thangavel, Whitefield-Gabrieli, Knutson, and Gabrieli (2006) found that mesolimbic areas, more specifically the ventral tegmental area and the nucleus accumbens, are recruited under reward conditions, affecting the subsequent encoding of stimuli and formation of memories in the hippocampus. Similarly, many dopaminergic neurons in the midbrain project to various regions of the PFC, including the dorsal PFC and the dorsal ACC (Haber & Knutson, 2010), areas commonly involved in executive attention, and dual tasks. An interesting question regards the actual influence of dopamine in the PFC and the ACC. What is the link between dopamine and executive attention to improved performance on intelligence measures or the Attention Network Tests reported by Rueda et al. (2005)? The authors argued that dopamine is involved in executive attention. Moreover, what may dopaminergic effects on motivation influence in the PFC and the ACC, seeing that dopamine influenced memory consolidation in the hippocampus from using motivators (Adcock et al., 2006)? Perhaps it leads to increased performance on cognitive tests due to increased motivation. Furthermore, what may be the relative role of motivation and executive attention in cognitive tasks, and their interrelations? Could it be that motivation enhances executive attention, or does it influence something else? Such questions should be answered for better understanding various influences in cognitive testing.

Consider performance within the experimental group in this study. Participants with the highest improvement in Dual N-Back performed significantly worse on AOSPAN and the Trail Making task as compared to participant with lower gains on Dual N-Back. One possible explanation may be that low performers perform worse due to lack of motivation. However, after their practicing a task a number of times their performance on that particular task will rise to the level of participants already scoring high on the task. If they had trained on any of the transfer tasks the same pattern may have occurred, initial high performers gaining little, low performers gaining more.

Regardless, the studies reported above do not directly relate to the WM tasks used here, even if intelligence tests do correlate with other tests of WM (Engle et al., 1999; Engle & Kane, 2004). However, Jimura, Locke, and Braver (2009) found that participants in a reward condition performed better on a WM task than participants in a non-reward condition. More specifically, the improvement in the reward condition was coupled with sustained activity in the right lateral PFC, being assumed to relate to active maintenance of task set and goals. The Dual N-Back task used in the present study is demanding for WM and sustained activation is likely crucial for successful performance of the task. In line with results from the Duckworth et al. (2011) study, some individuals benefited more from rewards. Jimura et al. (2009) further assessed reward sensitivity and found that the more reward sensitive participants benefited more from rewards. To summarize, these results highlight the importance of providing incentives to participants when performing complex cognitive tasks in order to increase performance. However, it is not yet clear how motivation would affect the learning curve for cognitive tests or the training of executive components. Therefore, future studies should investigate the role of motivation and monetary incentives in cognitive training studies.

A second critique is due to the experimenter giving task instructions and scoring the addition task being aware of who was appointed to the experimental and to the control group respectively. Hence, the study did not make use of a double-blind procedure, and experimenter expectations may have been introduced. However, this is unlikely as the control group actually performed better than the experimental group.

Thirdly, it may have been better to keep the same tasks on the first and the last days of the experiment, carrying out repeated measures analyses on all tasks. Unfortunately the two groups differed on some results of the pre-training session, which complicated further analyses of transfer effects. There may actually be a difference in performance due to practicing Dual N-Back, causing the groups not to differ on the AOSPAN and the dual task. However, it may also depend on the tasks being very different; hence, doing better on Dual N-Back does not lead to better performance on the transfer tasks. Conversely, results imply the opposite, revealing significant correlations between the complex tasks. Moreover, these correlations may also suggest that proper tasks have been selected for a training and transfer study as they probably share important components. However, one could argue that performing well on the AOSPAN and the dual task may be correlated due to differing abilities in mathematics. There are at least two reasons for why such differences do not entirely explain the correlations. First of all, in the AOSPAN, each subject’s speed in calculating the operations is taken into account, such that fast calculators have less time to respond. It may possibly even be a disadvantage responding quickly as less time is given to rehearse letters seeing that traces may decay without active articulation in the phonological loop (Repovs & Baddeley, 2006) Secondly, the Addition Task consisted of very simple additions, adding a number between one and nine. Finally, the Dual N-Back task does not involve mathematics at all.

