Age-related differences in Cognitive Plasticity of Executive Control Mechanisms: Exploring Transfer Effects Following iPad-based Dual-Task and N-Back Training

Ramzi Houdeib

A Thesis
in
The Department
of
Psychology

Presented in Partial Fulfillment of the Requirements
for the Degree of Master of Arts (Psychology) at
Concordia University
Montreal, Quebec, Canada

August 2018

CONCORDIA UNIVERSITY
School of Graduate Studies

This is to certify that the thesis prepared

By: Ramzi Houdeib

Entitled: Age-Related Differences in Cognitive Plasticity of Executive Control Mechanisms: Exploring Transfer Effects Following iPad-based Dual-Task and N-Back Training

and submitted in partial fulfillment of the requirements for the degree of

Master of Arts (Psychology)

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Signed by the final Examining Committee:

______________________________Chair
Dr. Andreas Arvanitogiannis

______________________________Examiner
Dr. Karen Li

______________________________Examiner
Dr. Natalie Phillips

______________________________Supervisor
Dr. Louis Bherer

Approved by ____
Dr. Andreas Arvanitogiannis

_____________2018

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André Roy, Dean of Faculty

ABSTRACT

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Ramzi Houdeib

Recent literature suggests that executive function (EF) is not a unitary construct but one that involves many executive control mechanisms (ECM), such as updating and divided attention. Some posit that cognitive training helps improve EF in younger (YA) and older (OA) adults, but transfer effects, which refer to improvements in an untrained task, remain somewhat limited. This study examined the age-related differences in transfer effects following cognitive training of ECM by comparing two training paradigms designed to involved distinct ECM.

Thirty-three YA and 42 OA were randomly assigned to a n-back (NB) or dual-task (DT) training group for three weeks. Pre/post-training assessment involved the trained task and their respective transfer tasks. Age was used as a between-subject factor, while session (pre/post) and task condition (low, medium, high load), as within-subjects factors.

Both training groups improved on their respective trained tasks and transfer task involving the same ECM (near-transfer). Transfer effects were also observed in a transfer task involving a different ECM (far-transfer). The DT group improved in the DT-transfer and one of the two NB tasks. The NB group improved in the NB-transfer and both DT tasks. Age-related differences in transfer were observed for the DT group, with the dual-task cost and 3-back accuracy of YA improving on the DT-transfer task and N-back task respectively, while OA only improved on the 1-back and 2-back.

Overall, the results suggest that OA and YA benefited from ECM training and that these benefits generalized to untrained tasks tapping the same and other ECM.

Acknowledgements

I would like to take this opportunity to thank people without whom this thesis would not have been possible. First and foremost, I want to thank and express my appreciation to Dr. Louis Bherer for his guidance and mentorship during my Master thesis. Without his valuable insight and comments, this work would not have been completed. He is an outstanding professor, an immense source of knowledge, and an exemplary model of hard work that I admire.

I am also indebted to Dr. Manon Maheux, who has supported me throughout the project and helped me tackle this colossal project. I can’t thank her enough for her immense patience, understanding, and constant support throughout the thesis.

I need to thank Kathia Saillant for all her help during recruitment and testing of participants. As well as her aid in data entry once the project was done.

I would like to thank Dr Maxime Lussier for his constant support and insight regarding the tasks used in this project. His feedback and ideas helped me grasp concepts I was struggling with.

I would also like to thank my committee members, Dr. Natalie Philips and Dr. Karen Li for accepting to evaluate this thesis.

Finally, I would like to thank all the members of the LESCA lab, especially Dr Laurence Desjardins-Crépeau, who have supported me during my project by attending my presentations and the feedback they provided. It truly is a spectacular lab, filled with members who intellectually challenge each other, work hard, and are some of the nicest and genuine people I’ve met.

Contribution of Authors

Dr. Louis Bherer designed the main project and supervised all the steps in the preparation of the study and thesis. My role in the project involved recruiting, testing and training participants, as well as data entry, the statistical analyses and writing the paper. Co-author Dr Manon Maheux coordinated each cohort of the project and was involved in the testing and training of the participants, as well as many administrative aspects such as room booking and ensuring the tasks were functional and appropriate for the study. Furthermore, she provided crucial feedback on the paper and the statistical analyses. Co-author Kathia Saillant helped during the testing of participants and data entry. Co-author Dr Maxime Lussier created the tasks used in the project and modified them to fit our project. He was also readily available to help with theoretical aspects of the project. This project was supported by a Discovery grant from The Natural Sciences and Engineering Research Council of Canada (NSERC).

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General Introduction

According to Statistics-Canada (2017), the number of seniors aged 65 and over surpasses children aged 14 and younger. It is also estimated that by 2036, seniors will account for close to 25% of the total population (Statistic-Canada, 2017). However, an increased life expectancy does not necessarily translate to a better quality of life due to age-related deficiencies, such as cognitive decline. It has been reported that the average per-person government spending on health care for Canadians above 65 years old is more than four times greater than their younger counterparts (Jackson, Clemens, & Palacios, 2017). The increasingly aging population means a substantial increase in cost, not only in terms of health care but resources and support programs as well (Jackson et al., 2017). The fiscal outcomes, while worrying, are not necessarily inevitable if proactive steps, such as interventions, are taken. One area that has been receiving much renewed interest in the past years is age-related cognitive decline in older adults (OA). Although the extent of the decline varies by individuals, age-associated symptoms often include slower inductive reasoning, gradual impairments in spatial orientation, perceptual speed, numeric ability, and verbal memory (Hedden & Gabrieli, 2004). Interestingly, few changes and in some cases, increases in performance are seen in verbal ability (Hedden & Gabrieli, 2004). These changes have profound implications on a person's functional capacities, which include activities of daily living (i.e., walking, bathing, eating, etc) and instrumental activities of daily living (IADL), such as housekeeping, food preparation, and others (Canada Institute for Health Information, 2011).

These activities have made the study of executive functions the focus of much research due to their importance and observable age-related changes (Miyake & Friedman, 2012). Executive function (EF) is an umbrella term used to refer to a set of cognitive processes (Elliott, 2003). Previous literature has identified inhibition, the ability to suppress an automatic response, working memory, and cognitive flexibility (also known as set shifting) as three core EFs (Diamond, 2013). The first, inhibition, is broken down into multiple processes. Cognitive inhibition refers to our ability to resist unwanted thoughts and memories, selective attention is our ability to stay focused on a specific task, and self-control is our ability to delay gratification (Diamond, 2013). Interference control, which is ignoring interfering stimuli when focused on a task, is due to a combination of cognitive inhibition and selective attention (Diamond, 2013). The second core EF, working memory, combined mechanisms of verbal and spatial working memory, as well as updating (Diamond, 2013). The latter is used to add or subtract information held in working memory depending on the task at hand (Miyake et al., 2000). The final core EF, cognitive flexibility, allows us to change our perspective, think outside the box, take advantage of serendipitous events and set shifting, which is sometimes called switching, such as switching between task instruction in a modified Stroop task (Desjardins-Crépeau et al., 2016; Diamond, 2013). These core EFs are the basis for higher order EFs, such as planning, problem solving, reasoning, goal selection, and others (Diamond, 2013; Jurado & Rosselli, 2007). With all the core and higher order EFs, researchers started questioning whether there is one underlying ability that could explain these processes or whether they were simply related but distinct (Miyake et al., 2000).

Researchers who believe in the notion of a unifying, single process that constitutes the basis for accurate performances on EF tasks have posited many potential common factors (Barkley, 1997; Friedman & Miyake, 2017). Early on, Baddeley's model of working memory seemed to include a unitary construct of EF, the central executive (Baddeley, 1986; Baddeley, 2000). Being the component underlying many cognitive functions (Reed, 2011), such as selecting strategies, integration of information, inhibition, selective attention and more, the central executive was hypothesized to be the underlying factor (McCabe, Roediger, McDaniel, Balota, & Hambrick, 2010). Many experiments have demonstrated this construct's involvement in different aspects of executive control across varying populations (Baddeley, 2000; Morris & Jones, 1990; Sebastian, Menor, & Elosua, 2006). Others have found supporting evidence for the unitary view amongst children with attention deficit hyperactivity disorder, wherein inhibition was hypothesized to be the common factor underlying working memory, self-regulation, reconstruction and internalization of speech (Barkley, 1997). Critics of the unity hypothesis have highlighted a low intercorrelation among a variety of executive tasks (Duncan, Johnson, Swale, & Freer, 1997; Friedman & Miyake, 2017) indicating that separate executive mechanisms may be involved. Neuropsychological assessments, using the Wisconsin Card Sorting Task and the Tower of Hanoi, have shown a dissociation in performances of patients that appeared to be impaired on one of the tests, suggesting distinct EF components (Miyake et al., 2000). Miyake and colleagues (2000) posited that despite these distinguishable aspects of EFs, they still share some commonality, resulting in their proposed Unity/Diversity framework. An issue they identified was the difficulty in measuring EFs given that the used tasks consistently revealed systematic variance that was attributed to non-executive processes (Miyake et al., 2000). As a result, a latent variable approach using confirmatory factor analysis was adopted whereby tasks that target a specific EF ability were selected a priori based on previous findings (Miyake et al., 2000). The Unity/Diversity framework was then evaluated by extracting the amount of shared variance across the chosen EF tasks. They found that each latent variable of shifting, updating and inhibition are correlated with each other (unified) but given that those correlations are not perfect, they must also be separable via some diversity factor (Miyake et al., 2000). In a later model, the Unity/Diversity framework was modified to include a common EF factor loading on all EF abilities, as well as separate shifting- and updating-specific factors (Miyake & Friedman, 2012). Once the common EF factor was accounted for, there was no unique variance left for inhibition, hence the lack of an inhibition-specific factor (Miyake & Friedman, 2012). While it may be tempting to propose that inhibitory control is the common EF factor, Miyake and Friedman (2012) reasoned that such an assumption would be combining processes that are both conceptually and empirically discrete. Instead, they speculate that the common EF factor involves frontal lobe areas monitoring competing information that will, on one hand, lead to correct responses and, on the other hand, lead to incorrect responses (Miyake & Friedman, 2012). This process is believed to be done via local lateral inhibition, wherein excited neurons reduce the activity of neighboring neuronal cells (Miyake & Friedman, 2012). This competition gives rise to the emergence of the inhibition of irrelevant stimuli, responses, and other mechanisms (Miyake & Friedman, 2012). An additional observation further suggesting that EF are supported by distinct mechanisms is the differential pattern of developmental changes and age-related impairments. For instance, the inhibition ability is not always reduced in normal aging (Kramer, Humphrey, Larish, Logan, & Strayer, 1994), while switching almost always is (Wasylyshyn, Verhaeghen, & Sliwinski, 2011). There has been a lot of research, since Miyake and his colleagues (2000) presented the Unity/Diversity framework, which corroborates this hypothesis in numerous populations like children (Duan, Wei, Wang, & Shi, 2010), adolescents (Rose, Feldman, & Jankowski, 2011), healthy adults (Friedman et al., 2006), and older adults (Vaughan & Giovanello, 2010).

Additionally, there is a vast amount of supporting neuroimaging evidence for the Unity/Diversity framework. The important mediating role of the prefrontal cortex (PFC) for EFs has been the focal point of much research due to the fact that it is connected to more brain regions than any other cortical region, it is a major neocortical target of the basal ganglia-thalamocortical circuits and it acts on already processed information (Royall et al., 2002). Despite the integral role (implying unity) of the frontal cortices, subcortical and regions outside the frontal lobes have been found to affect EF directly or indirectly as well, inferring diversity (Collette, Hogge, Salmon, & Van der Linden, 2006; Royall et al., 2002). Collette and colleagues (2006) reported activity in the superior and posterior parietal cortex in addition to the prefrontal dorsolateral cortex and inferior frontal cortex when participants performed tasks associated with updating. Also, shifting was associated with activation in parietal and occipital regions and inhibitory processes with parietal and temporal areas (Collette et al., 2006). Studies have also found distinct activation patterns within the frontal cortices, which further supports the notion of non-unity. Previous research found that reduced grey matter volume in the ventromedial PFC, dorsolateral PFC and right ventrolateral PFC were associated with better performance on the common EF, updating-specific and shifting-specific factors, respectively (Smolker, Depue, Reineberg, Orr, & Banich, 2015). Interestingly, some report the neural basis of the common EF factor to be the left ventrolateral PFC (Tsuchida & Fellows, 2012). Furthermore, increased fractional anisotropy in the superior longitudinal fasciculus and the inferior fronto-occipital fasciculus were associated with better performance on the common EF and shifting-specific factors (Smolker et al., 2015). Looking at neural activation patterns in the PFC of older and younger adults (YA), inhibition and switching were associated with different activation patterns, supporting the view that these ECM are distinct cognitive processes (Laguë-Beauvais, Brunet, Gagnon, Lesage, & Bherer, 2013). Laguë-Beauvais et al. (2013) found that the switching mechanism in older adults (OA) induced wider bilateral activation in the anterior dorsolateral prefrontal cortex (DLPFC) and the ventrolateral prefrontal cortex (VLPFC). While OA had a wider bilateral activation, YA also showed a bilateral anterior VLPFC and DLPFC activation, but with the left side being the most prevalent (Laguë-Beauvais et al., 2013). For inhibition, OA recruited the posterior left and the right anterior DLPFC, as well as the bilateral VLPFC, whereas YA did not reveal significant neural activity in the PFC (Laguë-Beauvais et al., 2013). Overall, the neuroimaging evidence seems to point to distinct and overlapping activation patterns for ECM, which supports a combined unifying and diversifying view of EF.

