EXECUTIVE FUNCTIONS AND AGEING

Published: Pires, L., Simões, M. R., Leitão, J. A., & Guerrini, C. (2016). As funções executivas e envelhecimento [Executive functions and ageing]. In H. Firmino, M., Simões, & J., Cerejeira. (Eds.) *Saúde mental nas pessoas mais velhas* [Mental health in older people] (pp. 93-108). Lisboa: Lidel Edições Técnicas.

1.1. Introduction

Executive functions (EF) are the "director" that drives other cognitive functions in order to evaluate and perform an action (Goldberg, 2001). These functions allow us to be constantly updated in order to organize relevant information. They also help to inhibit irrelevant information. Finally, they allow to make decisions to facilitate the adaptation to new situations or to contexts of greater complexity (Collette, Hogge, Salmon, & Van der Linden, 2006; Jurado & Rosselli, 2007).

An important feature of EF, that makes them especially relevant to mental health, is the emotional and social regulation of behaviour (Bechara, Damasio, Tranel, & Damasio, 1997; Dunn, Dalgleish, & Lawrence, 2006). EF are often referred as a set of functions in the literature. However, there is a controversy about the existence of different independent functions or the existence of unity among EF. Some researchers suggest that there is a single executive system that is not subdivided into different components (Duncan, Emslie, Williams, Johnson, & Freer, 1996; Kimberg, D'Esposito, & Farah, 1997). Other researchers advocate the existence of different EF (see Table 1), and even of distinct subprocesses in each EF (Burgess & Shallice, 1994; Friedman et al., 2006; Royall et al., 2002). Organizing, sequencing, monitoring, inhibiting and updating are some examples of cognitive functions that can perform executive functions (Elias & Treland, 2000; Royall et al., 2002; Stuss, Pogue, Buckle, & Bondar, 1994).

Table 1. Examples of cognitive functions that have been studied for the understanding of the executive system.

Planning (Sorel & Pennequin, 2008)
Prospective Memory (McDaniel & Einstein, 2011)
Inhibition (Andres, Guerrini, Phillips, & Perfect, 2008)
Cognitive Flexibility or Shifting (Kiesel et al., 2010)
Divided Attention (Verhaeghen & Cerella, 2002)
Selective Attention (Haring et al., 2013)
Working Memory (Toepper et al., 2014)
Abstraction (Goh, Beason-Held, An, Kraut, & Resnick, 2013)
Decision Making (Peters, Dieckmann, & Weller, 2011)

In this chapter, especially dedicated to the effects of ageing on EF, we will follow an intermediate approach advocated by Miyake et al. (2000) according to which the executive system is composed of distinct but interrelated functions.

EF have traditionally been associated with the functioning of frontal lobes and their disruption to specific behaviours such as impulsivity, disinhibition, inability to detect errors, greater cognitive slowing and forgetfulness related to attention deficits (Jurado & Rosselli, 2007). Initially, the EF were studied as superior cognitive functions that like memory or language, could be directly and independently assessed (Tranel, Anderson, & Benton, 1994). Later EF were interpreted according to a cybernetic perspective (Royall et al., 2002), following which EF interact with non-executive functions (nEF) in order to control the execution of complex activities. In this context, EF assume a role that is metacognitive and its implementation requires the effective activity of other cognitive functions such as attention, memory and language.

Among age-related cognitive changes, executive deficits are predominant (West, 2000) and are an important mediator of the effects of ageing on other cognitive functions (Salthouse, Atkinson, & Berish, 2003). However, some EF are more susceptible than others to the effects of ageing (Crawford, Bryan, Luszcz, Obonsawin, & Stewart, 2000; Lin, Chan, Zheng, Yang, & Wang, 2007).

In this chapter, we will first address the different cognitive and neuroanatomical models that contributed to a better understanding of EF. Next, we will focus on EF neuropsychological assessment, highlighting the different evaluative tools that have been used to test these functions. Finally, we will consider the different explanatory models of cognitive ageing, with a special focus on the models that value the role of EF, systematizing the changes that occur in different EF with ageing.

