Maintaining Executive Function in the Aging Population

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Executive functions are a group of higher-level cognitive abilities most commonly associated with the function of the prefrontal cortex (Gibb et al., 2021; Jurado & Rosselli, 2007). There is some consensus within the literature that there are three core executive functions (EFs) which include: inhibition, updating (often referred to as working memory), and shifting (often referred to as cognitive flexibility) (Miyake et al., 2000; Diamond, 2013). These core functions give rise to more complex aspects of executive function such as planning, problem-solving, goal-setting, and self-regulation (Diamond, 2013; Gibb et al., 2021).

Research suggests a general decline in the performance of the core EFs (inhibition, updating, shifting) with aging (Jurado & Rosselli, 2007; Diamond, 2013). This decline in executive function seems to be associated with normal age-related changes in specific regions of the brain, particularly the frontal lobes (Jurado & Rosselli, 2007). Executive functioning skills are necessary for our day-to-day living; therefore, we must have a thorough understanding of them in the aging population as well as ways in which these skills can be improved to promote independence in our senior population.

The purpose of this review is to investigate the literature regarding executive functioning in the aging population as well as evidence-based interventions for improving executive function in seniors. To begin, an overview of the aging brain will be given. Next, an in-depth examination of the pattern of decline of EFs in seniors will be provided. Finally, a review of interventions improving EFs in seniors will be conveyed. For the purposes of this review, seniors are defined as 55 years and older and executive functions refer to inhibitory control, working memory, and cognitive flexibility.

Overview of the aging brain*:*

In their review of executive functions, Jurado and Rosselli (2007) explain that the decline in executive abilities observed with aging seems to be associated with morphological changes in the brain, particularly the frontal lobes, as a normal process of aging. One of the morphological changes associated with aging is a reduction in brain volume. In their review, Hedman et al. (2012) discovered that after age 35, brain volume decreases at a rate of approximately 2% per year and increases to 5% at the age of 60. The rate of decline continues to increase past 5% in people over 60 years of age (Hedeman et al., 2012). However, the reduction in brain volume does not occur to the same extent in all regions of the brain (Peters, 2006). For example, in a cross-sectional study conducted by Decarli et al. (2005), they found that the frontal lobes showed the greatest decline in volume with age (approximately 12% across the cohort), followed by the temporal lobes (approximately 9%). Specifically, as a normal process of aging, the brain undergoes a reduction of both gray and white matter (Lee & Kim, 2022). In a longitudinal study conducted by Resnick et al. (2003), they found significant age-related tissue loss for both gray and white matter in a subgroup of 24 healthy older adults. Furthermore, Resnick et al. (2003) concluded that the decline in gray and white matter volume was greater in the frontal and parietal lobes compared to the temporal and occipital lobes. Lastly, the cerebral cortex thins with increased aging. In a longitudinal study examining age-related changes in cortical thickness, Thambisetty et al. (2010) concluded that there is an age-related decline in cortical thickness and that the frontal and parietal lobes exhibit greater rates of decline compared to the temporal and occipital lobes. Taken together, these findings suggest that the frontal lobes are particularly vulnerable to age-related change in the brain, which may explain the age-related decline in cognitive processes of the frontal lobes such as executive functions (Jurado & Rosselli, 2007).

Executive Functions:

As previously described, there are three core executive functions which include: inhibitory control, working memory, and cognitive flexibility (Miyake, 2000; Diamond, 2013). Inhibitory control refers to the ability to control and override our automatic responses and respond in an appropriate manner (Diamond, 2013). Inhibitory control makes it possible for us to choose how we would like to react to and behave in a particular situation (Diamond, 2013). Regarding attention, inhibitory control allows us to selectively attend to tasks while blocking out irrelevant or distracting stimuli (Diamond, 2013).

Working memory is the ability to temporarily hold information in the mind and mentally manipulate it to carry out other cognitive tasks such as decision-making, planning, and reasoning (Diamond, 2013). Working memory also refers to the ability to separate elements of an integrated whole and recombine them in new and creative ways (Diamond, 2013). Working memory and inhibitory control are thought to co-occur and support one another (Diamond, 2013).

Lastly, cognitive flexibility refers to the ability to adjust perspectives and alter our thinking and behaviors in response to changing environmental demands and shifts in priorities (Diamond, 2013). Cognitive flexibility allows us to effectively switch our attention between tasks that require different ways of thinking. Cognitive flexibility relies on both inhibitory control and working memory (Diamond, 2013).

Executive Functions in the Aging Population:

Research demonstrates that there is a correlation between a decline in performance on tasks measuring EFs and increased age. In their study examining the developmental trajectories of executive function, Ferguson et al. (2021) found that performance on the Stroop Colour-Word

Task, a common measure of inhibitory control, began to decline at approximately 36 years of age and continued to decline until 86 years of age (oldest age in the sample). Similarly, performance on the Operation Span Task (OSpan), a measure of working memory, began to decrease at approximately 30 years of age and continued to decline until 86 years of age (Ferguson et al., 2021).