Recently, it has been suggested that there seemed to be a shift in localization as individuals age (Cabeza, 2002; Reuter-Lorenz & Park, 2010). Numerous neuroimaging findings seem to point to age differences in brain activity on cognitive tasks targeting working memory (Cappell, Gmeindl, & Reuter-Lorenz, 2010; Saliasi, Geerligs, Lorist, & Maurits, 2014), inhibition (Grady, 2012), face recognition (Grady, 2012) and on the cognitive load of these tasks. Of the many proposed hypotheses to account for these age differences in neural activation, the compensation hypothesis posits that overactive regions in older adults' brains are using more resources than comparable sites in younger adults' brains to maintain a high performance on a task (Reuter-Lorenz & Cappell, 2008). To further explain these compensation mechanisms, Cabeza (2002), who had erstwhile observed such age-related hemispheric alterations, described the phenomenon he called the *Hemispheric asymmetry reduction in older adults* (HAROLD). Such occurrences were hypothesized to be the result of changes in the global and regional neurocognitive networks to compensate for age-related deficits (Cabeza, 2002). Reuter-Lorenz and Cappell (2008) explain that an underactivation pattern is often interpreted as impairment, but if the activation that occurs in one hemisphere in younger adults (YA) is occurring in both hemispheres for OA, this pattern should be understood as an overactivation. When performance is considered, an overactivation with inferior performance on a task is typically interpreted as impairment. In contrast, an overactivation with better performance may be indicative of a compensatory mechanism (Heinzel et al., 2014; Reuter-Lorenz & Cappell, 2008). To account for patterns of underactivation and overactivation in OA, the *compensation-related utilization of neural circuits hypothesis* (CRUNCH) was introduced (Reuter-Lorenz & Cappell, 2008). According to the CRUNCH, OA will recruit more cognitive resources compared to YA at lower levels of cognitive load (Reuter-Lorenz & Cappell, 2008). Using a verbal working memory task with varying difficulties, previous research has reported that more activation was seen at lower task difficulties for OA than for YA (Mattay et al., 2006). The CRUNCH suggests that younger and older adults' performances are equivalent at a low cognitive load, with OA showing increased neural activation (Grady, 2012). This illustrates a form of compensation by the older group to match the performances of their younger counterparts (Grady, 2012). At a medium cognitive load, age-equivalent performances are observed with an increase in neural activity in both age groups. Specifically, OA have more neural activity than the YA (Grady, 2012). Finally, from the medium to high cognitive load, the CRUNCH suggests that the depleted neural resources caused by the first two loads would result in a considerable decrease in performance for the OA as well as a plateau in neural activity, presumably due to the depleted cognitive resources. Whereas YA will show an increase in their neural activation accompanied by a smaller decrease in performance with task difficulty than the decrease observed in OA (Grady, 2012). While these models offer an explanatory framework to account for age-related changes in cognitive performances and associated brain activation patterns, no study so far have investigated if these models can also help explain effects of cognitive training and remediation in older adults.

A recent position paper from the national academies of sciences, engineering and medicine, placed high priority on cognitive training (Leshner, Landis, Stroud, & Downey, 2017). The many benefits of such an intervention, usually done using computer-based training software or commercialized packages (Leshner et al., 2017), can help elucidate theoretical and practical hurdles. Cognitive training can give insight into how the brain adapts its compensatory mechanisms, it can help us dissociate the different executive control mechanisms (ECM) such as updating, divided attention, switching and others by reducing intra-individual variability and specifying age-related differences in performance, and it can potentially help stave off cognitive decline (Leshner et al., 2017). During cognitive training, it is believed that participants are repeatedly activating neural regions associated with the training task, which therefore enhances the trained ECM (Maraver, Bajo, & Gomez-Ariza, 2016). There is evidence that dual-tasking (Bherer et al., 2005; Erickson et al., 2007; Lussier, Gagnon, & Bherer, 2012), updating (Dahlin, Neely, Larsson, Backman, & Nyberg, 2008b; Jaeggi, Buschkuehl, Jonides, & Shah, 2011; Salminen, Frensch, Strobach, & Schubert, 2016), and inhibition (Maraver et al., 2016; Spierer, Chavan, & Manuel, 2013) have all benefited from cognitive training. Previous research has effectively shown that, whether age groups are compared (Lussier et al., 2012) or individualized (Kundu, Sutterer, Emrich, & Postle, 2013; Salminen et al., 2016), both YA and OA improve on their trained tasks, suggesting that individual ECM can be trained.

A highly sought after characteristic of cognitive training studies is the transfer of trained abilities (Schubert, Strobach, & Karbach, 2014). The idea of training effects that lead to an enhanced neural region would generalize and transfer to untrained tasks that target the same ECM, a phenomenon referred to as near-transfer (Bigorra, Garolera, Guijarro, & Hervas, 2016; Borella et al., 2014; Karbach & Verhaeghen, 2014; Li et al., 2008; Thorell, Lindqvist, Bergman

Nutley, Bohlin, & Klingberg, 2009). In contrast, far-transfer effects are said to occur if the training effects lead to improvement in an untrained task that targets a separate ECM (Bherer et al., 2005; Borella et al., 2014; Borella, Carretti, Riboldi, & De Beni, 2010; Jaeggi, Buschkuehl, Jonides, & Perrig, 2008; Lussier, Brouillard, & Bherer, 2015) as long as they share comparable neural circuits (Maraver et al., 2016). Far-transfer effects are particularly important because they could entail improvements in day-to-day activities that impact both younger and older adults (Lussier et al., 2015). While the evidence for near-transfer effects is clear, many studies show far-transfer effects to be very limited or questionable (Melby-Lervåg, Redick, & Hulme, 2016; Spierer et al., 2013; Thorell et al., 2009). A recent paper by Sala and Gobet (2017) went so far as to suggest that the scarcity of positive far-transfer effects in the literature should be grounds for policymakers to halt resource spending on the topic. The overarching argument being that domain-specific training of dissociated mechanisms should not be expected to generalize to other untrained mechanisms (Sala & Gobet, 2017). However, other studies are more optimistic by showing not only large near-transfer effects, but significant, albeit smaller, far-transfer effects (Karbach & Verhaeghen, 2014). Another important consideration is the length of training and the number of sessions participants undergo. While there is a lot of variability amongst studies, most seem to opt for the training session to last between 45 and 60 min (Ballesteros, Kraft, Santana, & Tziraki, 2015). The few studies whose sessions are 30 min or less appear to compensate with many more sessions performed by the participants (Ballesteros et al., 2015). When investigating the length of time participants are trained in the intervention, previous research has shown significant effects following as little as 3 weeks, 5 weeks and 12 weeks (Ballesteros et al., 2015).

To our knowledge, studies looking at transfer between ECM are scarce, therefore, this project trained OA and YA on an updating or a divided attention task to explore these effect, as well as transfer effects within ECM and associated age differences.

Article

Age-related Differences in Cognitive Plasticity of Executive Control Mechanisms: Transfer Effects Following Dual-Task and N-Back Training

Ramzi Houdeib[1,2], Manon Maheux[1,2], Kathia Saillant[2,3], Maxime Lussier[2] & Louis Bherer[2,3,4]
[1] Psychology Department and PERFORM Center, Concordia University, Montréal, Canada
[2] Centre de recherche de l'Institut universitaire de gériatrie de Montréal (CRIUGM) Montréal, Canada
[3] Department of Medicine, University of Montreal, Montréal, Canada
[4] Preventive Medicine and Physical Activity Center and Research Center, Montreal Heart Institute, Montreal, Canada

Corresponding author:
Ramzi Houdeib
Centre de recherche de l'Institut universitaire de gériatrie de Montréal (CRIUGM),
4545, Queen-Mary road, Montreal, QC, Canada, H3W 1W5
Tel +1 514 340 3540 ext 4148
Email: ramzi.houdeib@gmail.com

It has often been reported that aging is associated with a decline in performance on multiple cognitive domains, including executive functions (EFs), memory and processing speeds (Dahlin et al., 2008b; Verhaeghen & Cerella, 2002). Studies suggest that a decrease in processing speed and task switching can be associated with impaired activities of daily living (Cahn-Weiner, Malloy, Boyle, Marran, & Salloway, 2000; Noelker & Browdie, 2014; Vaughan & Giovanello, 2010). With the ubiquity of age-related cognitive decline and their importance in daily life, there has been a renewed interest in the development of intervention strategies designed to improve executive function (EF) performances to stave off early cognitive impairment. Developing specific cognitive training protocols, exploring the possible transfer of trained abilities to untrained tasks, how these EF mechanisms are dissociated, and how they are modified following cognitive training (Lussier et al., 2012; Tsuchida & Fellows, 2012; Turner & Spreng, 2012) have been the subjects of continuous research (Belleville & Bherer, 2012; Leshner et al., 2017; Simons et al., 2016).

One important question is whether a single underlying ability can explain all the components of executive functioning or whether these components are supported by distinct processes that are related in some way. Proponents of the theory of unity suggest that a single factor is the basis for accurate performances on EFs. Fluid intelligence (Duncan, 2010), working memory (Kimberg & Farah, 1993), and behavioral inhibition (Barkley, 1997) are some of the proposed common factors underlying the unifying mechanism responsible for performances on EF tasks. Conversely, some researchers support a theory of diversity, according to which performances in EF tasks would be supported by multiple mechanisms. Low intercorrelation among various executive tasks is hypothesized to be due to different types of executive abilities instead of a unitary process (Friedman & Miyake, 2017). In a study by Miyake and his colleagues (2000), the core EFs of shifting, updating and inhibition were found to be substantially correlated with each other, indicating a possible common unifying factor. Importantly, these correlations were far from perfect (< 1.0), which may indicate that distinct mechanisms come into play (Miyake et al., 2000). The Unity/Diversity framework was proposed whereby the three core EFs were mediated by three factors; updating-specific, shifting-specific and a common EF (Miyake & Friedman, 2012). The heterogeneity of these mechanisms (i.e. the specific components) was further supported by the findings of separate developmental patterns, indicative of age-related differences in executive control tasks (Fraser & Bherer, 2013). Furthermore, functional brain imaging studies, using functional near-infrared spectroscopy (fNIRS), revealed that age-related differences in brain activation patterns are associated with specific ECM (Laguë-Beauvais et al., 2013). Using a computerized version of the modified Stroop task and a switching task, wherein participants were asked to read the word or name its color according to the given instruction, distinct brain activation patterns in the frontal lobes were associated to different mechanisms. Comparing older and younger adults (YA), Laguë-Beauvais et al. (2013) found that switching older adults (OA) induced bilateral activation in the anterior dorsolateral prefrontal cortex (DLPFC) and the ventrolateral prefrontal cortex (VLPFC). While OA had a wider bilateral activation, YA also showed a bilateral anterior VLPFC and DLPFC activation, but with the left side being the most prevalent (Laguë-Beauvais et al., 2013). For inhibition, OA recruited the posterior left and the right anterior DLPFC, as well as the bilateral VLPFC, whereas YA did not reveal significant neural activity in the PFC (Laguë-Beauvais et al., 2013). Other studies in neurocognitive aging also report distinct patterns of brain activity between OA and YA. A meta-analysis by Turner and Spreng (2012) explored these patterns by examining working memory and inhibition. Results showed that OA had increased activation in the bilateral DLPFC, supplementary motor cortex and left inferior parietal lobule for working memory, while inhibitory control activates the right inferior frontal gyrus and presupplementary motor area (Turner & Spreng, 2012). In contrast, activation patterns for the working memory in YA was seen in the left lateral PFC, right DLPFC, and bilateral parietal regions, while inhibitory control was associated with activity in the right anterior insula, bilateral DLPFC, and posterior parietal regions (Turner & Spreng, 2012). Overall, the neuroimaging evidence seems to point to distinct and overlapping activation patterns for ECM, which supports a combined unifying and diversifying view of EF.

