UNIVERSITY OF PADOVA

Department of General Psychology

Bachelor’s Degree Course in Psychological Science

Final Dissertation

Multitasking and Aging: Electrophysiological and Behavioral Insights

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Abstract

This study explores the underestimated yet compelling phenomenon of multitasking, specifically, dual-task interference (DTi) in older adults through electroencephalographic (EEG) and behavioral data. DTi refers to the reduction in performance when individuals engage in two tasks simultaneously compared to performing each task separately. The experimental task included two conditions: a single condition with image encoding and a dual condition with image and auditory encoding. Additionally, screening tests assessing global cognitive functions and cognitive reserve were administered. The primary focus was identifying patterns of neural activity associated with t the cost incurred, measured as a reduction in performance metrics between single-task and dual-task conditions. Moreover, the study aimed to determine if cost varied across scores on cognitive screening tests and age. Preliminary findings suggest that the MEMO task successfully elicited DTi in older adults, evidenced by a decreased significant difference in performance in the dual-task condition compared to single-task conditions. Moreover, the EEG data revealed event-related potentials (ERPs) during the experimental task, indicating distinct neural signatures linked to the different task conditions. Neural activity recorded during encoding was interpreted in the framework of subsequent memory effects, however, no behavioral interaction was found.

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Chapter 1: Introduction

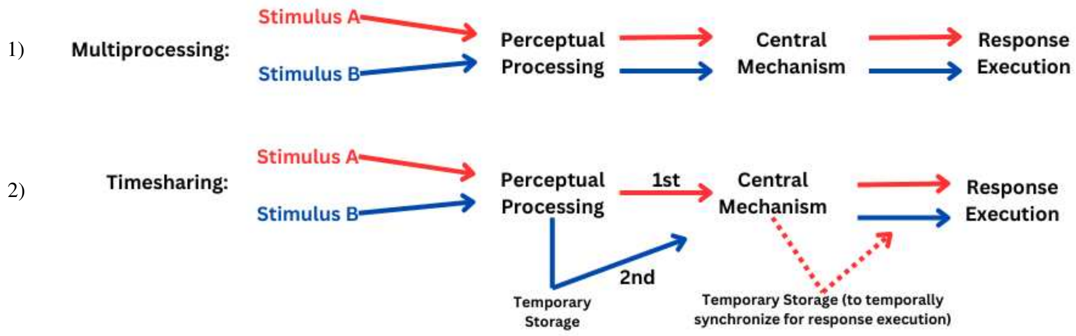
1.1 Multitasking

Multitasking can be defined as the simultaneous and parallel execution of multiple tasks accomplished through the allocation of an individual's limited cognitive resources among the tasks at play (Lin, 2013). Despite the growing emphasis on multitasking in an era driven by technology and the need for speed, the act of multitasking is not a novel process, but a process of survival importance. For instance, gathering food and resources required simultaneous attention to prey movements. Further, the monitoring of social cues while simultaneously engaging in conversation requires the employment of multitasking processes. Hence, even though a surplus of needs for multitasking has evolved, mostly due to the advances of fast and easy technology, the basic and vital need for multitasking remains.

However important the process, it possesses limits. The ability of humans to perform concurrent mental operations is restricted by the capacity of a central mechanism (Schweickert & Boggs, 1984). Support for the idea that it is a "central" mechanism, rather than peripheral, was provided by Davis (1957), who showed that such a delay occurs even when two stimuli are presented to different modalities. The central mechanism that allows for the processes of a task cannot overlap in time. If two stimuli arrive in the same instance, one must be held in storage while the central mechanism is occupied by the other. This definition underlies *timesharing models*, whereby one process can be interrupted during execution so that another process can be executed, in other words, switching between tasks, but processes are not executed at the same time. This can be contrasted with *multiprocessing models* in which the central mechanism processes stimuli concurrently and allocates a differentially weighted capacity for one task over the other, resulting in a lag in the difficulty of the tasks (Schweickert & Boggs, 1984). See Figure 1 for a visual representation of the aforementioned models. In the past literature, this central mechanism or the central processing stage has been defined as corresponding to response selection, i.e., the mapping between sensory information and motor action (Pashler and Johnston, 1989) or characterized as a decision-making process based on the noisy integration of evidence (Sigman and Dehaene, 2005).