To measure cognitive flexibility two tasks were administered: the single task and the mixed task. In both tasks, participants were presented with a 2x2 matrix (four quadrants) on a computer screen. Stimuli (coloured shapes: circle/triangle, blue/yellow) were presented one by one in the four quadrants. In the single task, the participants had to identify the shape (circle or triangle) of the stimuli presented on a screen in one block (the four quadrants), then identify the colour (blue or yellow) of the stimuli in a second block. In other words, participants had to switch from task one (identifying the shape of the stimuli) to task two (identifying the colour of the stimuli) then back to task one, and so on. However, in the mixed task, participants were required to identify the shape of the stimuli in the upper-left and upper-right quadrants, then identify the colour of the stimuli in the lower-right and lower-left quadrants (Ferguson et al., 2021).

Interestingly, the results revealed a dissociation between switch cost (single task) and mixing cost (mixed task). Ferguson et al. (2021) concluded that there was a *decrease* in switch cost (improvement in cognitive flexibility) beginning at 10 years old and improving as age increased, and an *increase* in mixing cost (decline in cognitive flexibility) beginning at age 10 and declining as age increased. Ferguson and colleagues (2021) explain that these findings suggest that younger people have more difficulty switching tasks, whereas older adults have more difficulty maintaining task sets in their working memory,

Interventions Improving Executive Function in the Aging Population

Executive functions are implicated in nearly every aspect of life including physical and mental health and quality of life (Diamond, 2013). Interestingly, in the year 2000, Cahn-Weiner and colleagues reported that executive dysfunction was the best predictor of functional decline in seniors, more so than other measures of cognitive function such as memory, language, and psychomotor speed. In the study conducted by Cahn-Weiner et al. (2000), functional decline was measured by the Occupational Therapy Assessment of Performance and Support (OTAPS), which examines four areas of everyday functioning including Safety, Meal Planning and preparation, Medical Administration, and Money Management. Thus, effective interventions aimed at maintaining executive function in seniors are needed. In this paper, I will be looking at three possible interventions which include: physical activity, cognitive training, and active music-making.

Physical Activity:

In this section, I will be looking at the impact of physical activity on executive function in the aging population. Multiple studies, such as the research done by Xiong et al. (2021), show that physical activity significantly improves executive function in seniors. In their meta-analysis examining the effects of physical exercise on executive function, Xiong et al. (2021) found that regular physical exercise training had a significant, positive benefit in improving executive function in cognitively healthy older adults. Further analysis of exercise type and intervention length revealed that aerobic exercise training (walking, treadmill training, seated cycling) ranging from 13-26 weeks in length led to a larger significant improvement in working memory compared to mind-body exercise (Tai Chi, yoga) and resistance training (muscle training). Regarding inhibitory control, further analysis found that only aerobic exercise training that was six months in length led to a significant improvement in inhibitory control whereas, mind-body exercise and resistance training did not, suggesting that interventions that seek to target inhibitory control should consider a minimum duration.

Lastly, further analysis found that only aerobic exercise ranging from 13-26 weeks in length, and resistance training significantly improved cognitive flexibility, whereas mind-body exercise did not. However, Xiong et al. (2021) explain that there were limited studies examining mind-body exercise and resistance training included within their meta-analysis, which may be a potential reason why mind-body exercise and resistance training did not show any significant improvement in inhibitory control and cognitive flexibility. Therefore, a further examination of the effect of mind-body exercise and resistance training on executive function in seniors should be considered.

Additionally, in an experimental study investigating the effect of aerobic exercise on brain volume in seniors, Colcombe et al. (2006) found that aerobic exercise increased both gray and white matter volume, primarily in the frontal and temporal cortices, both of which have been associated with age-related deterioration and cognitive decline. In Colcombe's study, seniors engaged in aerobic exercise by walking on a motorized treadmill for one hour a day, three times a week, and experienced a 16.1% increase in VO2 peak (oxygen uptake). The findings of this study suggest that aerobic exercise seems to reverse age-related brain deterioration and therefore could potentially reverse or slow down the decline of cognitive processes that are associated with those areas, such as executive function.