Another critique may be given to the removal of practice rounds from Dual N-Back on the last day, possibly leading to significantly worse performance, especially for the control group, as participants in that group were not as familiar with the task. Yet, performance of the control group on the Dual N-Back re-test was the least important analysis of the experiment for several reasons. First, the Name-Tag was an undemanding task and should not produce transfer to any of the other tasks. Second, the control group's performance on Dual N-Back on the first day should be a better indicator of AOSPAN and dual-task performance as they were not fatigued the first time they completed the task. A fatigue effect to a transfer task sharing the same executive component, and neural correlates, as a task performed prior to the transfer task has previously been demonstrated (Persson et al., 2007). Third, task specific gains for the experimental group would be expected to be much higher than any transfer gains on the other tasks. Consequently, Dual N-Back was chosen to be performed in the end for all subjects. The reason was to prioritize the avoidance of fatigue effects on the transfer tasks, especially as the task was well learned for the experimental group.

A final critique may be directed towards the amount of training, 20 min per day for five to six days. Many studies showing transfer of cognitive training have had participants training for weeks (Boot et al., 2008; Dahlin et al., 2008; Green & Bavelier, 2003; Hirst et al., 1980; Jaeggi et al., 2008; Olesen et al., 2004; Persson & Reuter-Lorenz, 2008; Spelke et al., 1976; Westerberg & Klingberg, 2007), but not even after prolonged practice does transfer necessarily occur (Boot et al., 2008; Owen et al., 2010). Nevertheless, training for five days or less has also led to significant improvements in performance on transfer tasks (Damos & Wickens, 1980; Kramer et al., 1995; Rueda et al., 2005). However, the study by Kramer et al.

(1995) may have transferred a strategy rather than training a specific component, and the study by Rueda et al. (2005) found transfer in children between ages four and six, the children possibly being more susceptible to training than adults. Future research should investigate exactly how long training is required to train specific executive components or functions in different populations.

Furthermore, Damos and Wickens (1980) claimed that a shift towards parallel processing was the cause of a transfer effect after merely one day of training. However, the present design does not allow settling debates over parallel processing. Such enquiries are better investigated by the use of the PRP paradigm (Pashler, 1994).

Future research should further investigate under what conditions successful transfer of training occurs. Why does training in some tasks transfer to other tasks, whereas others do not? Aspects like, neural correlates of transfer (Dahlin et al., 2008), the factor of strategy (Kramer et al., 1995), a shift in processing (Damos & Wickens, 1980), specific binding processes (Jaeggi et al., 2008), and executive attention (Kane & Engle, 2004) should be considered for better understanding of training and transfer effects. Interestingly, training of executive components and training of executive functions may differ in some respects. Executive component training can be relatively region-specific (Persson & Reuter-Lorenz, 2008), whereas executive functions may depend on the functional connectivity between regions. Consider Osaka et al. (2004), finding that activity in the PFC and ACC were closely linked temporally in high WMC subjects, whereas activity was less so for the low-span subjects. The researchers argued that this connectivity was the basis for a more efficient attentional control over WM.

To conclude, the present data suggest that training on a Dual N-Back task over a short five-day time-span proves rather task specific, not being transferred to the AOSPAN or the dual task. However, the study-design and the groups not performing equally in the pre-training session, make firm conclusions difficult. Significant correlations between the complex tasks indicate that a general cognitive ability predicts performance on these tasks. Moreover, as pre-training performance better predicted performance on the transfer task rather than did task-specific gains of training, the ability required for the Dual N-Back, the AOSPAN and the dual task is not easily trained in five days. However, the fact that groups differed in the pre-training session, but not on the transfer tasks may depend on an actual transfer effect from Dual N-Back training.

Acknowledgements

I would like to thank Joe Hardy, at Lumos Labs, for allowing me to use their online software for the home-practice sessions of the present study. I would also like to thank Jonas Persson, Department of Psychology, Stockholm University, for initial discussions on the topic. Finally, I would like to thank Randall Engle and Kenny Hicks, Attention and Working Memory Lab, Georgia Institute of Technology, for providing their Automated Operation Span Task.

References

Adcock, A., Constable, R. T., Gore, J. C., & Goldman-Rakic, P. S. (2000). Functional neuroanatomy of executive processes involved in dual-task performance. *Proceedings of the National Academy of Sciences of the United States of America*, *97*, 3567-3572. doi:10.1037/pnas.060588897

Adcock, R. A., Thangavel, A., Whitfield-Gabrieli, S., Knutson, B., & Gabrieli, J. D. E. (2006). Reward-motivated learning: Mesolimbic activation precedes memory formation. *Neuron*, *50,* 507-514. doi:10.1016/j.neuron.2006.03.036

Baddeley, A. (2000). The episodic buffer: a new component of working memory? *Trends in Cognitive Sciences*, *4*, 417-423. doi:10.1016/s1364-6613(00)01538-2