Figure 1

Multiprocessing Model and Timesharing Model of Multitasking



Note. Representation of different models of multitasking: 1) multiprocessing, and 2) timesharing. An individual perceives two different stimuli (A and B), that need a different response. The multiprocessing model suggests the two tasks are processed in a synchronized manner. Whilst the timesharing model suggests that while one of the stimuli is being processed, the other is interrupted (temporal storage). If the tasks require a synchronous response, then the answer for one first task could be held in storage. Own work.

The price of attending to one too many tasks is paid by a decrement in performance or an increase in reaction time (RT) or both (Strobach et al., 2018). Multitasking's effect on RT is typically studied through the Psychological Refractory Period (PRP) paradigm (Welford, 1952). To elaborate, when stimuli of two tasks are separated by a variable stimulus onset asynchrony (SOA), RT typically increases for shorter SOAs (e.g., 50 ms) and decreases for longer SOAs (e.g., 1,000 ms). However, there are different distinct stages of multitasking, namely, the perception stage, the cognition (or selection) stage, and the responding stage. The *central bottleneck theory* (Welford, 1952) holds that the selection cannot be made in parallel, while the initial perception stage (during which stimuli are processed) and the final motor response stage (during which the motor response is executed) can. Thus, response selection is regarded as a central processing bottleneck, leading to RT differences at short vs. long SOAs and, hence, the PRP effect (Pashler, 1994). In other words, even though PRP and RT difference exists for the central mechanism, it is not generalizable for the whole process of multitasking.

Investigating multitasking in terms of task switching where tasks do not temporarily overlap has facilitated the understanding of multitasking more than the central mechanism due to its observability during testing (Strobach et al. 2018). A paradigm for investigating task switching is realized by Rogers and Monsell (1995) and Meiran (1996), whereby tasks

(A and B) are presented individually either in a sequence such as AABBAABB or with a random sequence and a task cue that precedes the stimuli. Essentially, the tasks can either repeat from one trial to the next (i.e., task repetitions) or switch (i.e., task switches). *Switch costs* are defined as the difference between the performance in task switch trials and the performance in task repetition trials (Rogers and Monsell, 1995). Switch costs are attributed to both the time it takes to reconfigure task sets and priming from previous task execution (Allport et al., 1994). Regarding priming, task-set inhibition plays a crucial role, evidenced by the N-2 task repetition effect, where the final trial of an ABA task sequence tends to be associated with slower responses than the final trial of a CBA sequence (Mayr and Keele, 2000).

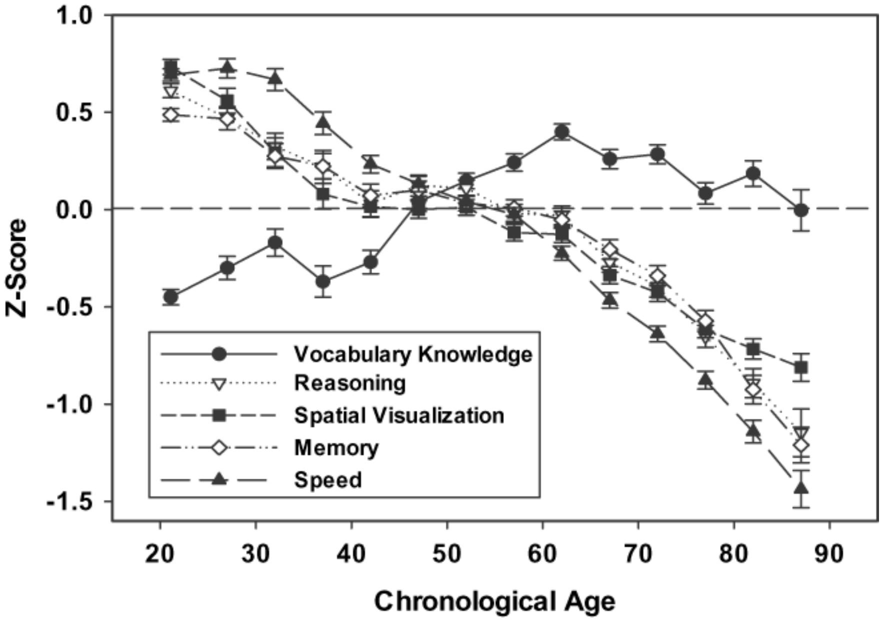
1.2 Cognitive Aging: Cognitive Decline in Normal Aging versus Pathological Aging