Lastly, in their meta-analysis examining the effect of exercise training on executive function, Chen et al. (2020) found that exercise training interventions significantly improved executive function in older adults, although the effect size was small. Chen et al. (2020) found that exercise interventions are beneficial in improving executive function regardless of the type of exercise being performed, how frequently the exercise is performed, the level of intensity of the exercise, the time duration of the training session, the length of the training period (how many weeks) or the sex of the participant. However, they did find that exercise training that was moderate in frequency (3-4 times per week), vigorous in intensity (6.01–9.00 METs; 14–16 on the RPE of Borg scale; 61–85% HRR/VO2max; 71–90% HRmax; 71–84% 1-RM), was approximately 45-60 minutes, and one to three months in length produced more beneficial effects on executive function. Furthermore, the exercise type that produced the most beneficial effects was “other forms of exercise” which included dance and coordination exercises; followed by Tai Chi and yoga, resistance exercise, combined exercise (two or more exercises), and aerobic exercise. However, Chen et al. (2020) explain that the finding regarding exercise type should be interpreted with caution as there were a small number of effect sizes for all types of exercise except for aerobic exercise.

Interestingly, Chen et al. (2020) found that there were no significant benefits of physical exercise on executive function in participants over the age of 75. Therefore, a further, in-depth examination of the effects of physical activity on executive function in seniors over the age of 75 should be considered. Lastly, Chen et al. (2020) included both cognitively healthy older adults and older adults with mild cognitive impairment (MCI) in their meta-analysis. Physical exercise had significant benefits for both types of participants, however, the benefits were larger for those who were cognitively healthy in comparison to those with MCI (Chen et al., 2020).

In conclusion, regular physical activity, particularly aerobic exercise, significantly improves executive function in the aging population. Therefore, a physical exercise component should be considered when developing a curriculum to maintain executive function in seniors.

Active Music Making:

In this section, I will be reviewing the impact of active music-making on executive function in the aging population. Multiple studies, such as the research done by Bugos et al. (2007), provide evidence that learning to play a musical instrument significantly improves aspects of executive function in musically naive seniors (ages 60-85). In this study, participants in the intervention group were required to attend a 30-minute piano lesson and complete three hours of practice per week. Bugos and colleagues (2007) found that participants who underwent six months of piano lessons showed significant improvements, compared to a non-active control group, on the Trail Making Test- B and the Digit Symbol Test, which are measures of cognitive flexibility and working memory, respectively (de Assis Faria et al., 2015). However, the beneficial effects of the piano lessons for working memory disappeared after a three-month period in which the intervention was discontinued (Bugos et al., 2007).

In another study examining the effect of musical training on cognitive function in musically naive seniors (ages 60-84), Seinfeld et al. (2013) found that participation in a four-month group piano training program led to significant improvements in the Stroop Task, a measure of inhibitory control. In this study, participants in the intervention group were required to attend group piano lessons once per week that lasted approximately one and a half hours. In addition, participants received three homework exercises per lesson in which they were required to practice independently for 45 minutes per day for at least five days a week.

Interestingly, Seinfeld et al. (2013) found that there were no significant differences between the intervention and active control group on measures of cognitive flexibility (TMT-B) and working memory (Digit Symbol Test). Seinfeld and colleagues (2013) highlight that this latter finding is in contrast to the research done by Bugos et al. (2007) (the study described previously). Seinfeld et al. (2013) speculate that it may be a result of the shorter duration of their training program.

In conclusion, the research suggests that regular, active music-making significantly improves executive function in musically naive and cognitively healthy seniors. Therefore, an active music-making component should be taken into account when developing a curriculum of games to improve executive functioning in the aging population. However, it is important to note that the studies included in my review only focused on the effect of piano training. Therefore, further investigation into the impact of other musical instruments (e.g., drums) may be worthwhile.

Future students may consider examining the effect of other musical activities such as music listening and singing, on seniors' executive function. For example, in 2007, Mammarella, Fairfield & Cornoldi concluded that passive exposure to classical background music (excerpt of Vivaldi's "Four Seasons") significantly improved older adults' performance on measures of working memory. Moreover, in 2020, Miyazaki & Mori concluded that frequent karaoke training (one-hour training session and one hour of homework per week for 12 consecutive weeks) led to significant improvements in overall scores on the Frontal Battery Assessment, which consists of several neuropsychological tasks that assess frontal lobe function, including inhibitory control and mental flexibility (Dubois et al., 2000). Although these two studies seem to suggest that music listening and singing may improve aspects of executive functioning in seniors, a more in-depth examination is needed.

Cognitive Training:

In this section, I will be looking at the effect of cognitive training on executive function in an aging population. From their meta-analysis of 31 randomized controlled trials, Chiu et al.

(2017) concluded that cognitive-based training has a significant and moderate effect on executive function in healthy seniors (>65 years old). Additionally, subgroup analysis revealed that the effect size was significantly greater when the intervention was three or more times per week and if there were 24 or more total training sessions. This suggests that for cognitive training to be beneficial, it must be provided frequently (Chiu et al., 2017).