A census report by the national academies of sciences, engineering and medicine, placed high priority on cognitive training to stave off cognitive impairment (Leshner, Landis, Stroud, & Downey, 2017). This type of training is usually done using computer-based training software or commercialized packages (Leshner et al., 2017). There has also been evidence that dual-tasking (Bherer et al., 2005; Erickson et al., 2007; Lussier et al., 2012) and updating (Dahlin et al., 2008b; Jaeggi et al., 2011; Salminen et al., 2016) have both benefited from cognitive training. Dahlin and colleagues (2008) trained younger and older adults on various tasks targeting the ECM of updating. After five weeks of training, both age groups improved significantly more than their control counterparts, and, at the 18-month follow up, they maintained a similar performance (Dahlin, Nyberg, Backman, & Neely, 2008). Studies done exclusively with OA show the same pattern as well. Stepankova and colleagues (2014) assigned OA to a n-back (NB) training program that consisted of either 10 or 20 sessions over a month. Both groups outperformed the control group with participants who received 20 sessions obtaining significantly better results than those with 10 sessions. Salminen and colleagues (2016) divided OA into two training groups; auditory and visual NB training. They found that both groups benefited from their cognitive training when compared to the performance of YA in the literature (Salminen et al., 2016). Kundu and colleagues (2013) demonstrated the positive improvements for YA following five weeks of cognitive training on a visuospatial dual NB task. Whether age groups are compared (Lussier et al., 2012) or individualized (Kundu et al., 2013; Salminen et al., 2016), both YA and OA improve on their trained tasks, suggesting that individual ECM can be trained.

What seems to be a more important debate is to what extent training effects generalize to untrained tasks, the so-called transfer effects. To better define and reconcile the many findings of these phenomena, Barnett and Ceci (2002) proposed a taxonomy in which transfer effects were classified as near and far. They identified two main dimensions of transfer; content, which refers to what is being transferred, and context, which is further subdivided into multiple descriptors to better define the distance between the trained and transferred abilities. The physical context relates to the location of the training and testing (i.e., laboratory, home). Most studies usually keep the physical context unchanged. The temporal context refers to the time between the training and the testing, such that transfer effects observed immediately after training are described as temporally near, while those done one or more months later, are temporally far (Zelinski, 2009). The functional context describes the function for which “the skill is positioned and the mind-set it induces” (Barnett & Ceci, 2002). In other words, training a specific skill for a given function may not transfer to another function since the trained ability is fixed on its original purpose (Barnett & Ceci, 2002). For example, a study where transfer effects to task switching, working memory, visual short-term memory, and reasoning are measured following training on video games would consist of functionally far transfer effects (Zelinski, 2009). The social context refers to whether the ability was acquired individually or collaboratively (Barnett

& Ceci, 2002). Finally, the last dimension mentioned by Barnett and Ceci (2002) is modality, which refers to the sensory modality used to test transfer effects. For example, if an individual's performance increases on an untrained task that has the same stimulus and response modalities as the trained task but with different stimuli, then near-transfer effects are said to have occurred. This effect has also been referred to as within-modality transfer in some studies (Bherer et al., 2005). In contrast, a performance increase on an untrained task that has different stimulus modalities (i.e., visual to auditory) and/or response modalities (i.e., manual tapping to foot tapping) to the trained task (Lussier et al., 2012), would be considered a modality far-transfer. This concept is sometimes referred to as cross-modality transfer in some studies (Bherer et al., 2005). In the context of cognitive training, it has been posited that transfer effects may be enhanced if the training paradigm targets ECM instead of specific strategies or basic processing commodities (Lussier et al., 2015; Lustig, Shah, Seidler, & Reuter-Lorenz, 2009). While age-related effects on the dual-task (DT) seem to be more pronounced when both the training and transfer tasks share input and output modalities (Lussier et al., 2012), few studies have investigated the potential transfer among the ECM. In this scenario, a transfer task utilizing the same underlying ECM as the trained task but with varying stimuli could be considered as a near-transfer task, while a task tapping into a different ECM could be one of far-transfer. Within the Unity/Diversity framework proposed by Miyake and Friedman (2012), should one expect transfer to occur if transfer tasks are using a different mechanism? In terms of near-transfer effects, or within-mechanism transfer, it can be argued that such effects are to be expected given that the same underlying mechanism of each task is trained. In contrast, far-transfer effects, or cross-mechanism transfer, could be present due to the common EF factor, albeit limited. Indeed, limited far-transfer effects compared to their more robust near-transfer counterparts, have been observed following cognitive training (Karbach & Verhaeghen, 2014). Crucially, the complex nature of the taxonomy suggests that transfer effects are inherently contextual, hence the recommendation by Barnett and Ceci (2002) to specify whether the transfer task is near or far along each dimension. The training and transfer effects that arise from cognitive training could be used as another way to gain insight into how the brain adapts to new situations and helps us dissociate the different ECM by reducing intra-individual variability and specifying age-related differences in performance. In fact, findings that show transfer effects to be limited to untrained tasks tapping the same ECM suggest that cognitive training could be used to specify the behavioural patterns associated with ECM (Lussier et al., 2012). However, if results do not show transfer effects among ECM, then this may suggest that the training effects are specific, which would gain support to the notion that ECM are dissociated and partially independent attentional control mechanisms.

Transfer effects have been a contentious area of research with studies finding mixed results for their existence. Following 20 sessions of dual NB training where auditory letter and visual shapes were simultaneously presented, Thompson and colleagues (2013) found significant training effects. However, when investigating near-transfer effects on various working memory tasks and far-transfer effects on tasks of standardized intelligence, reading comprehension and speed of processing, no significant transfer effects were found. Conversely, Li and colleagues (2008) recruited younger and OA who trained on a spatial working memory task with two levels of cognitive load for 15 minutes per day for 45 days. In addition to the expected improved performances on the trained task, their findings revealed near-transfer effects, independent of age, on the more demanding condition of a spatial NB transfer task and to a numerical NB task (Li et al., 2008). Unfortunately, they failed to observe far-transfer effects on the two complex span tasks used; operation span and rotation span (Li et al., 2008). A recent paper by Sala and Gobet (2017) went so far as to suggest that the scarcity of positive far-transfer effects in the literature should be grounds for policymakers to halt resource spending on the topic. The overarching argument being that domain-specific training of dissociated mechanisms should not be expected to generalize to other untrained mechanisms (Sala & Gobet, 2017). In addition, they posit that the neural activity seen in people engaged in tasks requiring a high cognitive load reflect domain-specific abilities, as opposed to an enhanced domain-general cognitive ability (Sala & Gobet, 2017). Research in other domains has also noted an absence of far-transfer (Oei & Patterson, 2015). Some studies have suggested that action-video-game training can lead to transfer to multiple visuo-attentional and cognitive tasks (Achtman, Green, & Bavelier, 2008; Green & Bavelier, 2003). However, after assigning participants to four different training groups, each with different video game, Oei and Patternson (2015) found that improvements were limited to cognitive abilities trained for by the groups' given game only. Other studies, as indicated by Karbach and Verhaeghen's meta-analysis (2014), show large near-transfer effects and smaller but significant far-transfer effects. However, they found no age effects in treatment gain despite earlier studies showing more improvements in YA (Karbach & Verhaeghen, 2014). This may be due to the types of trainings included in this meta-analysis. The longer training regimens of the chosen studies may have contributed to the development of better cognitive strategies in OA, leading to performances on par with their younger counterparts (Karbach & Verhaeghen, 2014). Within the studies that detect transfer effects, a recurrent result is the lack of age-related differences. Lussier and colleagues (2012), posit that this further supports the hypothesis that cognitive plasticity is conserved in old age. In contrast, previous studies report age-related differences in aspects of far-transfer effects for dual-tasking, whereby OA do not perform as well as their younger counterparts (Bherer et al., 2008; Hartley & Little, 1999; Hein & Schubert, 2004). It has been suggested that this is due to the maximal input and output interference that performing two tasks simultaneously implies (Bherer et al., 2008). While literature on DT cognitive training reveals limited age-related differences in far-transfer, few studies have fully investigated the same for the ECM of updating.

The present study investigates whether cognitive training on a task that is designed to engage a given ECM would lead to transfer effect in a task designed to engage another ECM. Based on past studies showing cognitive plasticity for attentional control with dual-task training and n-back training, we opted to compare transfer effects after training with these two tasks. We hypothesized that each task would lead to transfer effects in a new task that tap the same ECM (considered near-transfer). Given that executive abilities share a common factor, we also expected to obtain some level of transfer in a new task engaging a different ECM than the one that was trained (considered far-transfer), although this type of transfer would be reduced when compared to the near-transfer task. To our knowledge this is the first study that systematically compared cognitive training effect following two attentional control tasks engaging different ECM. The study also compares age-related differences in training gains and transfer effects by comparing older and younger adults' performances. Moreover, both training tasks involved diverse levels of complexity allowing us to provide insight with regards to potential age-related differences.

Method

Participants

One hundred-one participants were initially recruited. Twenty-six participants did not complete the study either due to their inability to perform the 2-back or missing sessions. Thirty-three younger adults (YA) and forty-two older adults (OA) completed the study. YA were recruited using posters around different universities' campuses and online student groups, while OA were recruited through the laboratory's participant bank, advertisements in local newspaper, and from the research center's participant pool. Exclusion criteria included any major surgery with general anesthetic in the past six months, any medications known to affect cognition (e.g., anxiolytic), motor limitations in the upper limbs, a history of neurological or psychiatric disorders, dementia, or participation in another research project that used the same tasks within the last year. Participants were compensated a total of 130$ (10 CAD/training sessions and 20 CAD/evaluation sessions). The study was approved by the Ethics Review Board of the geriatric institution where the study took place and by the University's Research Ethics Unit.

Participants were recruited at the rate of 4-7 for each age group per cohort and were randomly assigned to the training groups. Based on previous studies (Lussier et al., 2012), we aimed to recruit enough participants such that our sub groups would contain 15 to 20 individuals. Participants were randomly assigned to either Dual-Task training (DT) or n-back training (NB). Fourteen YA and 23 OA were assigned to the NB training group and 19 YA and 20 OA were assigned to the DT training group.

Screening Session. Screening tasks were administered to characterize participants and ensure global physical and cognitive health. Standardized neuropsychological assessments allowed us to evaluate general cognitive health. To exclude persons with dementia, OA completed the Mini-Mental State Examination (MMSE; Folstein, Folstein, & McHugh, 1975) and the Montreal Cognitive Assessment (MoCA; Nasreddine et al., 2005). Other assessed functions included; short-term and working memory (Digit Span subtest of the Wechsler Adult Intelligence Scale—Revised (WAIS-3), Wechsler, 1981), processing speed (Digit Symbol Substitution subtests of the WAIS-3 and Trail Making Test A (TMT), Reitan, 1958), attention and executive control (Digit Symbol Substitution subtests of the WAIS-3 and Trail Making Test B (TMT), Reitan, 1958), visuospatial memory (Brief Visuospatial Memory Test-Revised (BVMT-R), Benedict & Brandt, 1997), and verbal concept formation and abstraction (Similarities subset task of the WAIS-3). We screened participants for perceptual impairment by having them complete questionnaires on auditory function and tests for near and far visual acuity. Questionnaires were also used to assess depression (YA: Beck Depression Inventory (BDI), Beck, Steer, & Garbin, 1988; OA: Geriatric Depression Scale (GDS), Yesavage, 1988). Functional tests were also done to further characterize our participants. Table 1 presents the participants' characteristics.

Table 1.