1.2. Cognitive and neuroanatomical models of executive functions

Frontal lobes have unique characteristics that associate them with EF (Royall et al., 2002). They play a metamodal role, working on information that has already been processed at a lower level. The frontal region of the brain is also the system that receives more information from the cortical-basal ganglia-thalamic circuits and has more connections with other cerebral regions than any other cortical region. Frontal lobes are the main receptors of limbic system information, integrating cognitive and sensory-motor information with emotional valence and internal motivation. Even before this understanding of the structure and function of the frontal lobes, Luria, Karpov, and Yarbuss (1966) published a case study of a 54-year-old patient with a tumour in the right frontal lobe. The patient was oriented in time and space but euphoric, emotionally unstable, with concentration deficiencies and error *perseveration* even after correction by the examiner. Luria et al. (1966) associated the functioning of the frontal lobes, and in particular the prefrontal cortex, to the EF, responsible for the programming, regulation and monitoring of human behaviour. Later, Norman and Shallice (1986) modified the model proposed by Luria et al. (1966) by dividing the frontal system into two main systems, the contention scheduler, responsible for evaluating the relative importance of different behaviours, selecting the most appropriate behaviour and defining the order in which they should be executed when facing a routine situation, and the Supervisory Attentional System (SAS), responsible for the regulation and sequencing of new behaviours. This model is particularly important because it allows us to understand that even if the executive system is preserved in the person's daily life, it may be impaired in adapting to new situations. Another model considered relevant is the hierarchical model of EF proposed by Stuss and Benson (1986) that emphasizes the interaction of distinct EF and nEF at different levels. According to this model there are four higher-order EF: anticipation, goal selection, pre-planning and monitoring. These higher hierarchical functions would control other EF such as initiative and sequencing (which would involve working memory, prospective memory, and inhibition). And it would be these second-order EF that would direct nEF such as attention, memory, and language. Thus, this model implies the impossibility of evaluating the functioning of the executive system without the evaluation of the cognitive systems coordinated by it. Another important point in Stuss and Benson's (1986) model is the reference to self-awareness. Self-awareness would be the awareness of ourselves, of the goals we intend to achieve, but also of the awareness of our successes and failures in pursuit of those goals, necessary for us to be able to readjust our behaviours in order to better achieve the goals. For Stuss and Benson (1986) self-consciousness would be at the top of the hierarchy, directing the higher order EF.

Subsequently, Stuss, Shallice, Alexander and Picton (1995) identified different neuronal substrates for different EF. For example, inhibition would be related to the dorsolateral prefrontal cortex while planning would involve not only areas of the prefrontal cortex but also areas of the parietal cortex. Thus, the results found by Stuss et al. (1995) suggest that different EF have different anatomical substrates. Further studies using brain imaging techniques have shown that there is indeed a specificity of EF but, at the same time, there is a commonality that is observed at both cognitive and brain levels. Table 2 shows different studies that aimed to evaluate the anatomical substrates of EF. These studies are divided into two types: cognitive subtraction studies and cognitive conjunction studies. Cognitive subtraction studies involve the subtraction between the brain areas activated during the performance of a task involving a particular cognitive component under investigation and the brain areas activated during a control task that shares all the characteristics of the experimental task except the cognitive component under investigation. Conjunction studies can be seen as an extension of previous ones because they involve a series of subtractions, seeking to make two or more comparisons in order to isolate the brain areas responsible for processing the cognitive component of interest (Price & Friston, 1997). The set of studies presented in Table 2 suggest that although different EF anatomic substrates have been found, EF seems mainly associated with prefrontal and parietal brain regions.

Table 2. Neuroanatomical substrates associated with different Executive Functions identified with cognitive subtraction studies and with a cognitive study of conjunction.