Ben-Shakhar, & G., Sheffer, L. (2001). The relationship between the ability to divide attention and standard measures of general cognitive abilities. *Intelligence*, *29*, 293-306. doi:10.1016/s0160-2896(00)00056-8

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

Boot, W. R., Kramer, A. F., Simons, D. J., Fabiani, M., & Gratton, G. (2008). The effects of video game playing on attention, memory, and executive control. *Acta Psychologica*, *129,* 387-398. doi:10.1016/j.actpsy.2008.09.005

Braver, T. S., Reynolds, J. R., & Donaldson, D. I. (2003). Neural mechanisms of transient and sustained cognitive control during task switching. *Neuron*, *39*, 713-726. doi:10.1016/S0896-6273(03)00466-5

Bunting, M. F., Conway, A. R. A., & Heitz, R. P. (2004). Individual differences in the fan effect and working memory capacity. *Journal of Memory and Language*, *51*, 604-622. doi:10.1016/j.jml.2004.07.007

Burgess, P. W., Veitch, E., de Lacy Costello, A., & Shallice, T. (2000) The cognitive and neuroanatomical correlates of multitasking. *Neuropsychologia*, *38*, 848-863. doi:10.1016/S0028-3932(99)00134-7

Collette, F., & Van der Linden, M. (2002). Brain imaging of the central executive component of working memory. *Neuroscience and Biobehavioral Reviews*, *26*, 105-125. doi:10.1016/S0149-7634(01)00063-X

D'Esposito, M., Detre, J. A., Alsop, D. C., Shin, R. K., Atlas, S., & Grossman, M. (1995). The neural basis of the central executive system of working memory. *Nature*, *378*, 279-281. doi:10.1038/378279a0

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

Damos, D. L., & Wickens, C. D. (1980). The identification and transfer of timesharing. *Acta Psychologica*, *46*, 15-39. doi:10.1016/0001-6918(80)90057-8

Donaldson, W. (1996). The role of decision processes in remembering and knowing. *Memory & Cognition*, *24*, 523-533. doi:10.3758/bf03200940

Dreher, J-C., Koechlin, E., Tierney, M., & Grafman, J. (2008) Damage to the fronto-polar cortex is associated with impaired multitasking. *Plos One*, *3*, e3227. doi:10.1371/journal.pone.0003227

Duckworth, A. L., Quinn, P. D., Lynam, D. R., Loeber, R., & Stouthamer-Loeber, M. (2011). Role of test motivation in intelligence testing. *Proceedings of the National Academy of Sciences of the United States of America*, *108*(19), 7716-7720. doi:10.1073/pnas.1018601108

Dux, P. E., Tombu, M. N., Harrison, S., Rogers, B. P., Tong, F., & Marois, R. (2009). Training improves multitasking performance by increasing the speed of information processing in human prefrontal cortex. *Neuron*, *63*, 127-138. doi:10.1016/j.neuron.2009.06.005

Engle, R. W., & Kane, M. J. (2004). Executive attention, working memory capacity, and a two-factor theory of cognitive control. In B. Ross (Ed.), *The psychology of learning and motivation: Vol. 44. Advances in Research and Theory* (pp. 145-199). San Diego, CA: Elsevier Academic Press

Engle, R. W., Tuholski, S. W., Laughlin, J. E., & Conway, A. R. A. (1999). Working memory, short-term memory, and general fluid intelligence: A latent-variable approach. *Journal of Experimental Psychology: General¸ 128*, 309-331. doi:10.1037/0096-3445.128.3.309

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

Haber, S. N., & Knutson, B. (2010). The reward circuit: Linking primate anatomy and human imaging. *Neuropsychopharmacology Reviews*, *35*, 4-26. doi:10.1038/npp.2009.129

Hazeltine, E., Teague, D., & Ivry, R. B. (2002). Simultaneous dual-task performance reveals parallel response selection after practice. *Journal of Experimental Psychology: Human Perception and Performance*, *28*, 527-545. Doi:10.1037//0096-1523.28.3.527

Hedden, T., & Yoon, C., (2006). Individual differences in executive processing predict susceptibility to interference in verbal working memory. *Neuropsychology, 20,* 511-528. doi:10.1037/0894-4105.20.5.511

Hirst, W., Spelke, E., Reaves, C. C., Caharack, G., & Neisser, U. (1980). Dividing attention without alternation or automaticity. *Journal of Experimental Psychology: General, 109,* 98-117. doi:10.1037/0096-3445.109.1.98