Demographics and Cognitive Data

Age group	OA				YA			
Training group	NB (n = 23)		DT (n = 20)		NB (n = 14)		DT (n = 19)	
	M	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
Age (years)	70.57	6.58	69.95	8.34	25.15	4.41	24.16	3.80
Gender (# of women)	17		17		10		14	
Education (years)	14.83	2.55	14.82	2.98	17.23	3.56	16.89	2.51
Depression scale (GDS, BDI)	4.83	5.27	4.68	3.97	9.79	8.58	5.84	4.87
MMSE	28.26	1.10	28.30	1.13	-	-	-	-
MoCA	26.87	1.71	26.00	2.71	-	-	-	-
Similarity (WAIS-III)	21.39	5.91	21.65	6.52	23.71	3.81	24.58	3.69
Digit span Forward	9.26	1.84	9.85	2.64	10.14	2.07	10.68	1.70
Digit Span Backward	7.39	1.85	7.50	2.76	6.36	2.02	7.21	2.55
BVMT-R Immediate recall	16.04	7.99	16.45	7.92	24.50	5.88	24.74	6.36
BVMT-R Delayed recall	7.09	2.76	6.95	2.67	9.64	1.60	9.32	2.24
Digit symbol substitution	62.74	13.78	63.75	14.71	78.43	18.22	87.58	19.07
Trail A (s)	35.98	9.93	34.77	10.35	24.49	9.19	23.68	7.39
Trail B (s)	83.44	35.48	83.59	33.52	51.31	14.55	57.37	24.88

Note. NB = N-Back, DT = Dual-Task, GDS score out of (Max score = 30), BDI (Max score = 63), MMSE = Mini-mental state examination (Max score = 30), MoCA = Montreal cognitive assessment (Max score = 30), Similarity (Max score = 33), Digit span forward (Max score = 16), Digit span backward (Max score = 14), BVMT-R = Brief visuospatial memory test-revised (Max score for immediate recall = 33, delayed recall = 12). Digit symbol substitution (Max score = 133). For the GDS variable of the DT group, 19 OA completed the question instead of 20. The Stroop-Read variable contains 22 OA and 19 OA for the NB and DT groups respectively due to two participants unable to complete it. The Trail B variable contains 13 YA in the NB due to one participants' inability to complete the task.

Independent sample t-tests were conducted to explore age and training group differences to characterize our participants and to ensure that each training groups were comparable. Comparing OA in the NB training group to those of the DT training group, our analyses revealed no significant differences in; MoCA scores ($t(41) = 1.27$, n.s.), MMSE scores ($t(41) = -0.12$, n.s.) nor GDS scores ($t(40) = 0.10$, n.s.). Both age groups (YA and OA) of each training groups (NB and DT) were then compared on the remainder of the tasks. The independent sample t-test used on the immediate recall of the BVMT-R scores revealed no significant differences between YA ($t(31) = -0.11$, $p = .914$) of each training group nor between OA of each training group ($t(41) = -0.17$, n.s.). No significant results were found for the delayed recall of the BVMT-R (YA: ($t(31) = 0.47$, n.s.), OA: ($t(41) = 0.17$, n.s.), digit symbol substitution (YA: ($t(31) = -1.39$, n.s.), OA: ($t(41) = -0.23$, n.s.), digit span forward (YA: ($t(31) = -0.82$, n.s.), OA: ($t(41) = -0.86$, n.s.), digit span backward (YA: ($t(31) = -1.03$, n.s.), OA: ($t(41) = -0.15$, n.s.), trail making test A (YA: ($t(31) = 0.28$, n.s.), OA: ($t(41) = 0.39$, n.s.), and trail making test B (YA: ($t(30) = -0.79$, n.s.), OA: ($t(41) = -0.02$, n.s.).

Procedure

During the initial telephone conversation, a questionnaire was administered to assess participants' eligibility for the study. If the participant was determined to be eligible, 10 sessions were scheduled. The first being a screening session, wherein we administered neuropsychological tests, functional assessments and questionnaires to characterize our participants. Then, the pre-training evaluation was conducted the following week in which two versions of both the DT task and the NB task (further described below) were given. Students trained in neuropsychological testing administered all the evaluations. Once randomized into either the NB or DT training group, participants completed six 1-hour training sessions supervised by a research assistant. The post-training evaluation took place within two weeks following the last training session.

Throughout the project, OA were always scheduled in the morning while YA were scheduled in the afternoon. This was done based on previous research that reported a decrease in cognitive performance in OA as the day progresses while an increase was observed for YA (Blatter & Cajochen, 2007). Participants were comfortably seated at a table and conducted all the computerized tasks on an iPad held on an adjustable stand in front of them with the option to use a wrist support should they choose to do so.

Pre-training and post-training evaluation sessions tasks. After a brief familiarization phase, with the DT and NB, all participants performed the DT training task, followed by the DT transfer task (DTt), then the NB training task and finally, the NB transfer task (NBt).

DT paradigm. The DT paradigm involved two visual discrimination tasks that had to be performed alone or concurrently. In the DT training tasks participants had to identify which animal (snake, dog, or bird) and/or celestial body (planet, star, or sun) appeared on the screen. Responses were provided by pressing a visual button on the iPad screen. Similarly, in the DTt task, participants had to identify which one of three modes of transportation (car, plane and boat) and/or fruits (banana, apple and pineapple) was presented. The paradigm involved three different trial types; single-pure (SP), single-mixed (SM), and dual-mixed (DM). In the SP trials, a single stimulus is displayed, and participants were asked to press the corresponding button of one stimulus of a single task-set that represented the image shown. The buttons for animal stimuli and modes of transportation were always presented on the left side of the screen and the celestial bodies and fruits' buttons were always on the right side of the screen. In the SM trials, all buttons were made available but only one stimulus of either task was displayed on the screen. The DM trials were like the SM trials, but two stimuli were presented at the same time on the screen (one from each task-set; Figure 1). Crucially, the feedback and speedometers were only present during the training sessions and not the evaluations sessions. Participants performed four types of blocks over the course of any given session, multiple times, in a semi-randomized order: SP blocks consisting of SP trials only, SM blocks consisting of SM trials only, DM blocks consisting of DM trials only, and SM/DM blocks consisting of a mix of SM and DM trials. Furthermore, participants were instructed to respond as fast as possible without prioritizing one task over the other and to avoid grouping their answers (i.e. voluntarily answering both tasks simultaneously) because doing so suggests that they wait until they recognize both stimuli before answering causing a non-representative reaction time (RT). Stimuli were presented on the iPad's dark grey screen for a total of 2750 ms, regardless of whether a response is recorded or not. Then, each presentation was followed by a black screen lasting 250ms.

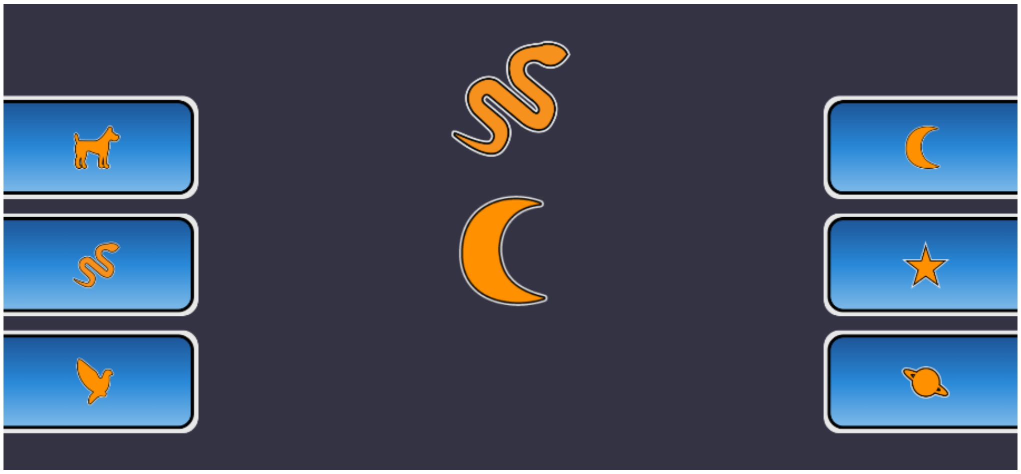

Figure 1. Dual-Task evaluation task. DM trial shown whereby one stimulus from each task set (animals and celestial bodies) appears.

Comparisons between the different trial types provides valuable information regarding the potential mechanisms involved in the DT task. The performances on SP trials, as measured by the RT, are interpreted as indicators of general processing speed (Lussier et al., 2012). Comparing the SP and SM trials yielded a measure of the amount of processing time needed to prepare and maintain multiple task sets, known as the task-set cost (Lussier et al., 2012). Comparing the SM and DM trials is considered to reflect the dual-task cost, which represents the ability to coordinate the execution of two motor responses upon perceiving multiple stimuli (Lussier et al., 2012). Each block began with instructions on how to perform the task, which the participant could skip by pressing a "Next" button located on the bottom of the screen. Each of the three blocks of acquisition were counterbalanced to contain 10 SP trials with the left hand, 10 SP trials with the right hand, 15 SM trials, 10 DM trials and 15 trials made of eight SM and 7 DM trials. For the 14-minute duration of the task, participants were instructed to press the button(s) corresponding to the stimuli that appear using their thumbs and received no feedback.

NB paradigm. The NB tasks requires participants to name an item that was presented *n* position before in a string of items. The NB trained task used numbers (from 1 to 9) and three conditions of increasing cognitive load: 1-back, 2-back, and 3-back. Each block consists of a series of 15 numbers presented one at a time semi-randomly in the middle of the screen, on a dark grey background. Each stimulus is presented for 750 ms and is followed by an empty screen for 3000 ms giving participants a total of 3750 ms to respond. Each block is followed by an "off" block during which a white asterisk is presented in the middle of the screen for 750 ms. Participants performed three blocks of each condition over the span of 11 minutes. With the 1-back being A, 2-back being B and 3-back as C, the order of the task followed the sequence of A-

B-C-B-C-A-C-B-A. Fifteen stimuli were presented in each block, however, depending on the condition, a specific number of responses were expected. In the 1-back, participants cannot provide a response to the first stimulus since there are no previous stimuli to compare it with, resulting in 14 responses for this condition. Similarly, the 2-back yields 13 responses and the 3-back, 12 responses. Participants were instructed to indicate if the number they saw was equal or not to the number seen *n* positions before (either 1, 2 or 3 depending on the condition) by pressing the '=' or '≠' button on the right side of the tablet (Figure 2). Like the DT task, participants received no feedback during evaluation sessions. The NBt was constructed using the same parameters but using letters instead of numbers. Only consonants were used (B, C, F, J, N, Q, S, V, and X) to prevent the participants from forming and memorizing words instead of letters.

Figure 2. N-Back evaluation task. In the 1-back, the presented stimuli were in green, in the 2-back, they were in yellow and in the 3-back, they were in red.

Using the pre- and post-training performances on the 1-back as a baseline measure, we compared the performance on the 1-back and 2-back to obtain a measure of the cost associated with performing the 2-back. Then, using the 1-back and 3-back, we calculated the cost associated with performing a 3-back. An example of the formula to calculate the 2-back accuracy cost is as follows:

$$2back\ Cost = -\left(\frac{2back\ Accuracy\ at\ Pre - 1back\ Accuracy\ at\ Pre}{1back\ Accuracy\ at\ Pre} \times 100\right)$$

Once the cost ratio is calculated, it is multiplied by 100 to obtain a percentage. The whole formula is then made negative so that a positive cost means that participants are using more resources and a negative one means they are using less.

Training sessions. Training sessions were conducted twice per week for a total of six sessions. Each session was done in groups of a maximum of seven individuals and lasted between 45 and 60 minutes. With every completed training session, feedback in the form of a graph showing their mean RT, was presented for them to see their individual progress.

Training on the DT task was done using hand prioritisation, such that participants were instructed, before starting the block, that they would have to prioritize the left or right hand when two stimuli appeared on the screen. Session 1 started with four blocks of SP trials (two on the left side and two on the right side of the iPad, order was counterbalanced across participants) and ended with two blocks of SP trials (one on the left side and one on the right side). Session 1 included seven blocks of SM-DM trials with no prioritisation. Sessions 2 to 6 started with 1 block of SP right, then SP left and ended with those two blocks as well. They followed with one block of SM-DM without prioritisation, four blocks of SM-DM with an alternating left- and right-hand prioritisation, then three blocks of SM-DM without prioritisation, and finally the aforementioned two SP blocks to end the session.