COGNITIVE SUBTRACTION STUDIES			
Authors	Task (EF)	Method	Brain Areas
Phelps, Hyder, Blamire, & Shulman (1997)	Phonemic Verbal Fluency task (Initiation, Cognitive Flexibility)	FMRI[a]	Lower Left Frontal Turn, Anterior Cingulate, Dorsolateral Prefrontal Cortex, Lower Parietal Turn
Van der Linden et al. (1999)	*Continuous Performance Task (Update Working Memory)*	PET[b]	Anterior Prefrontal Cortex and Dorsolateral Prefrontal Cortex
Jahanshahi, Dirnberger, Fuller, & Frith (2000)	*Random Number Generation task (Cognitive Flexibility)*	PET	Left Dorsolateral Prefrontal Cortex, Anterior Cingulate, Upper Bilateral Parietal Cortex
Aron, Fletcher, Bullmore, Sahakian, & Robbins, (2003) Collette et al. (2001)	*Stop-signal task and Hayling task (Inhibition)*	FMRI	Prefrontal Cortex, Cingulate Circuit, Parietal Cortex, Temporal Cortex
Newman, Carpenter, Varma, & Just (2003)	*Tower of London (Planning)*	FMRI	Prefrontal Cortex - Right Part (Elaboration of the Plan) Left side (Plan execution), Bilateral Upper Parietal Cortex, Bilateral Occipital Cortex
Perianez et al. (2004)	*Wisconsin Card Sorting Test - WCST (Cognitive Flexibility)*	MEG[c]	Anterior frontal rotation, Anterior Cingulate Cortex and Supra Marginal Gyrus (Parietal Cortex)
Hagen et al. (2014)	*Trail Making Test - TMT (Cognitive Flexibility)*	FNIRS[d]	Dorsolateral Prefrontal Cortex, Frontopolar Cortex and Broca Area.
COGNITIVE CONJUNCTION STUDY			
Authors	Task (EF)	Method	Brain Areas
Collette et al. (2005)	*Different Continuous Performance tasks (Update Working Memory)*	PET	Anterior Prefrontal Cortex and Dorsolateral Prefrontal Cortex, Pre-Motor Cortex and Cortex Supplemental Motor, Lower Left Frontal Turn
	Switching Tasks (Cognitive Flexibility))		Supra-marginal gyrus, left pre cuneus and left part of the parietal cortex (parietal lobe)
	Stroop task and Antisaccade task (Inhibition)		Lower Right Frontal Cortex

	Work Memory Update Tasks + Cognitive Flexibility Tasks + Inhibition Tasks	PET	Upper Left Parietal Groove, Right Intra-Parietal Groove, Right Middle and Bottom Front Turn

[A] FUNCTIONAL MAGNETIC RESONANCE IMAGING OR FUNCTIONAL MRI; [B] POSITRON EMISSION TOMOGRAPHY; [C] MAGNETOENCEPHALOGRAPHY; [D] FUNCTIONAL NEAR-INFRARED SPECTROSCOPY.

Another aspect particularly relevant to the understanding of EF in mental health is the role of the frontal lobes and, in particular, the prefrontal cortex, on emotions, social behaviour, and decision making. This role is emphasized in Damasio's "*somatic marker hypothesis*" (1996). In Damasio's model (1996) emotions would be mediated by the connections of the prefrontal cortex to other cortical regions such as the ventromedial cortex and subcortical regions such as the thalamus, amygdala and hypothalamus. Patients with lesions in the prefrontal cortex and, specifically, lesions in the ventromedial region, present a deficit in decision making but maintain other cognitive abilities totally preserved. This model thus identifies a component of EF that is primarily responsible for emotional regulation rather than cognitive control.

1.3. Executive functions assessment in older adults

The frontal lobes occupy a large area of our brain and most of the EF also involve the functioning of other cerebral regions, such as the parietal lobes, and for this reason it is difficult to devise a single instrument for the assessment of EF. In order to achieve this aim, multiple tests and even different assessment test batteries have been developed (Salthouse, 2005). Table 3 identifies examples of different evaluation tools and the executive components they are intended to examine.

Table 3. Examples of Executive Functions assessment tests.