Cognitive aging refers to the gradual reduction in cognitive abilities that typically occurs as people age. This decline can manifest in various ways, such as decreased processing speed, declines in memory, and attention deficits (Salthouse, 2000; Nyberg et al., 2012; Hawkins et al., 1992). While age-related cognitive decline is considered a normal part of aging, it does not drastically or suddenly interfere significantly with daily functioning or independence. However, there is no precise agreed-upon age where cognitive decline starts to manifest. This is due to a large number of contributing factors including but not limited to cardiovascular health, cognitive reserve, neurotoxins, stress, and depression, which leads to a variable age range (Fotuhi et al., 2012; Willis et al., 2006). In addition, due to its undetectable manifestations during onset, even if it begins during midlife, it is difficult to detect when cognitive decline has started. Even yet, some neuropsychological assessments that have been designed specifically to detect cognitive decline still make omissions.

The most well-studied and universal effect of aging on cognitive processes regards crystallized abilities and fluid abilities. Crystallized abilities are the cumulative skills and memories that result from cognitive processing that occurred in the past, typically in the form of acquired knowledge; whereas fluid abilities require cognitive processing at the time of assessment and reflect manipulation and transformation of information to complete the test (Murman, 2015). Many studies have shown that there is an increase in crystallized abilities until approximately age 60, and a steady decline in fluid abilities from age 20 to age 80. For example, there is a nearly linear decline in processing speed, a fluid ability that also allows multiple tasks to be processed in rapid succession (Fig. 2) (Dux et al., 2009; Salthouse, 2010).

Figure 2

Cognitive abilities across different ages.



Note. Mean composite scores in five abilities as a function of age. Speed is a fluid ability whereas vocabulary knowledge is a crystallized ability. From *Selective review of cognitive aging,* by Salthouse T.A. 2010, Journal of the International Neuropsychological Society Copyright © 2010, Cambridge University Press.

Some suggest however that the division into fluid and crystallized abilities falls short on the variability of developmental patterns of cognitive domains (Hartshorne and Germine, 2015). Consequently, it may not be feasible to provide a number as to how many separate age-related influences there are on cognition. Because unless there is a specific neurobiological dysfunction (as is the case with lesions), aging in the brain is global. Since the brain holds different cognitive systems that are in interaction with one another whereby one system can compensate for the other or one failing system can sabotage the other, it is difficult to design cognitive tests that target each cognitive system individually. Another challenge in pinpointing the effects of aging is that some healthy aging individuals experience drastic age-related cognitive decline while others maintain their levels of cognitive ability. Hence, it has been proposed that individuals may differ regarding compensatory resources that later support the maintenance of cognitive performance in the face of age-related brain degeneration. Cognitive reserve, which relates to levels of intelligence, and educational and occupational attainment, can allow individuals to cope with brain deterioration, avoiding detrimental impacts on cognitive ability (Stern, 2002).

On the other end of the spectrum of cognitive decline lies dementia. Dementia is defined as a Neurocognitive Disorder (NCD) in the Diagnostic and Statistical Manual of Mental Disorders (DSM-5). Here, “cognitive” refers to processes such as attention, planning, inhibition, learning, memory, language, visual perception, or spatial skills, and the term “neurocognitive” has been applied to these disorders to emphasize that brain disease and disrupted brain function lead to symptoms of NCD. Although dementia predominantly affects older people, it is not a normal part of aging.

Before dementia occurs, a transition stage of Mild Cognitive Impairment (MCI) is typically expected. MCI is characterized by observable cognitive deficits that resemble but are less severe than, those typical of dementias. In order to be diagnosed with MCI, cognitive deficits must be greater than would be expected from the individual’s age and education level but not significantly impair daily functioning as in dementia (Irwin et al., 2018; Diagnostic and Statistical Manual of Mental Disorders, 2013). For instance, episodic memory usually remains steady until 60 years (Rönnlund et al., 2005), hence a decline before those years may indicate pathological aging. Similarly, significant impairment in executive function (which includes multitasking ability) before the age of 65 would indicate a divergence from healthy aging. Further, visuospatial performance revealed a sharp inflection point 3 years before Alzheimer’s Disease diagnosis and continued to further decline, whereas those who did not develop AD remained roughly stable (Johnson et al., 2009).