Instructions used were the same as the pre-training evaluation session, but feedback was provided for every trial on both accuracy and speed. A correct answer would turn the response button green while an incorrect one would turn the response button red and cause the stimuli to shake. Speedometers were used to provide feedback on the speed of a participant's RT (Figure 3). The speedometer's display is based on the average baseline RT per hand of the previously completed SM trial. In the case of the first session, 1100 ms was used by default. If there was no prioritization between the left and right hands during the trial, then the minimum speedometer value was equivalent to the product of the previously mentioned baseline SM RT multiplied by one, while multiplying it by two yields the maximum value. If the trial required prioritization of one hand, its SM RT baseline was multiplied by 0.75 for the minimum value and by 1.5 for the maximum value (Lussier, Bugaiska & Bherer, 2015). For the non-prioritized hand, the minimum value was represented by the baseline SM RT multiplied by 1.5 and the maximum value was achieved by multiplying by 3 (Lussier et al, 2015). The speedometer's hand is placed between the minimum and maximum values based on the average RT of the latest DM trial with the last trial given a weight of 5, the one before that given a weight of 4, then 3 and so on and so forth.

Figure 3. Training session Dual-Task task. Feedback and speedometers were only available during training sessions, not evaluation sessions. Feedback given after the 5th correct response in a row in the DM condition. All three conditions (SP, SM, DM) utilize the same feedback bar. Speedometers located above the stimuli buttons display faster responses as the hand moves to the right.

In all blocks, a feedback bar on the bottom of the screen provided the following feedback as participants answered correctly (Figure 3); "WELL DONE" after the first correct response, "GREAT" after the second correct response, "SUPER" after the third correct response, "AWESOME!" after the fifth correct response (Figure 3), "FANTASTIC!!" after the 10th correct response, "AMAZING!!!" after the 15th correct response, "INCREDIBLE!!!!!" after the 25th correct response. If an incorrect answer is given, the accuracy-streak restarts from the beginning.

Progressive training was used with the NB group. A practice block of five trials preceded the 1-back blocks, six practice trials preceded the 2-back blocks, and seven practice trials were done before the 3-back blocks. The first two sessions included only the 1-back (six blocks of 41 trials) and 2-back (seven blocks of 42 trials) conditions, sessions 3 and 4 included 1-back (four blocks of 41 trials), 2-back (six blocks of 42 trials), and 3-back, (four blocks of 43 trials), and sessions 5 and 6 included only the 2-back (seven blocks of 42 trials) and 3-back (seven blocks of 43 trials) conditions. Instructions used were the same as the pre-training evaluation session and feedback was provided for each trial: upon response, the button would turn green (for a correct answer) or red (for an incorrect one). Additional feedback was provided using the same feedback bar paradigm as for the DT based on the number of accurate responses given by the participant (Figure 3).

Analysis

Analysis of variance (ANOVA) were performed on RT (ms) and accuracy (% of correct responses) for both trained and transfer tasks with Age (older vs. younger) as between-subjects factor, and Session (Pre vs. Post) and Condition (SP, SM, DM; 1-back, 2-back, 3-back) as within-subjects factors. Significant interactions were decomposed with simple effects. However, in the case of a significant interaction with more than two levels of a repeated factor (e.g., condition), repeated contrasts were used. Such analyses provide a comparison of differences in RT and accuracy between two consecutive levels of a repeated factor. Statistical analyses of the data were performed on SPSS 24. An effect was reported significant according to the adjusted alpha level (Greenhouse–Geisser) when required – that is, when the Mauchly's test of sphericity was significant. Effect sizes (eta squared) are also reported. Performances from pre-test to post-test on the NB, NBt, DT and DTt tasks will be presented.

Results

All participants demonstrated very high accuracy on the DT task in pre- and post-training sessions (YA: 98.97%, OA: 98.15%). We conducted an ANOVA and found no significant differences between sessions (*F (*1, 71) = 0.95, *p* = 0.33) nor between age groups (*F (*1, 71) = 0.93, *p* = 0.34). Therefore, RT is used as the critical variable in the DT tasks. For the NB task and the NBt task, the variable of interest is the accuracy because the participants were instructed to focus on the correct response as opposed to the speed at which they responded. Accuracy was calculated as a percentage of correct responses for each condition.

Pre vs. Post-Training Testing Sessions

For each training group, an ANOVA was performed with Session (pre-, post-training) and Condition (SP, SM, DM for the DT tasks; 1-back, 2-back, 3-back for NB tasks) as the within-subjects factors, and age group (YA, OA) as between-subjects factor. When the Mauchly's test of sphericity revealed that the assumption of sphericity was violated, a Greenhouse-Geisser correction was applied. The results are split in two parts to address the main questions. The first part focuses on the DT trained group's performance to explore whether training led to significant transfer and age-related differences in the trained task (DT), the near-transfer task (DTt), and far-transfer tasks (NB, NBt). The second part discusses the same effects but with the focus on the NB trained group's performance on their trained task (NB), near-transfer task (NBt), and their far-transfer tasks (DT, DTt).

Dual-task trained group.

Results of the DT task revealed a statistically significant main effect of session suggesting an improvement from pre- to post-training in the trained task (Table 2).

Table 2.

Results of the ANOVA for the DT trained group showing training, near- and far-transfer effects

	Training effects (DT)				Near Transfer (DTt)				Far Transfer (NB)				Far Transfer (NBt)			
	df	F	p	η^2	df	F	p	η^2	df	F	p	η^2	df	F	p	η^2
Session (Pre, Post)	1.00	98.96	0.00*	0.73	1.00	34.04	0.00*	0.45	1.00	13.89	0.00*	0.27	1.00	1.13	0.30	0.03
Age (YA, OA)	1.00	41.73	0.00*	0.53	1.00	31.71	0.00*	0.46	1.00	24.02	0.00*	0.40	1.00	26.70	0.00*	0.42
Condition	1.08	710.97	0.00*	0.92	1.18	857.75	0.00*	0.96	2.00	56.31	0.00*	0.57	2.00	43.30	0.00*	0.50
Session*Age	1.00	0.27	0.61	0.00	1.00	4.35	0.04*	0.11	1.00	0.01	0.94	0.00	1.00	0.16	0.69	0.00
Condition*Age	1.08	17.50	0.00*	0.02	1.18	2.77	0.10	0.07	2.00	5.50	0.00*	0.06	2.00	6.43	0.00*	0.07
Session*Condition	1.28	107.85	0.00*	0.74	1.67	19.67	0.00*	0.35	1.72	0.44	0.62	0.01	2.00	0.64	0.53	0.02
Session*Condition *Age	1.28	1.54	0.23	0.01	1.67	6.02	0.01*	0.14	1.72	3.32	0.04*	0.08	2.00	0.11	0.90	0.00

Note. $^*p < 0.05$. The Conditions for the DT tasks are SP, SM, DM and the Conditions for the NB tasks are 1-back, 2-back, 3-back

This improvement was equivalent among age groups given that no interaction with Age was found. However, the effect of Session was qualified by a Session × Condition interaction. Performances on the SP, SM, and DM conditions of the task were found to be significantly improved (i.e. faster) by 77.33 ms, 136.71 ms, and 260.06 ms respectively. Task-set cost ($F(1, 38) = 65.39$, $p = .000$, $\eta^2 = .63$) and dual-task cost ($F(1, 38) = 12.49$, $p = .001$, $\eta^2 = .25$) were analyzed using an ANOVA and a significant decrease of 7.33% and 6.96% respectively.

When investigating near-transfer effects, results on the DTt task revealed a statistically significant main effect of session suggesting an improvement from pre- to post-training in the near-transfer task (Table 2). This effect was further characterized by a Session × Condition × Age interaction with simple comparisons revealing that the YA of the DT trained group became significantly faster on the SP, SM, and DM conditions of the task by 50.34 ms, 67.97 ms, and 169.68 ms respectively following their training (Figure 4; top right panel). In contrast, OA were only significantly faster in the SM and DM conditions by 41.40 ms and 66.15 ms respectively (Figure 4; top right panel). However, on every condition, OA were significantly slower than YA at pre- and post-training sessions. To further investigate age differences, analyses on cost were conducted. No significant differences from pre- to post-training sessions in task-set cost were found for neither YA ($F(1, 18) = 0.83$, n.s.) nor OA ($F(1, 19) = 0.55$, n.s.). However, a significant decrease of 7.82% in dual-task cost was found for the YA ($F(1, 18) = 5.60$, $p = .029$, $\eta^2 = 0.24$), but not the OA ($F(1, 19) = 0.15$, n.s.) (Figure 5, top right panel).

Far-transfer effects on the NB task yielded a statistically significant main effect of session, suggesting an improvement from pre- to post-training on this untrained task (Table 2). This effect was characterized by an interaction of Session × Condition × Age, which was broken down to investigate age differences in far-transfer. Simple comparisons revealed that OA significantly improved their accuracy on the 1-back and 2-back conditions by 5.68% and 6.64% respectively, whereas YA only improved on the 3-back condition by 6.87% (Figure 4; bottom left panel). Furthermore, age-related differences were found such that OA had a significantly lower accuracy than YA in both pre- and post-training sessions in all conditions (Figure 4; bottom left panel). Despite the improvements from the pre- to post-training sessions, neither age group had a significant decrease in cost associated with the 2-back (YA: $F(1, 18) = 0.82$, n.s.; OA: $F(1, 18) = 0.12$, n.s.) nor 3-back (YA: $F(1, 18) = 4.03$, n.s.; OA: $F(1, 19) = 1.48$, n.s.).

In contrast, far-transfer effects on the NBt task did not result in a significant effect of session. This null result was equivalent among age groups given that no interaction with Age was found. Moreover, no significant decreases in 2-back cost ($F(1, 38) = 0.72$, n.s.) nor 3-back cost ($F(1, 38) = 0.10$, n.s.) were found.

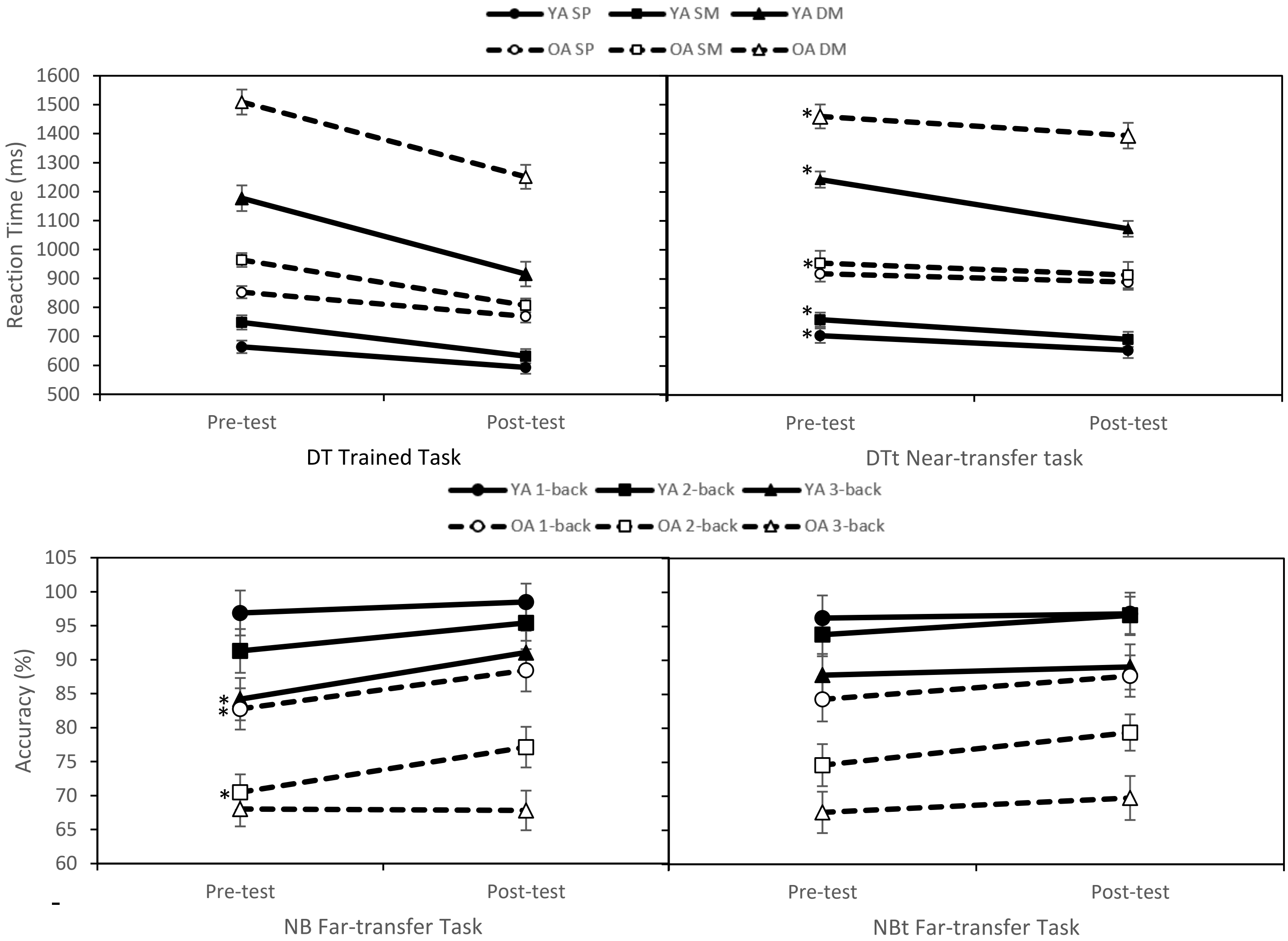

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Figure 4. DT trained group's performance on all tasks done pre- and post-training. Error bars represent Standard Error values. DTt task (*top right panel*): A Sesssion × Condition × Age interaction revealed significant improvement on the SP, SM, DM conditions of YA and only the SM and DM conditions of the OA. NB task (*bottom left panel*): A Sesssion × Condition × Age interaction revealed significant improvement on the 3-back of YA and the 1-back and 2-back of OA. *$p < 0.05$.