Jaeggi, S. M., Buschkuehl, M., Jonides, J., & Perrig, W. J. (2008). Improved fluid intelligence with training on working memory. *Proceedings of the National Academy of Sciences of the United States of America, 105,* 6829-6833. doi:10.1073/pnas.0801268105

Jimura, K., Locke, H. S., & Braver, T. S. (2009). Prefrontal cortex mediation of cognitive enhancement in rewarding motivational contexts. *Proceedings of the National Academy of Sciences of the United States of America*, *107,* 8871-8876. doi:10.1073/pnas.1002007107

Jonides, J., Lacey, S. C., & Nee, D. E. (2005). Processes of working memory in mind and brain. *Current Directions in Psychological Science*, *14,* 2-5. doi:10.1111/j.0963-7214.2005.00323.x

Just, M. A., Keller, T. A., & Cynkar, J. (2008). A decrease in brain activation associated with driving when listening to someone speak. *Brain Research*, *1205,* 70-80. doi:10.1016/j.brainres.2007.12.075

Kane, M. J., & Engle, R. W. (2003). Working-memory capacity and the control of attention: The contributions of goal neglect, response competition, and task set to stroop interference. *Journal of Experimental Psychology: General*, *132*, 47-70. doi:10.1037/0096-3445.132.1.47

Kim, C., Kroger, J. K., & Kim, J. (2011). A functional dissociation of conflict processing within anterior cingulate cortex. *Human Brain Mapping¸ 32*, 304-312. doi:10.1002/hbm.21020

Klingberg, T. (1998). Concurrent performance of two working memory tasks: Potential mechanisms of interference. *Cerebral Cortex, 8*, 593-601. doi:10.1093/cercor/8.7.593

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 & Adolescent Psychiatry, 44*, 177-186. doi:10.1097/00004583200502000-00010

Kramer, A. F., Larish, J. F., & Strayer D. L. (1995). Training for attentional control in dual task settings: A comparison of young and old adults. *Journal of Experimental Psychology: Applied, 1*, 50-76. doi:10.1037/1076-898x.1.1.50

Li, K. Z. H., Roudaia, E., Lussier, M., Bherer, L., Leroux, A., & McKinley, P. A. (2010). Benefits of cognitive dual-task training on balance performance in healthy older adults. *Journal of Gerontology: Series A Biological Sciences Medical Sciences, 65A*, 1344-1352. doi:10.1093/Gerona/glq151

Liu, Y., & Wickens, C. D. (1992). Visual scanning with or without spatial uncertainty and divided and selective attention. *Acta Psychologica*, *79*, 131-153. doi:10.1016/0001-6918(92)90029-D

McLeod, P. (1977). A dual task response modality effect: Support for multiprocessor models of attention. *The Quarterly Journal of Experimental Psychology*, *29*, 651-667. doi:10.1080/14640747708400639

McNab, F., & Klingberg, T. (2008). Prefrontal cortex and basal ganglia control access to working memory. *Nature Neuroscience*, *11*, 103-107. doi:10.1038/nn2024

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

Murayama, K., & Kuhbandner, C. (2011). Money enhances memory consolidation – but only for boring material. *Cognition*, *119*, 120-124. doi:10.1016/j.cognition.2011.01.001

Oberauer, K., & Kliegl, R. (2004). Simultaneous cognitive operations in working memory after dual-task practice. *Journal of Experimental Psychology: Human Perception and Performance*, *30*, 689-707. doi:10.1037/0096-1523.30.4.689

Olesen, P. J., Westerberg, H., & Klingberg, T., (2004). Increased prefrontal and parietal activity after training of working memory. *Nature Neuroscience*, *7*, 75-79. doi:10.1038/nn1165

Osaka, N., Osaka, M., Kondo, H., Morishita, M., Fukuyama, H., & Shibasaki, H. (2004). The neural basis of executive function in working memory: An fMRI study based on individual differences. *Neuroimage*¸ *21*, 623-631. doi:10.1016/j.neuroimage.2003.09.069.