Tests	Function
Tower of London test (Shallice, 1982); *Tower test* (*Delis-Kaplan Executive Function System* - DKEFS; Delis, Kaplan, & Kramer, 2001); *Zoo Map test* (*Behavioural Assessment of the Dysexecutive Syndrome* - BADS; Wilson, Alderman, Burgess, Emslie, & Evans, 1996).	Planning - organize behaviour in order to achieve a particular goal.
Stroop (Stroop, 1935; Castro, Martins & Cunha, 2003; Fernandes, 2009); *Hayling Sentence Completion test* (Burgess & Shallice, 1996).	Inhibition - removing information that is not relevant or has become irrelevant and restricting to the interference of inappropriate information.
Controlled Oral Word Association Test – Phonemic Fluency Test (COWAT; Benton & Hamsher, 1989; Cavaco et al., 2013a).	Initiation - initiate a task or activity and independently generate ideas, responses, or problem-solving strategies.
Trail Making Test - Part A minus Part B (TMT; Retain, 1958; Cavaco et al. 2013b); *Wisconsin Card Sorting Test* (WCST; Grant & Berg, 1948).	Cognitive flexibility - switching between two tasks or between two ways of performing the same task.
Semantic Fluency Test - *Animals* (Cavaco et al., 2013a).	Categorization - ability to organize into categories objects, people or events, recognizing the similarities between them and the differences that separate one category from another.
Corsi (Corsi, 1972; Constâncio, 2009); Letter-Number Sequencing (*Wechsler Adult Intelligence Scale – third edition* - WAIS-III; Wechsler, 1997a, 2008a); Digit Span – Backward (*Wechsler Memory Scale– third edition* - WMS-III; Wechsler, 1997b, 2008b)	Working Memory - information manipulation and temporary storage of information.
Cambridge Prospective Memory Test (CAMPROMPT; Wilson et al., 2005); Rivermead Behavioural Memory Test (RBMT; Wilson, Cockburn, & Baddeley, 1986);	Prospective Memory - remember a planned task that will have to be developed in the future.
Similarities (WAIS-III; Wechsler, 1997a, 2008a)	Abstraction - conceptual process by which general rules or concepts are derived from specific, concrete objects.
Iowa Gambling task (Bechara, Damasio, Damasio & Anderson, 1994)	Decision Making - Select an action or thought among several alternatives.
d2 Test of Attention (Brickenkamp & Zilmer, 1998; Ferreira & Rocha, 2006; Canelas, 2014)	Selective attention - Selective focus on one aspect of the information while ignoring the remaining information
Difference between time per target in two tasks: *Telephone Search* and *Dual task Telephone Search*	Divided Attention - concentration on two or more aspects of information at the same time.

(*Test of Everyday Attention*; Robertson, Ward, Ridgeway & Nimmo-Smith, 1996)	

Although each instrument presented in Table 3 aims to evaluate a specific EF (e.g., the Wisconsin Card Sorting Test - WCST - intends to assess cognitive flexibility), the fact is that however simple the instrument or task will be, other EF will always be involved (e.g. WCST in addition to cognitive flexibility is also involved inhibition or planning) and even nEF (e.g., WCST involves memory and language processes). Thus, it is important, in the neuropsychological evaluation of the EF, to assess nEF in order to identify whether there is a deficit in the executive domain, in non-executive domain or both.

In addition to the tests developed for the assessment of specific domains of EF, there are also neuropsychological assessment batteries whose objective is the comprehensive evaluation of EF. Among the neuropsychological assessment batteries of EF that have been most used are the Delis-Kaplan Executive Function System (D-KEFS, Delis, Haplan, & Kramer, 2001) and the Behavioural Assessment of the Dysexecutive Syndrome (BADS; Wilson, Alderman, Burgess, Emslie, & Evans, 1996). D-KEFS is composed of 9 tests that allow the evaluation of the EF components whose neuronal substrate is related to the frontal lobe, such as cognitive flexibility, inhibition or planning. BADS is also sensitive to abilities dependent on the functioning of the frontal lobes but was specially constructed in order to evaluate the EF in a way close to the person's daily life. In addition to the six tests that comprise it and which aim to evaluate EF such as cognitive flexibility, planning and monitoring, BADS also includes a questionnaire of 20 items, the Dysexecutive Questionnaire (DEX; Wilson, Alderman, Burgess, Emslie, & Evans, 1996), which aims to evaluate the impact of a possible executive dysfunction on day-to-day tasks, particularly it aims to identify behavioural, personality, motivational, emotional or cognitive changes.

Despite the existence of different EF tests and EF test batteries, there is still no consensus regarding the test or group of tests ideal for the evaluation of these functions. For example, in a review by Royall et al. (2002), the authors present 46 studies conducted between 1983 and 2001 in which 34 different tests are used for EF assessment. There are, however, some criteria that can be used to select the most appropriate test or test battery in a given situation. First, it is necessary to contextualize the assessment that will be carried out. What is the main objective of the assessment? The assessment of a particular

EF, with a specific instrument, or the comprehensive assessment of executive functioning, with a battery of tests? What is the target population? This is important to select tests that have been used in previous studies with the type of population being assessed. Related to this last question is the representativeness of the test in previous studies.