☐Pre-test ■Post-test

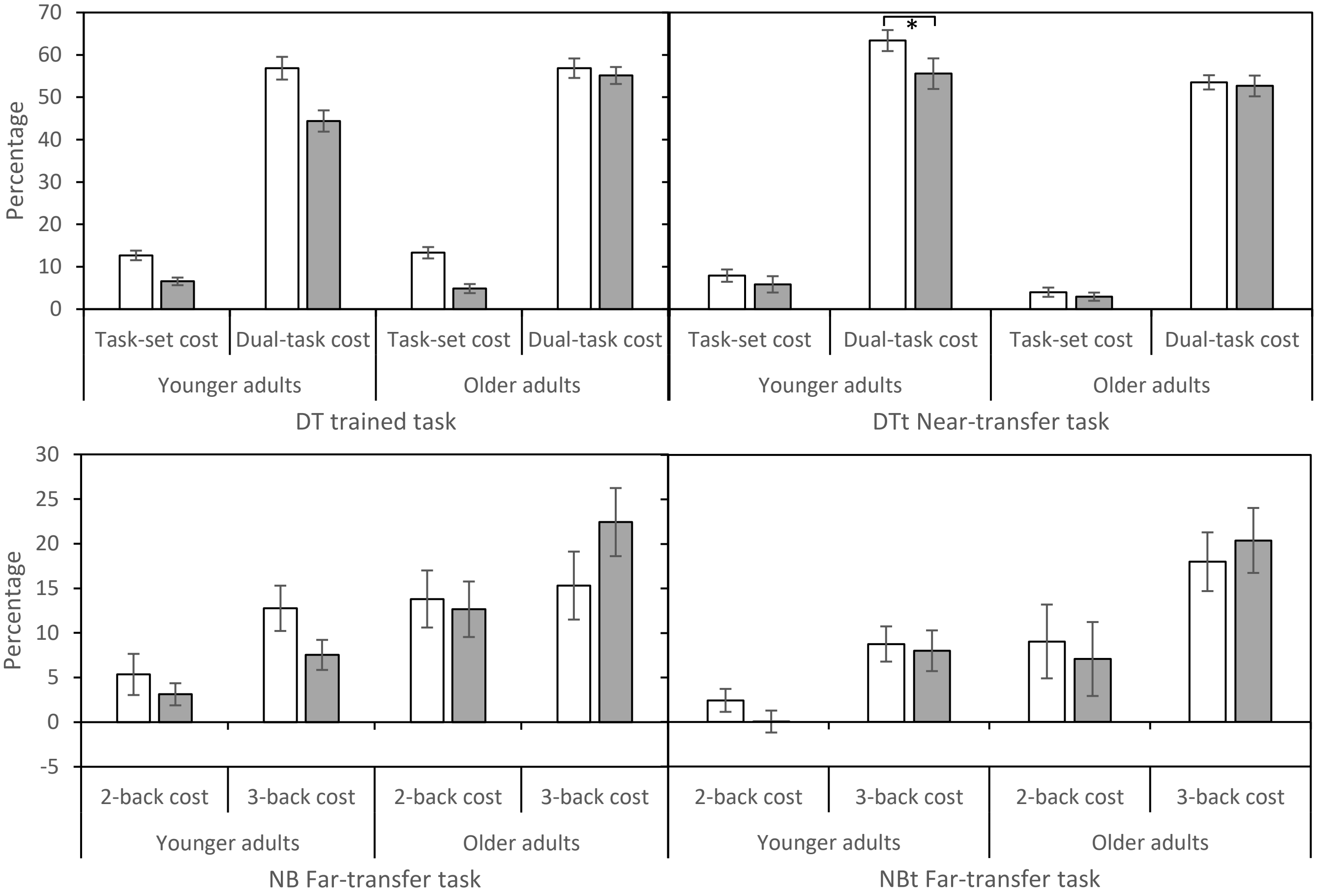

Figure 5. DT trained group's cost on all tasks done pre- and post-training. Error bars represent Standard Error values. A significant decrease of 7.82% in dual-task cost on the DTt task (*top right panel*) was observed for YA. *$p < 0.05$.

N-back trained group.

Results of the NB task revealed a statistically significant main effect of session suggesting an improvement from pre- to post-training on the trained task (Table 3). Figure 6 demonstrates the NB trained group’s performance on all evaluation tasks and Figure 7 shows the 2-back and 3-back costs associated with each age group.

Table 3.

Results of the ANOVA for the NB trained group showing training, near- and far-transfer effects

	Training effects (NB)				Near Transfer (NBt)				Far Transfer (DT)				Far Transfer (DTt)			
	df	F	p	η^2	df	F	p	η^2	df	F	p	η^2	df	F	p	η^2
Session (Pre, Post)	1.00	61.69	0.00*	0.62	1.00	20.90	0.00*	0.37	1.00	50.53	0.00*	0.59	1.00	18.27	0.00*	0.34
Age (YA, OA)	1.00	12.75	0.00*	0.27	1.00	7.42	0.01*	0.17	1.00	40.43	0.00*	0.54	1.00	25.75	0.00*	0.42
Condition	1.64	33.27	0.00*	0.46	1.43	39.44	0.00*	0.51	1.23	1097.20	0.00*	0.96	1.18	726.47	0.00*	0.95
Session*Age	1.00	3.61	0.07	0.04	1.00	1.23	0.28	0.02	1.00	0.23	0.64	0.00	1.00	0.60	0.45	0.01
Condition*Age	1.64	3.34	0.05*	0.05	1.43	2.69	0.09	0.03	1.23	15.05	0.00*	0.01	1.18	2.88	0.09	0.00
Session*Condition	2.00	22.18	0.00*	0.38	2.00	12.60	0.00*	0.25	1.64	18.95	0.00*	0.34	1.38	8.30	0.00*	0.19
Session*Condition *Age	2.00	1.68	0.19	0.03	2.00	2.84	0.07	0.06	1.64	1.40	0.25	0.03	1.38	1.43	0.25	0.03

Notes. *$p < 0.05$. The Conditions for the DT tasks are SP, SM, DM and the Conditions for the NB tasks are 1-back, 2-back, 3-back

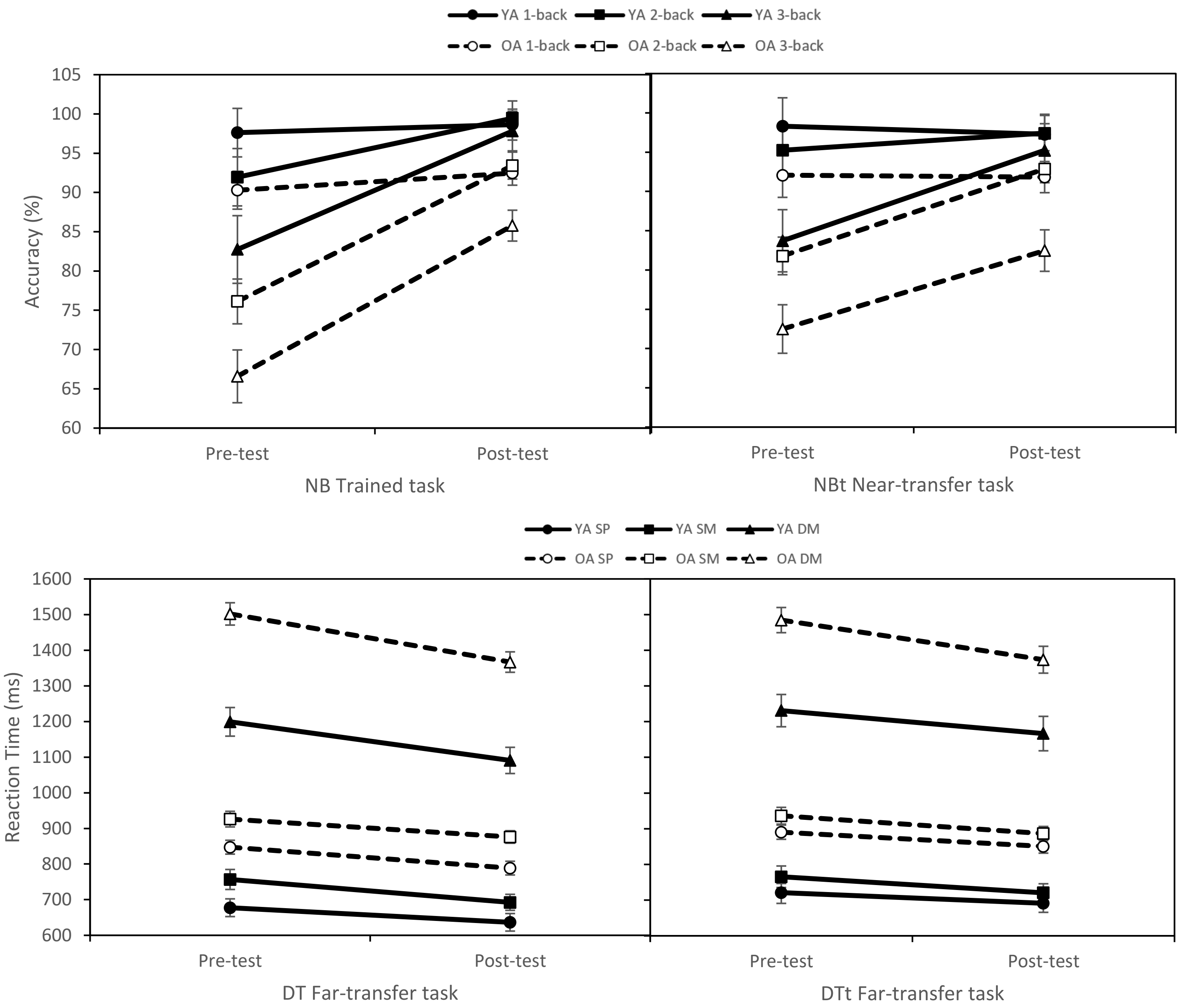

Figure 6. NB trained group's performance on all tasks done pre- and post-training. Error bars represent Standard Error values.