A study by Jansen et al. (2018) explored the associations of age and many neuropathologies with trajectories of cognitive decline and found that pathologies were robustly related to late-life trajectories of cognitive decline. Further, no evidence of age-related cognitive decline was found after accounting for neuropathologic indices. This implies that cognitive decline in elderly individuals is primarily a doing of pathological processes rather than typical age-related development. Hence, the decrease in cognitive function with age can be attributed to subtle and potentially undetectable pathological factors in earlier stages of late life and identifiable pathology in later stages. Therefore, in this report, “healthy aging” will be referred to as a developmental process that brings decrements in minor but detectable cognitive abilities, some more than others, either due to undetectable neuropathologies or simply neuronal and synaptic changes, typically beginning after 60 years of age.

1.2.1 Multitasking in Healthy Aging

Signs of cognitive aging are typically noticed by family members or friends who notice minor struggles or behavioral changes as the individual is performing day-to-day tasks. Carrying out most of these daily tasks requires performing multiple activities simultaneously. However, experimental tests designed for the aging population often focus on a single task, which has consequences for ecological validity. A study by Lundin-Olsson et al. (1997) demonstrated how the tendency to halt walking while talking predicted a higher risk of falling among elderly individuals. By placing an increased strain on the individual's cognitive system, or central mechanism, multitasking increases task difficulty. This demonstrates the potential of multitasking paradigms as a valuable tool for offering predictive and diagnostic benefits.

A useful example of how multitasking can reveal hidden cognitive impairments is in spatial neglect patients. These patients are usually subject to paper-and-pen assessments for diagnosis that focus on single tasks to assess deficits in attention towards the contralesional space. However, Bonato et al. (2013) demonstrated that in a computerized task, participants with the right hemispheric stroke which usually causes neglect showed good performance on the single-task condition, but a significantly worse performance the in dual-task, when the target was in the contralesional space.

In a study on healthy adults aged between 50 and 89 years, a visual memory task combined with a sustained attention task was administered (Contemori et al., 2022). Specifically, participants were asked to memorize a series of images either without performing any other task or while simultaneously performing an auditory task and then recognize them among four alternatives (the same task used for this study, explained in Chapter 2.2.5). The results showed that with increasing age, performance declined linearly, while the cost remained stable regardless of age. Further dividing the participants into three different clusters revealed that those with higher cost had significantly lower scores on a self-administered cognitive test, irrespective of age.

Brain imaging studies have found evidence of structural interference, i.e., brain regions that are shared by both component tasks, which resulted in perceptual bottlenecks in the intraparietal sulcus (Marois et al., 2005) and response selection bottlenecks in the premotor area, left inferior frontal gyrus and pre-supplementary motor area (Dux et al., 2006). The biggest age-related additional activation was on the banks of the central sulcus, around the sensorimotor regions which may be a consequence of the elderly’s increased effort to analyze visual and somatosensory information.

Working memory is strictly involved in multitasking. Many studies have shown older adults have significant impairment in working memory performance when they encounter interference, i.e., intervening stimuli that are purposefully attended to as an aspect of a secondary task, beyond that experienced by younger adults, (Gazzaley et al., 2008). Interruption requires a reallocation of cognitive resources, as well as processes involved in reactivating the disrupted representation afterward (Clapp & Gazzaley, 2012). Notably, it was found that interruptors disproportionately impaired working memory performance in older adults as compared to younger adults. This means that older participants experienced a greater impact on their working memory by an interference when corrected by their performance without interference (Clapp & Gazzaley, 2012). This suggests that the difference between young and older individuals is more noticeable when multiple tasks are being performed.

1.3 Electroencephalographic Insights on Multitasking and Memory

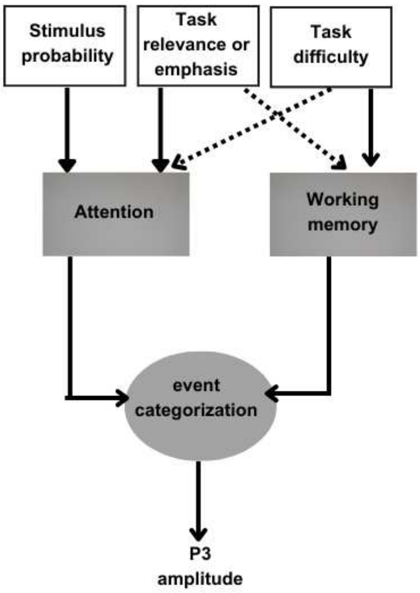
Event-related potentials (ERPs) are neural responses to specific events or stimuli that are recorded by EEG and obtained by averaging multiple trials. A study of the PRP effect (refer to Chapter 1.1), that used the task-switching paradigms focused on the N1 and P3 components.