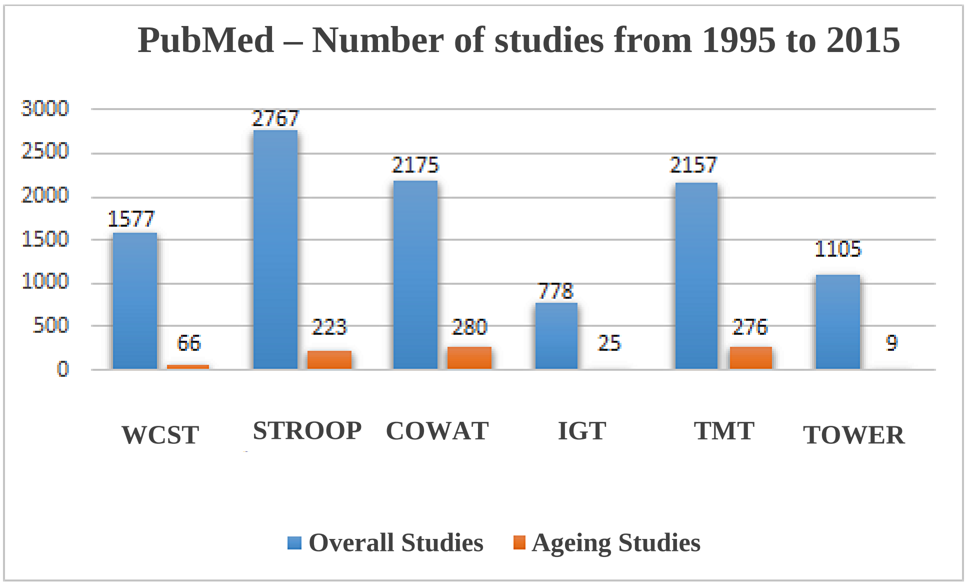

Figure 1. Number of studies that were published between April 1st 1995 and April 1st 2015, in the PubMed Central archive, which mentioned the Tower of London (TOWER), the Stroop Colour-Word test (STROOP), the Wisconsin Card Sorting Test (WCST), the Trail Making Test (TMT), the Controlled Oral Word Association Test (COWAT), and the Iowa Gambling Task (IGT). Among these studies, the number of the ageing studies was identified.

Figure 1 presents the results of a literature search that intended to identify the number of studies that were published between April 1, 1995 and April 1, 2015, in the PubMed Central archive, which mentioned the following tests: Tower of London, Stroop Colour-Word test, the Wisconsin Card Sorting test (WCST), Trail Making Test (TMT), Controlled Oral Word Association Test (COWAT) and the Iowa Gambling Task (IGT). This literature search comprised two distinct phases. In the first phase the tests were selected and a search was conducted for the number of studies that mentioned them during the 20 years period mentioned above (1995-2015). Only tests that have been used as specific EF measures were considered. The EF tests included in this literature search were selected also by its use in clinical settings, with the inclusion of the most often used tests. In the search for the number of studies that mentioned those tests, only the studies published in the form of complete scientific articles were considered. The keywords used were the full names of the assessment tests in English. In a second phase, the full test names were crossed with the term "ageing". In Figure 1, we can see that among the tests most frequently mentioned in the literature in the last 20 years are the Stroop Test, the COWAT and the TMT, whereas the IGT is the least mentioned. The same pattern is found for ageing studies although there are considerably less ageing studies. So, if the representativeness of the test in previous studies is used as a criteria the Stroop test, the TMT and the Verbal Fluency tests would be the best choices. Other criteria for the tests selection is the selection of the EF tests with the best psychometric properties. In a simple way, we can reduce the psychometric properties of an instrument to its reliability and validity. An instrument is reliable when it produces consistent test-retest results. Examples of measures of an instrument's reliability are internal consistency, time stability, interrater reliability and error of measurement. An instrument is valid when evaluates the variable you want to measure. Examples of validity are content, concurrent, predictive, construct, convergent and discriminant validity. Chan, Shum, Toulopoulou, and Chen (2008) made some considerations on EF assessment tests and highlighted some psychometric aspects especially relevant for the evaluation of EF: reliability and ecological validity. EF allow us, as already mentioned in the introduction to this chapter, to better adaptation to complex environments and novel tasks. However, when the task is not new it may be more difficult to detect EF deficits because the level of EF involvement is reduced by task repetition. Thus, the test-retest reliability scores of EF tests are generally low. In relation to the validity of the EF tests, ecological validity is of particular relevance (Goldstein, 1996; Chaytora, Schmitter-Edgecombea, & Burr, 2006; Lamberts, Evans, & Spikman, 2010). It is generally assumed that brain changes that result in poor performance in a neuropsychological assessment test also imply a lower ability to perform related daily activities outside the assessment context. However, this relationship between performance in the test and functional capacity is not always found in the literature. Some studies have found robust relationships (Burgess, Alderman, Evans, Emslie, & Wilson, 1998; Dimitrov, Grafman, & Hollnagel, 1996; Mitchell & Miller, 2008) while others have not identified any significant relationship (Amieva, Phillips, & Della Sala, 2003; Bogod, Mateer, & MacDonald, 2003; Chan, 2001). Despite this inconsistency, longitudinal studies have shown that EF alone can indeed predict the decline in the ability to perform daily activities (Cahn-Weiner, Malloy, Boyle, Marran, & Salloway, 2000; Royall, Palmer, Chiodo, & Polk, 2004). Table 4 presents examples of activities in our daily lives for which the contribution of EF is decisive.