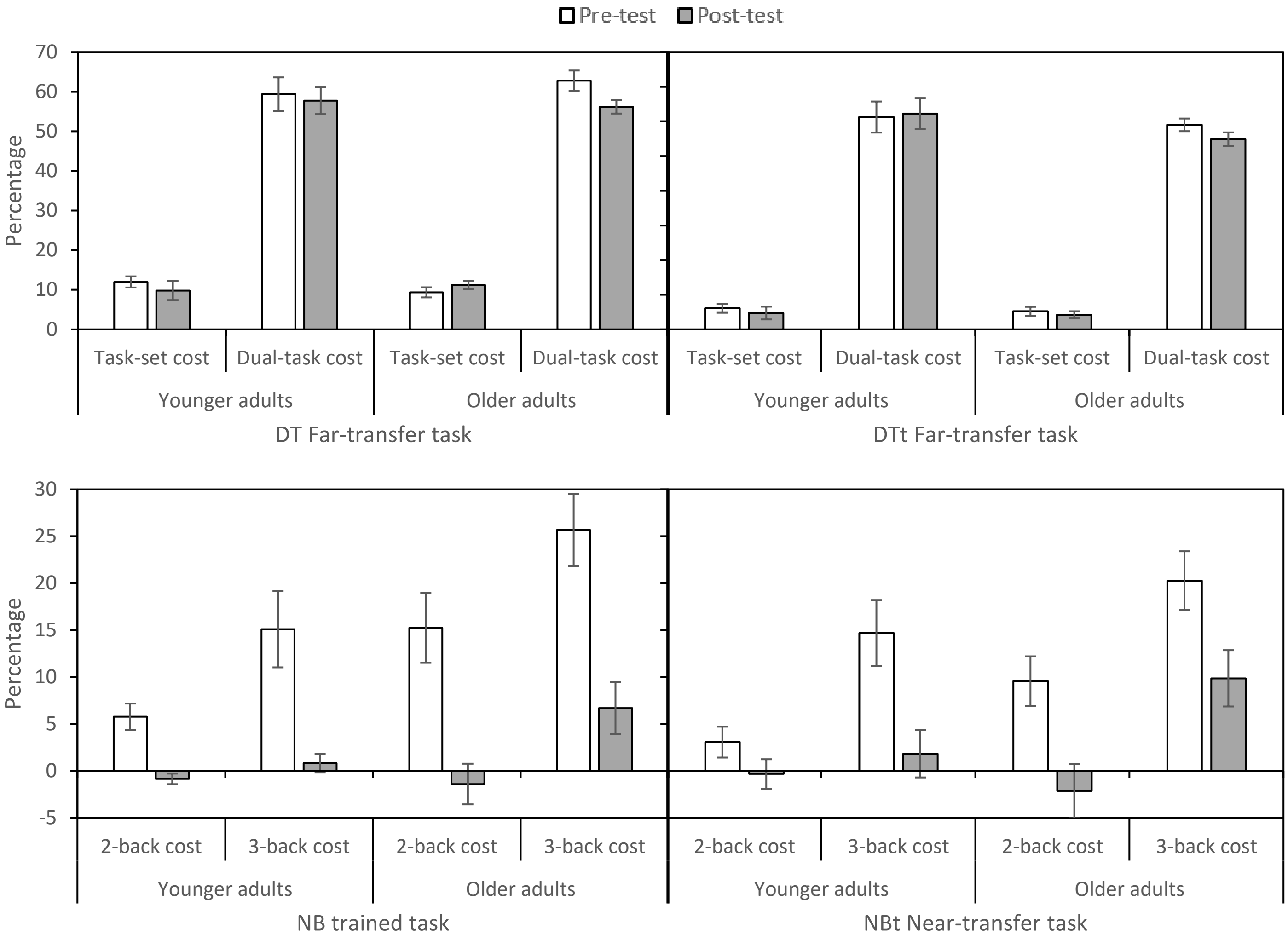

Figure 7. NB trained group's cost analysis on all tasks done pre- and post-training for both YA and OA. Given that no interaction with age was found, these table are showing all the data we obtained while significant results are discussed in the text.

This improvement from pre- to post-training sessions was equivalent among age groups given that no interaction with Age was found. However, the effect of Session was qualified by a Session × Condition interaction, with accuracy performances on the 2-back and 3-back significantly improving by 12.40% and 17.13% respectively at the post-testing session. Significant decreases in 2-back cost ($F(1, 36) = 28.79$, $p = .000$, $\eta^2 = .44$) of 12.85% and 3-back cost ($F(1, 36) = 34.96$, $p = .000$, $\eta^2 = .49$) of 17.20% were found, suggesting that it costs less to perform these conditions at post- than at pre-training.

When investigating near-transfer effects, results on the NBt task revealed a statistically significant main effect of session suggesting an improvement from pre- to post-training on the near-transfer task (Table 3). The lack of interaction with Age indicates that this improvement was equivalent among age groups. However, the effect of Session was qualified by a Session × Condition interaction where performances significantly improved on the 2-back and 3-back conditions by 6.63% and 10.75% respectively. Furthermore, significant decreases in 2-back cost ($F(1, 36) = 8.34$, $p = .007$, $\eta^2 = .19$) of 8.57% and 3-back cost ($F(1, 36) = 18.18$, $p = .000$, $\eta^2 = .34$) of 11.35% were found, suggesting that it costs less to perform these conditions at post- than at pre-training.

Far-transfer effects were found on the DT task with a statistically significant main effect of Session indicating an improvement from pre- to post-training sessions (Table 3). Although this improvement was equivalent among age groups as suggested by the absence of an interaction with Age, this effect was qualified by an interaction of Session × Condition, with simple comparisons revealing significantly faster RT on the SP, SM, and DM conditions of the task by 49.83, 57.12, and 121.71 ms respectively. Interestingly, while no task-set cost was found

(*F*(1, 36) = 0.07, n.s.), the NB trained group's dual-task cost significantly decreased (*F*(1, 36) = 6.18, $p = .02$, $\eta^2 = .15$) from pre- to post-testing by 4.71%.

Far-transfer effects were found on the DTt task due to a statistically significant main effect of Session (Table 3). No interactions with Age were found, thereby indicating that our age groups improved similarly on the task. However, the effect of Session was further qualified by an interaction of Session × Condition. Simple comparisons reveal that the NB trained group were significantly faster on the SP, SM, and DM conditions of the task by 34.83 ms, 47.44 ms, and 87.69 ms respectively. However, no significant task-set cost (*F*(1, 36) = 1.50, n.s.) nor dual-task cost (*F*(1, 36) = 1.50, n.s.) were found.

Discussion

The present study assessed the effects of a three-week cognitive training program using a 2×2×3 factorial design in which YA and OA underwent training with a designated task (NB or DT) containing three conditions. The main objectives were to investigate, age differences and transfer effects for each training group, specifically, near-transfer effects to an untrained task that targets the same ECM, and far-transfer effects to an untrained task that targets a different ECM. Both groups demonstrated the expected training effects as seen by their significant improvement following the intervention. Although we did not include a passive control group, the training effects on the tasks we used are well documented (Bherer et al., 2005; Erickson et al., 2007; Jaeggi et al., 2011; Lussier et al., 2012; Salminen et al., 2016; Stepankova et al., 2014; von Bastian & Oberauer, 2014). We also found evidence of near- and far-transfer effects with both age-groups improving similarly on the evaluation tasks. According to Barnett and Ceci's taxonomy (2002), the transfer effects in this study could be described as temporally near, functionally near and modality near with an unchanged physical context. When describing near-transfer effects in this study, the trained ECM and the ECM used by the untrained transfer task are identical, such that it can be thought of as mechanism near or within-mechanism transfer. As for far-transfer effects, the trained ECM and the ECM used by the untrained transfer task are not the same, such that it can be thought of as mechanism far or cross-mechanism transfer.

We began by analyzing the various effects and age-related differences in the DT trained participants. The DT trained group had a lower RT on the SP, SM and DM conditions of the DT task at the post-training evaluation session compared to their pre-training performance. The lack of an interaction with age suggests that both YA and OA improved equivalently on the task. These results suggest that our training paradigm helps participants improve their speed of processing. Furthermore, a decrease in task-set cost and dual-task cost was observed from pre- to post-training sessions. These results, in line with previous studies that included control groups (Bherer et al., 2005, 2008; Lussier et al., 2015), suggest that participants required less time to prepare and maintain multiple task sets and were better able to coordinate the execution of two motor responses upon perceiving multiple stimuli . When investigating their near-transfer effects on the DTt task, age differences were observed such that YA improved on the SP, SM and DM conditions, while OA only improved on the SM and DM conditions. Furthermore, cost analysis revealed no significant decreases in task-set cost in either age group, but YA did decrease their dual-task cost. This suggests that younger adult's ability to coordinate the execution of two motor responses upon perceiving multiple stimuli transferred to a similar task targeting the same ECM. The lack of cost differences for OA in combination with the lower RT observed in the post-training session seem to indicate that training on the DT task improved their speed of processing on the near-transfer task. In terms of far-transfer effects to the NB task, we observed age-related differences, such that YA obtained a higher accuracy on the 3-back and OA, on the 1-back and 2-back. The lack of cost improvement in both age groups may suggest that either minimal exposure to the NB task (test–retest effect) leads to significant improvements in accuracy or that far-transfer of an unknown ability has enabled the participants to better perform on the task. The fact that the age groups did not improve on the same conditions may indicate that mechanisms related to far-transfer effects may be at play instead of practice effects. Previous research has argued that the 2-back relies mainly on the ability of focus switching, with memory load and coordination contributing, although to a lesser extent, to the performance (Bopp & Verhaeghen, 2018; Van Gerven, Meijer, Prickaerts, & Van der Veen, 2008). The coordination ability, in the context of an NB task, enables participants to coordinate the continuously changing roles of the presented stimuli (Van Gerven et al., 2008). When *n* = 1, there are two roles that need to be considered, the “probe” (i.e. current stimulus), and the “target”, which, in a 1-back, is the digit one position behind (Van Gerven et al., 2008). If *n* > 1, in addition to the probe and target, there is now a new role, the “future target” (Van Gerven et al., 2008). This is an item, not yet in the focus of attention, that is queued to be compared with an upcoming probe (Van Gerven et al., 2008). Given that our results do not show significant decreases in cost, it is difficult to attribute the observed improvements to an enhancement in focus switching, coordination or memory load. Interestingly, YA, who had improved in dual-task cost on the DTt task, were trending towards significance in terms of a 3-back cost decrease (Figure 4). Perhaps the 3-back cost of YA would significantly decrease with a larger sample size. In which case, given the importance of coordination in a DT task (Schubert, Liepelt, Kubler, & Strobach, 2017), this would suggest that the improved coordination that transferred to the DTt presumably transferred to the NB task to affect their 3-back performance. Interestingly, when we analyzed the other far-transfer task, the NBt, no significant improvements in accuracy from pre- to post-training were observed. Two hypotheses may explain these results. First, this finding could indicate that in doing the NBt at the end of the evaluation sessions, participants were cognitively fatigued. Second, far-transfer may be dependent on stimuli type (letters versus numbers) or, more broadly, only occur in specific NB tasks. In a study by Tsuchida and Fellows (2012), participants with focal damage in the PFC performed a series of tasks for shifting, inhibition and updating. Their results revealed that the inhibition and attentional shifting tasks, not the spatial updating task, were affected by lesions in the left ventrolateral PFC. Updating was instead impaired by lesions to other areas, thereby conflicting with the Unity/Diversity framework since they expected the performance to be impaired following lesions to an area believed to be the neural underpinning for the common EF factor. Interestingly, when they used a letter NB task, their findings were in line with the Unity/Diversity model and the task was impaired following lesions to the left ventrolateral PFC (Tsuchida & Fellows, 2012). Given that the NB task is reliant on many processes (Bopp & Verhaeghen, 2018) and that these processes vary from one NB type to another, it could mean that training on a DT task can only transfer to specific types of NB tasks. This entails that DT training could be affecting a process utilized in the number NB and not the letter NB.

We then analyzed the various effects and age-related differences in the NB trained participants. All participants that trained on the NB task improved their accuracy on the 2- and 3-back. The unchanged pre- and post-testing scores of the 1-back condition did not come as a surprise given the already high accuracy score at the pre-training session. The lack of an interaction with Age suggests that both YA and OA improved equivalently on the task. When analyzing accuracy costs, results revealed a decrease from pre- to post-training in 2-back cost. This suggests that the accuracy cost incurred performing the 2-back decreases after training on the task, indicating that the ability of focus switching has been improved by following our training paradigm. Results also revealed significant decreases in 3-back cost, which would suggest that they have been able to increase their memory load and/or their ability to coordinate the continuously changing roles of the presented stimuli. Near-transfer effects were also observed on the NBt whereby the 2-back and 3-back conditions improved in terms of accuracy. Once again, the lack of an interaction with Age suggests that both YA and OA improved equivalently on an untrained task that is targeting the same ECM (near-transfer). Furthermore, accuracy cost analysis revealed a decrease in both the 2-back and 3-back cost. This suggest that the ability of focus switching, coordinating the ever-changing roles of the presented stimuli, and an enhancement in memory load have all transferred to an untrained task that shares the same ECM. When investigating far-transfer effects to a different ECM, results demonstrate that the NB trained participants improved significantly reduced their reaction time on all conditions of the DT task, despite being told to focus on accuracy during their training and not response time. In addition, while no age difference was present, a significant decrease in dual-task cost was observed for the group. This may suggest that the ability they developed by training on the NB to coordinate the changing roles of the stimuli, as seen by their decrease in 3-back cost, has not only shown to transfer to a near-transfer task but also has aided capacity to coordinate the execution of two motor responses upon perceiving multiple stimuli on the far-transfer task. Interestingly, when looking at the far-transfer effects on the DTt task, results show improvements in RT on all conditions with no change in task-set nor dual-task cost. Since participants were instructed to focus on accuracy during their training, this increase in speed of processing indicates that some form of transfer has taken place. However, no age differences were found, suggesting both age groups improved equivalently on the task.