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

Pashler, H. (1994) Dual-task interference in simple tasks: Data and theory. *Psychological Bulletin, 116,* 220-244. doi:10.1037//0033-2909.116.2.220

Pashler, H., Johnston, J. C., & Ruthruff, E. (2001). Attention and performance. *Annual Review of Psychology, 52*, 629-651. doi:10.1146/annurev.psych.52.1.629

Persson, J., & Reuter-Lorenz, P. A. (2008). Gaining control: Training executive function and far transfer of the ability to resolve interference. *Psychological Science, 19,* 881-888. doi:10.1111/j.1467-9280.2008.02172.x

Persson, J., Welsh, K. M., Jonides, J., & Reuter-Lorenz, P. A. (2007). Cognitive fatigue of executive processes: Interaction between interference resolution tasks. *Neuropsychologia, 45*, 1571-1579. doi:10.1016/j.neuropsychologia.2006.12.007

Raz, A., & Buhle, J. (2006). Typologies of attentional networks. *Nature Reviews Neuroscience, 7,* 367-379. doi:10.1038/nrn1903

Repovs, G., & Baddeley, A. (2006). The multi-component model of working memory: Explorations in experimental cognitive psychology. *Neuroscience, 139,* 5-21. doi:10.1016/j.neuroscience.2005.12.061

Rossi, A. F., Pessoa, L., Desimone, R., & Ungerleider, L. G. (2009). The prefrontal cortex and the executive control of attention. *Experimental Brain Research, 192,* 489-497. doi:10.1007/s00221-008-1642-z

Rueda, M. R., Rothbart, M. K., McCandliss, B. D., Saccomanno, L., & Posner, M. I. (2005). Training, maturation, and genetic influences on the development of executive attention. *Proceedings of the National Academy of Sciences of the United States of America, 102,* 14931-14936. doi:10.1073/pnas.0506897102

Ruthruff, E., Van Selst, M., Johnston, J. C., & Remington, R. (2006). How does practice reduce dual-task interference: Integration, automatization, or just stage-shortening? *Psychological Research, 70,* 125-142. doi:10.1007/s00426-004-0192-7

Slagter, H. A., Davidson, R. J., & Lutz, A. (2011). Mental training as a tool in the neuroscientific study of brain and cognitive plasticity. *Frontiers in Human Neuroscience*¸ *5,* 1-12. doi:10.3389/fnhum.2011.00017.

Smith, E. E., & Jonides, J., (1999). Storage and executive processes in the frontal lobes. *Science, 283,* 1657-1661. doi:10.1126/science.283.5408.1657

Spelke, E., Hirst, W., & Neisser, U. (1976). Skills of divided attention. *Cognition, 4,* 215-230. doi:10.1016/0010-0277(76)90018-4

Szameitat, A. J., Schubert, T., Müller, K., & Von Cramon, Y. D. (2002). Localization of executive functions in dual-task performance with fMRI. *Journal of Cognitive Neuroscience, 14,* 1184-1199. doi:10.1162/089892902760807195

Thoma, P., Koch, B., Heyder, K., Schwarz, M., & Daum, I. (2008) Subcortical contributions to multitasking and response inhibition. *Behavioural Brain Research, 194,* 214-222. doi:10.1016/j.bbr.2008.07.016

Unsworth, N., Heitz, R. P., Schrock, J. C., & Engle, R.W. (2005). An automated version of the operation span task. *Behavior Research Methods, 37,* 498-505. doi:10.3758/bf03192720

Vogel, E. K., McCollough, A. W., & Machizawa, M. G. (2005). Neural measures reveal individual differences in controlling access to working memory. *Nature*, *438*, 500-503. doi:10.1038/nature04171

West, R., & Alain, C. (1999). Event-related neural activity associated with the Stroop task. *Cognitive Brain Research*, *8*, 157-164. doi:10.1016/S0926-6410(99)00017-8

West, R., & Alain, C. (2000). Evidence for the transient nature of a neural system supporting goal-directed action. *Cerebral Cortex*, *10*, 748-752 . doi:10.1093/cercor/10.8.748

Westerberg, H., & Klingberg, T. (2007). Changes in cortical activity after training of working memory – a single-subject analysis. *Physiology & Behavior, 92,* 186-192. doi:10.1016/j.physbeh.2007.05.041

Wickens, C. D. (1980). The structure of attentional resources. In R. S. Nickerson (Ed.), *Attention and Performance VIII* (pp. 239-257). Hillsdale, NJ: Lawrence Erlbaum Associates, Inc.

Wickens, C. D. (2002). Multiple resources and performance prediction. *Theoretical Issues in Ergonomics Science*, *3*, 159-177. doi:10.1080/14639220210123806

Wickens, C. D. (2008). Multiple resources and mental workload. *Human Factors, 50,* 449-455. doi:10.1518/001872008X288394

Wu, T., & Hallet, M. (2008). Neural correlates of dual task performance in patients with parkinson’s disease. *Journal of Neurology, Neurosurgery & Psychiatry*, *79*, 760-766. doi:10.1136/jnnp.2007.126599