Table 4. Daily activities in which Executive Functions are involved.

- Read a book for several days, remembering what has already been read and anticipating what is going to be read;
- Remember where we put something;
- Remember to take a medicine;
- Organize important personal documents such as bills (e.g., water, electricity, health expenses), VAT, insurances, etc.;
- Dealing with a problem for the first time;
- Make mental calculations while shopping;
- Count the amount of money needed to make a payment;
- Planning and carrying out weekly activities;
- Control the time needed to complete a task;
- Learn new tasks or assimilate new instructions;
- Talk in a noisy environment;
- Dial a phone number to make a call;
-Use a map to locate an office or store to which we are addressing for the first time;
- Understand sequential steps necessary for build something;
- Write a short letter or message to someone.

1.4. Cognitive ageing and executive functions

One of the explanatory hypotheses for age-related cognitive changes is the frontal ageing hypothesis (West, 1996). According to this hypothesis, there is a greater reduction in general volume, white matter density and synaptic density with ageing in the prefrontal cortex, compared to other brain regions (Hedden & Gabrieli, 2004). Neuroimaging studies have shown that with ageing the first changes in brain structure and function occur in the frontal lobes (Raz, Williamson, Gunning-Dixon, Head, & Acker, 2000). Consequently, cognitive functions whose anatomic substrate are related to the frontal lobes and more specifically to the prefrontal cortex are more (early) sensitive to the effects of ageing than functions related to other brain areas (Phillips & Henry, 2008). Particularly relevant in this relationship between executive functioning and ageing is the role of inhibition (Andres & Van der Linden, 2000). With ageing there is a weakening of inhibitory mechanisms (Hasher & Zacks, 1988), which are responsible for the suppression of irrelevant information and the reduction of susceptibility to information interference that although relevant, is contextually inappropriate. These inhibitory deficits have been used to explain other age-related cognitive deficits such as an increased distractibility (Wascher, Schneider, Hoffmann, Beste, & Sänger, 2012), the need for more time to provide an adequate response (Anguera & Gazzaley, 2012), greater forgetfulness due to coding inefficiency or competition between related ideas (Raaijmakers & Jakab, 2013), greater difficulty to understand a conversation when other conversations occur at the same time (Tun, O'Kane, And Wingfield, 2002), or greater inability to ignore visually distracting information in a reading task (Li, Hasher, Jonas, Rahhal, & May, 1998). Despite this negative impact of the inhibitory deficit, Biss, Ngo, Hasher, Campbell and Rowe (2013) suggest that this age-related inhibition deficit may be beneficial in the daily life of older adults. Biss et al. (2013) found that the repeated presentation of previously memorized items as irrelevant information only benefited elderly and not young adults in the subsequent recall of the memorized items. Older adults, that did not ignored the distracting information due to inhibition deficits, implicitly used this information to minimize or eliminate forgetting associated with ageing. Thus, Biss et al. (2013) suggest that older adults may, in some situations, produce more informed, and even more accurate, decisions because they include more elements that would initially be irrelevant to the decision.