Included within the meta-analysis described above was a study conducted by Nouchi and colleagues in 2012. Nouchi et al. (2012) found that playing a brain-training game led to significant improvements in executive function as measured by the Frontal Battery Assessment (FAB) and the Trail-Making Test Part B (TMT-B). As previously mentioned, the FAB consists of tasks that assess functions of the frontal lobe, such as inhibitory control and cognitive flexibility, and the TMT-B is predominantly used as a measure of cognitive flexibility (de Assis Faria et al., 2015). In the study by Nouchi and colleagues (2012), participants in the brain training group were required to play Brain Age, which is a video game that is played on a portable console (Nintendo DSi). Participants received the instruction that they were to play Brain Age for at least 15 minutes per day, five days a week, for a total of four weeks. Participants were allowed to play a total of eight games, three of which they were required to play each training day. The three games that participants were required to play included components of calculation, reading aloud, and memory.

Another study included in the meta-analysis described above concluded that a TV-based cognitive training program led to significant improvements in tests of working memory and executive control in healthy older adults aged 60-87 years (Shatil et al., 2014). Compared to the active control group, participants in the brain training group significantly improved on both the Trail Making Test and the Digit Span Test. All participants in the study were required to attend three 20-minute training sessions for a total of eight weeks. In the cognitive training group, participants had to complete three of 21 training exercises per session which consisted of several cognitive tasks, including divided attention, inhibition, planning, focus, updating, monitoring, memory, perception, and naming (Shatil et al., 2014). Whereas participants in the control group engaged in three non-cognitive, TV-based activities.

Lastly, in their study investigating the effect of cognitive training on executive function, Chiu and colleagues (2017) concluded that executive function training significantly improved performance on measures of cognitive flexibility and working memory. However, no significant improvements were found in measures of inhibitory control. In this study, all participants attended a 30-minute training session three times a week for eight weeks (24 sessions total). During the training session, participants in the cognitive training group completed several computerized cognitive training modules whereas participants in the active control group engaged in a variety of “individualized passive information activities” which included reading e-books and solving online puzzles (Chiu et al., 2017, p. 1103).

The cognitive training modules completed by the experimental group consisted of three major components which included mental set shifting, working memory, and inhibition. The set-shifting component focused on strengthening the participants’ ability to shift between distinct tasks or operations. This was done using calculation and logical reasoning training. The working memory element “...trained the participants in updating and monitoring their working memory performance” (Chiu et al., 2017, p. 1103). This was done using “real-life” shopping scenarios in which participants had to locate and purchase specific grocery items. Lastly, “The inhibition component trained the participants to deliberately suppress their originally expected behaviours and instead perform new target behaviours” (Chiu et al., 2017, p. 1104). They did this using a

Plan-a-Day approach in which the participants were expected to organize a full-day schedule including times and places. This trained inhibitory control as participants had to meet the requirements for arriving at various places on time, and therefore had to suppress any behaviours that may interfere with completing the task (Chiu et al., 2017)

However, it is important to note that the cognitive training program had both a significant immediate and long-term effect (up to six months) on mental set shifting, however, training only had a significant immediate effect on working memory. Similar to the meta-analysis previously described, this finding suggests that for cognitive training to be effective, it must be practiced consistently. In conclusion, the above studies seem to suggest that consistent cognitive training can improve or maintain aspects of executive function in older adults. Therefore, when developing a curriculum of games to maintain executive function in seniors, a cognitive training component should be considered.

Conclusion:

This review examined the literature regarding executive function in seniors, and possible interventions to improve executive functioning in the aging population. During middle adulthood, the three core executive functions -inhibitory control, working memory, and cognitive flexibility- begin to decline, and continue to decline with aging. This decline in executive functioning seems to be associated with typical age-related brain changes, particularly in the frontal lobes. Executive functions are necessary for successful day-to-day living and maintaining independence in seniors. Thus, it is crucial to find interventions that improve these abilities in older adults. Throughout this paper, I have examined three interventions -physical activity, active music-making, and cognitive training- as possible means to improve executive function in seniors. Physical activity, particularly aerobic exercise, when participated in regularly, has been shown to lead to improvements in tests of executive function in older adults. Similarly, participation in both individualized and group piano lessons was beneficial in improving executive function in seniors. Lastly, cognitive training that targets aspects of executive function also leads to significant improvements in measures of executive function such as the TMT-B and Digit Span. However, for cognitive training to be effective, it must be engaged in consistently. Therefore, when developing a curriculum of games aimed to improve executive functioning in seniors, physical activity, active music-making, and cognitive training should be implemented in some way.

Future Directions:

Future students working on this project should consider conducting a more in-depth examination of each of the three interventions I discussed to gain a deeper understanding of their impact on executive function in seniors. Additionally, future students may consider investigating the effect of other interventions such as social interaction and art therapy, on executive functioning in seniors. Furthermore, students should examine the combined effects of interventions (eg: physical activity and cognitive training) on improving executive function in seniors. Lastly, future students should investigate which interventions would be simplest to implement in a curriculum format, while providing the greatest benefit to seniors' executive function.

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