As previously mentioned, the Unity/Diversity framework posits that the updating and shifting abilities consist of a common EF factor combined with an updating-specific or a shifting-specific component (Friedman & Miyake, 2017). As for the inhibition ability, it was found to be accounted for entirely by the common EF factor only (Friedman & Miyake, 2017). Our study further supports the Unity/Diversity framework due to the transfer findings. For near-transfer to occur, the underlying ability of one type of task needs to be trained such that performance on an untrained task utilizing the same ability improves. Such is the evidence we find when looking at the near-transfer effects in our training groups. For example, training on the

NB may have heavily targeted the updating-specific component of the framework, thus resulting in an improvement in the near-transfer task, NBt. Given that the NB consists of many different abilities (Bopp & Verhaeghen, 2018), one can posit that the common EF factor, may contain many components, all shared among the core EFs. Those sub-components would contribute to the cross-mechanism far-transfer that we have observed. While it is difficult to find a definitive answer due to tasks requiring many processes, our results seem to suggest that a commonality between the DT and NB task is the ability to coordinate, if we follow the trend seen on the 3-back condition of YA trained on the DT. While the DT was concerned with coordinating the execution of two motor responses upon perceiving multiple stimuli, the NB dealt with coordinating the continuously changing roles of the presented stimuli (Bopp & Verhaeghen, 2018; Lussier et al., 2012; Oberauer, Süß, Wilhelm, & Wittman, 2003). Variations in the ability to coordinate has been observed to be integral in executive functioning (Kramer, Hahn, & Gopher, 1999; Rigoli, Piek, Kane, & Oosterlaan, 2012), which leads to the question of whether coordination is one of the sub-components of the common EF factor.

There are some caveats in this study that should be addressed. In a meta-analysis by Sala and Gobet (2017), beyond their skepticism towards the existence of far-transfer, they strongly suggested that future studies should include passive and active control groups. Although control groups help to better define training effects, their absence in this study is not a major set back considering that these effects are already well documented. As for the transfer effects, which are the focus of the article, they are intra-individual effects and thus do not necessarily require the use of controls. Finally, as is the issue with many studies trying to tease apart ECM, the tasks used are complex and involve many different processes that may not be accounted for (Bopp & Verhaeghen, 2018).

An interesting future direction would be to explore the transfer effects between other ECM (i.e. inhibition, task switching), which would lend to our understanding on how several factors in executive control interact with each other. In addition to being one of the few studies to look at transfer effects between ECM, the inclusion of neuroimaging data with the fNIRS at the pre-, mid- and post-training sessions and the data obtained during each training session will provide more details of the effects of cognitive training in future papers. Clues to explain our findings in transfer effects in both training groups may be found in our neuroimaging data and in previous neuroimaging studies. While different structures are hypothesized to be linked to certain abilities, various regions in the PFC, as previously discussed, are integral for EFs (Laguë-Beauvais et al., 2013; Royall et al., 2002; Tsuchida & Fellows, 2012). Overlapping neural networks may be the neurobiological underpinning that can allow us to explain why we see improvements in near- and far-transfer. A future paper is in preparation that analyses and interprets our neuroimaging results in conjunction with the behavioral findings hitherto discussed. An interesting inclusion for future projects would be a follow-up session. Studies have reported that working memory and DT training and transfer effects are maintained from three to 12 months later (Bherer et al., 2005; Borella et al., 2014; Borella et al., 2010; Buschkuehl et al., 2008; Dahlin et al., 2008; Jaeggi et al., 2011; Li et al., 2008). However, the long-term maintenance of cross-ECM transfer has been less explored and therefore would be an area rife for future inquiry. Another interesting avenue to investigate are the potential transfer effects across ECM in a population with executive dysfunction. Cognitive training studies have been conducted in patients with Parkinson disease (Leung et al., 2015) and Alzheimer's disease (Bahar-Fuchs, Clare, & Woods, 2013) to find a potential intervention that can help these populations in their IADL. Other research, less focused on the clinical aspect, with patients suffering focal frontal damage in the frontal lobes, has found that the left ventrolateral PFC may account for the common EF factor of the Unity/Diversity framework (Tsuchida & Fellows, 2012). Further investigation can not only identify key components in the organization of EF, but they can inform how interventions should be constructed and administered to help patients.

In conclusion, this study examined the effects of a three-week cognitive intervention on training and transfer effects in community-dwelling YA and OA. The hypotheses on near-transfer were verified, while far-transfer effects were found, albeit limited. This would suggest that transfer effects are more apparent in near-transfer tasks but still, to a lesser degree, occur in far-transfer tasks across ECM. These findings support the existence of transfer effects following training and highlights age-related differences in improvements.

General Conclusion

The aims of the present project were to identify the potential transfer effect following cognitive training, on the NB or DT tasks, in older and younger adults. The current literature reviewed suggests the existence of training effects, near-transfer effects and, albeit more limited and debated, far-transfer effects (Maraver et al., 2016). To study the limits of transfer from one ECM to another (updating and divided attention), 33 YA and 42 OA were randomly assigned to train on either task for three weeks. While behavioral and neuroimaging data were collected throughout the project, this project focused on participants' behavioral data at the pre-training and post-training evaluation sessions. Results showed that a three-week cognitive training program on either task resulted in near-transfer effects and, to a lesser degree, far-transfer effects. Interestingly, decreases in cost were only observed on one of the far-transfer tasks of the NB trained participants.

This project adds to the existing literature of transfer by demonstrating that transfer effects do indeed occur. In addition, as one of the few studies to specifically look at transfer between ECM, the findings that there is evidence of cross mechanism transfer is quite novel and suggests a few implications.

The lack of far-transfer on the NBt of the DT trained participants may be explained by one or a combination of two hypotheses. First, as previously mentioned, this finding could indicate that since the NBt was the last task done in the evaluation sessions, participants were cognitively fatigued. Second, far-transfer may be dependent on stimuli type (letters versus numbers) or, more broadly, only occur in specific NB tasks. In a study by Tsuchida and Fellows (2012), participants with focal damage in the PFC performed a series of tasks for shifting, inhibition and updating. Their results revealed that the inhibition and attentional shifting tasks, not the spatial updating task, were affected by lesions in the left ventrolateral PFC. Updating was instead impaired by lesions to other areas, thereby conflicting with the Unity/Diversity framework since they expected the performance to be impaired following lesions to an area believed to be the neural underpinning for the common EF factor. Interestingly, when they did the study with a letter NB task, their findings were in line with the Unity/Diversity model and the task was impaired following lesions to the left ventrolateral PFC (Tsuchida & Fellows, 2012). Given that the NB task is reliant on many processes (Bopp & Verhaeghen, 2018) and that these processes vary from one type to another, it could mean that training on a DT task can only transfer to specific types of NB tasks. This entails that DT training could be affecting a process utilized in the number NB and not the letter NB.

Considering that the neuroimaging data have not been analyzed yet, we must tread carefully when discussing compensation models. However, what we do see in the behavioral results are a diminishing of age-related differences in accuracy and RT following the training paradigm. Whether cognitive training allows for better compensation in terms of behavioral performance and how is still unclear.

As previously mentioned, the Unity/Diversity framework posits that the updating and shifting abilities consist of a common EF factor combined with an updating-specific or a shifting-specific component (Friedman & Miyake, 2017). As for the inhibition ability, it was found to be accounted for entirely by the common EF factor only (Friedman & Miyake, 2017). Our study further supports the Unity/Diversity framework due to the transfer findings. For near-transfer to occur, the underlying ability of one type of task needs to be trained such that performance on an untrained task utilizing the same ability improves. Such is the evidence we find when looking at the near-transfer effects in our training groups. For example, training on the

NB may have heavily targeted the updating-specific component of the framework, thus resulting in an improvement in the near-transfer task, NBt. Given that the NB consists of many different abilities (Bopp & Verhaeghen, 2018), one can posit that the common EF factor, may involve many components, all shared among the core EFs. Those sub-components would contribute to the cross-mechanism far-transfer that we have observed. According to our study, only a far-transfer of dual-task cost decrease was observed on the DT task for the NB trained participants. For YA trained on the DT task, the potential decrease in 3-back cost on their NB performance, as seen by the statistical trend, would indicate that coordination may constitute a piece of the common EF ability, albeit very limited. This would also explain the aforementioned far-transfer of dual-task cost on the DT task. However, the absence of the same phenomenon on the DTt task of the NB trained participants is curious. While it is difficult to find a definitive answer due to tasks requiring many processes, our results seem to suggest that a commonality between the DT and NB task is the ability to coordinate. While the DT was concerned with coordinating the execution of two motor responses upon perceiving multiple stimuli, the NB dealt with coordinating the continuously changing roles of the presented stimuli (Bopp & Verhaeghen, 2018; Lussier et al., 2012; Oberauer et al., 2003). Variations in the ability to coordinate has been observed to be integral in executive functioning (Kramer et al., 1999; Rigoli et al., 2012), which leads to the question of whether coordination is one of the sub-components of the common EF factor.

There are some caveats in this study that should be addressed. In a meta-analysis by Sala and Gobet (2017), beyond their skepticism towards the existence of far-transfer, they strongly suggested that future studies should include passive and active control groups. Although control groups help to better define training effects, their absence in this study is not a major set back considering that these effects are already well documented. As for the transfer effects, which are the focus of the article, they are inter-individual effects and thus do not necessarily require the use of controls. Additionally, as is the issue with many studies trying to tease apart ECM, the tasks used are complex and involve many different processes that may not be accounted for (Bopp & Verhaeghen, 2018).

An interesting future direction would be to explore the transfer effects between other ECM (i.e. inhibition, task switching), which would lend to our understanding on how several factors in executive control interact with each other. In addition to being one of the few studies to look at transfer effects between ECM, the inclusion of neuroimaging data with the fNIRS at the pre-, mid- and post-training sessions and the data obtained during each training session will provide more details of the effects of cognitive training as the data is analyzed. Clues to explain our findings in transfer effects in both training groups may be found in our neuroimaging data and in previous neuroimaging studies. While different structures are hypothesized to be linked to certain abilities, various regions in the prefrontal cortex discussed in the introduction are integral for EFs (Laguë-Beauvais et al., 2013; Royall et al., 2002). Overlapping neural networks may be the neurobiological underpinning that can allow us to explain why we see improvements in near- and far-transfer. A future paper is in preparation to analyse and interpret our neuroimaging results in conjunction with the behavioral findings hitherto discussed. An interesting inclusion for future projects would be a follow-up session. Studies have reported that working memory and DT training and transfer effects are maintained from three to 12 months later (Bherer et al., 2005; Borella et al., 2014; Borella et al., 2010; Buschkuehl et al., 2008; Dahlin et al., 2008; Jaeggi et al., 2011; Li et al., 2008). However, the long-term maintenance of cross-ECM transfer has been less explored and therefore would be an area rife for future inquiry. Another interesting avenue to investigate are the potential transfer effects across ECM in a population with executive dysfunction. Cognitive training studies have been conducted in patients with Parkinson disease (Leung et al., 2015) and Alzheimer's disease (Bahar-Fuchs et al., 2013) to find a potential intervention that can help these populations in their IADL. In addition, previous literature with patients with focal frontal damage has found that the left ventrolateral PFC may account for the common EF factor of the Unity/Diversity framework (Tsuchida & Fellows, 2012). Further investigation can not only identify key components in the organization of EF, but they can inform how interventions should be constructed and administered to help patients.

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