Another relevant model for understanding the cognitive ageing process is the automatic and controlled processing model proposed by Shiffrin and Schneider (1977). According to this model, automatic processes can occur without conscious control. Thus, these processes are fast and can occur in parallel with other operations without losing efficiency. On the other hand, controlled processes require substantial control by the subject, are slow, and rely on limited capacity resources, which reduce the possibility of mobilizing another process at the same time (Posner & Snyder, 1975). However, this limited capacity is, according to Shiffrin and Schneider (1977, pp. 2-3), "*balanced by the benefits deriving from the ease with which such processes may be set up, altered, and applied in novel situations for which automatic sequences have never been learned*.". Examples of controlled and automatic processes can be found in our daily lives. Driving is arguably the best example for understanding the nature of automatic and controlled processing. An experienced driver while driving in known, traffic-free roads uses the mechanisms that control the steering, acceleration and braking of the vehicle automatically. Other tasks like looking through mirrors and following more complex road rules require controlled processes. As demonstrated in this example, daily activities require both controlled and automatic processes. It is also important to note that controlled and automatic processes are not totally distinct processes and that a controlled process may over time become automatic (e.g., if the vehicle is equipped with manual transmission, the driver can initially use the gear in a controlled way, but with experience, it begins to use it automatically, without conscious control). With ageing, controlled processing undergoes a greater decline than automatic processing (Andres et al., 2008).

Cross-sectional and longitudinal investigations have demonstrated the existence of an earlier and more pronounced decline with ageing in EF compared to other cognitive functions (Adkins et al., 2000, Andres & Van der Linden 2000, Crawford et al., 2004). In particular, there is a lower performance of older adults compared to young adults in EF tests such as WCST, Stroop Test or TMT. However, the executive deficit found is not generalized, and the performance of older adults may be similar to that of young adults, even in complex EF tests such as the Tower tests (Collette & Salmon, 2014; Collette, Schmidt, Scherrer, Adam, & Salmon, 2009; Raz et al., 2000). In the following section we will illustrate some examples of the repercussions of ageing on different EF, highlighting the effects of ageing on cognitive flexibility, divided attention, working memory, inhibition and planning.

A central notion of many theories of executive control is the need for specialized mechanisms to allow flexibility and shifts between different tasks to be completed. It is well-known that with ageing there is a loss of the ability to coordinate multiple tasks. Classically, processes underlying task coordination have been studied in ageing research using shifting paradigms, divided attention and dual-task paradigms. Older adults have demonstrated a lower cognitive flexibility capacity than young adults when this ability is assessed by TMT (Salthouse, 2000) and WCST (Crawford et al., 2000). There are two levels of cognitive flexibility differently affected by ageing. The overall cognitive flexibility, the ability to select and maintain two mental plans, is reduced with ageing; the specific cognitive flexibility, the ability to alternate between two mental plans, is preserved with ageing (Verhaeghen & Cerella, 2002; Wasylyshyn, Verhaeghen, & Sliwinski, 2011). Other ability related to our multiple tasks coordination is the ability of divided attention. There is a general agreement that there is a decrease in divided attention abilities with ageing (Bopp & Verhaeghen, 2005). However divided attention can be seen at three different modalities that seem to be differentially affected by ageing: maintaining and manipulating visuospatial information; maintaining and manipulating verbal information; and the ability to coordinate different types of information. The ability to maintain and manipulate multiple verbal information simultaneously and to coordinate different types of information, which requires storage in working memory, are diminished with ageing. However, the ability to maintain and manipulate visuospatial information is even more compromised with ageing (Fournier, Herbert, & Farris, 2004). On the contrary, there is greater capacity for divided attention if the divided attention tasks involve different modalities (Hein & Schubert, 2004).

Working memory (WM) is diminished with ageing (Rajah & D'Esposito, 2005). However, various WM functions or systems seem to be differently affected by ageing. There is a decrease in the capacity of updating WM (i.e., central executive) but not in storage capacity (i.e., phonological cycle, episodic buffer and visuospatial storage area) (De Leon & Palladino, Rettenbach, Nase, & Sireteanu, 2002). Another important point to understand age-related changes in WM is the type of information to be maintained and modified. There is a greater decline in the performance of older adults in spatial WM tasks than in verbal WM tasks has been identified (Myerson, Hale, Rhee, & Jenkins, 1999). WM for spatial information is then especially weakened with ageing.

Despite the decline in the efficiency of the inhibitory processes with ageing already discussed throughout this chapter, not all inhibitory processes are decline with ageing. In a recent review, Pires, Leitão, Guerrini, and Simões (2014) suggest that the activation of inhibitory processes for the suppression of irrelevant information is diminished with ageing but only with respect to controlled inhibition processes such as motor inhibition or inhibition that is activated to resolve the interference in a Stroop task. Other inhibition processes are related to automatic processes and are more resistant to ageing effects. The inhibition involved in interference resolution in an Eriksen Flanker task (in which the irrelevant and relevant information are spatially segregate), semantic inhibition and sensory inhibition are a few examples of these inhibition processes less affected by ageing.

Older adults have a reduced planning ability while compared with young adults (Godbout, Doucet, & Fiola, 2000). However, planning can be described on two levels differently affected by ageing. The formulation of the plan, which involves the ability to develop a logical mental strategy to achieve a goal, would be more diminished with ageing than the execution of the plan, which involves the ability to monitor and guide the successful execution of plan (Allain et al., 2005). Table 5 summarizes EF that are preserved and EF that are impaired in older adults compared to young adults.

Table 5. Ageing of Executive Functions (EF): preserved functions vs age-related deficit functions.

Preserved EF	EF with age-related deficit
Specific Cognitive Flexibility (e.g., alternation between two semantic categories) (Verhaeghen & Cerella, 2002; Wasylyshyn, Verhaeghen, & Sliwinski, 2011)	Global Cognitive Flexibility (Verhaeghen & Cerella, 2002; Wasylyshyn, Verhaeghen, & Sliwinski, 2011)
Ability to divide attention between visuospatial tasks (Fournier, Herbert, & Farris, 2004)	Divided Attention for verbal tasks (although it is less compromised when the two tasks do not share the same sensory modality) (Hein & Schubert, 2004)
Storage capacity in working memory (De Beni & Palladino, 2004; Leonards et al. 2002; Myerson et al., 1999)	Update capacity in working memory (De Beni & Palladino, 2004; Leonards et al. 2002; Myerson et al., 1999)
Semantic inhibition, sensory inhibition and resistance to interference from inappropriate information (Pires et al., 2014)	Motor Inhibition; Inhibition of irrelevant information (Pires et al., 2014)
	Planning (although the ability to formulate a plan is more harmed than the ability to execute the plan) (Allain et al., 2005).

Some of the differences found in executive functioning between older adults and young adults may be explained by a decrease in processing speed in older adults. These age-related slowing is an important mediator of the diminished performance usually found for older adults in EF tests (Albinet, Boucard, & Audiffren, 2012). On the contrary, similar performance of older adults and young adults in the same executive task does not determine that EF processing is unaffected (Burke & Barnes, 2006). In fact, older adults and young adults exhibit different brain activity patterns that seems to reflect the use of different strategies for an efficient task performance (Phillips & Andres, 2010; Turner & Spreng, 2012). Functional brain imaging of executive control processes reported robust differences in brain activity during the same executive task between older adults and young adults (Turner & Spreng, 2012). One of the explanatory hypotheses for these discrepancy is the compensatory hypothesis proposed by Reuter-Lorenz and Cappell (2008). According to this hypothesis there is a compensatory use of extra neuronal circuits in older adults that results in efficient processing even in tasks in which greater executive control is needed. For example, in older adults there is an extra activation of the lateral prefrontal cortex regions that function as a neural scaffold that temporarily supports performance in complex or novel tasks (Park & Reuter-Lorenz, 2009).

In conclusion, ageing is accompanied by a decrease in performance in tasks that mobilize different EF. However, this deterioration in EF is not general. Older adults can perform similarly to young adults in different EF tasks, especially if variables such as processing speed are controlled. Nevertheless, this similar performance at a behavioural level can reflect the existence of compensatory mechanisms in older adults such as the recruitment of other executive and non-executive functions.

Acknowledgments

This work was supported by a fellowship from the Portuguese national funding agency for science, research and technology [FCT; (SFRH/BD/70011/2010/Psicologia)].

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