The N1 is a negative going component with respect to an average mastoid reference and peaks around 150 ms post-stimulus, typically in response to stimuli in attended vs. unattended locations. The amplitude of the N1 component can be modulated by attention, as when individuals are instructed to attend to a specific stimulus, the N1 amplitude for that stimulus is often enhanced. The N1 component is also sensitive to the physical properties of stimuli, such as intensity and frequency. This sensitivity allows it to play a role in the discrimination of different sensory inputs, which may be useful in differentiation and recognition.

The P3 component is an endogenous positive ERP involved in the process of decision-making making is typically studied within the oddball paradigm and peaks around 300 – 400 milliseconds. Kok (2001) pointed out the major determinants of P3 in a simplistic model in an attempt to integrate the experimental findings (see Figure 3). The core element of the model is the assumption that the P3 amplitude reflects attentional capacity invested in the categorization of task-relevant events. Event categorization then is conceived of as a process that makes the decision whether the external stimulus matches or does not match an internal representation of a specific category of stimuli. This could encompass many tasks, for example in an n-back task whether a target stimulus matches the one n counts before, or whether a stimulus has been successfully encoded (internal representation) in an image memorization task. Event categorization could be elicited by target as well as nontarget or even novel stimuli. Low probability or high saliency of events and task relevance are assumed to increase neural activities associated with event categorization, leading to larger P3s. Conversely, task difficulty is assumed to counteract this process, leading to smaller P3s.

Figure 3

Diagram for determinants of the P3 component.

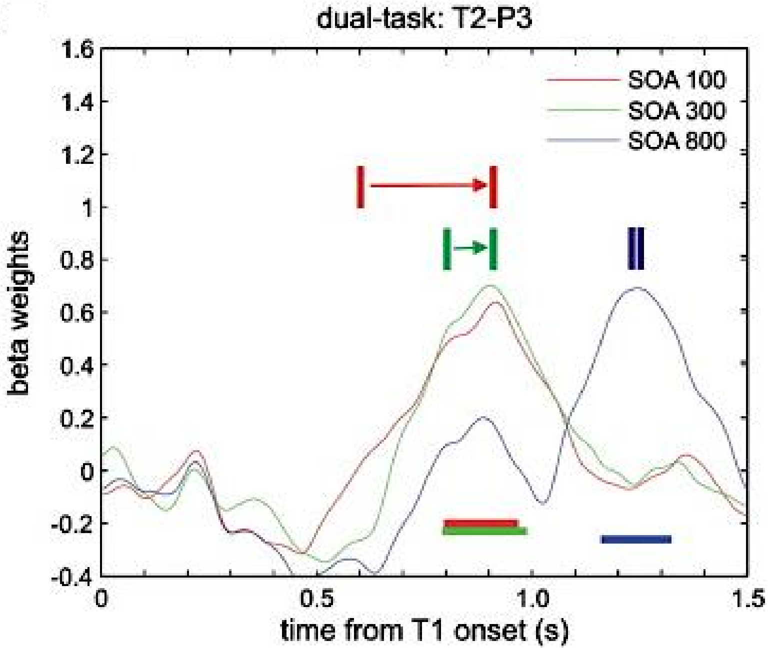


Note. This model shows the major determinant (white boxes), the underlying mechanisms (dark boxes), and their effects on the event categorization process and consequently the P3 component. Adjusted from “On the utility of P3 amplitude as a measure of processing capacity”, by Kok A. 2001, Psychophysiology. *Copyright © 2003 Society for Psychophysiological Research.*

Going back to the PRP framework, in an experiment where participants were instructed to switch from target 1 and target 2, no suppression of the evoked N1 was found for the second target (Hesselmann et al., 2011), which can be inferred as no difference in the allocation of attention. This data suggests evidence for a *post-perceptual* bottleneck, a bottleneck leading to constraints not at the perceptual level, but in cognitive processing. Accordingly, the latency of the P3 component, evoked by the first target remained unaffected while a substantial delay at short SOAs for the second target was seen (see Figure 4). However, studies on whether the behavioral effects (reaction time or accuracy) of the second tasks can be related to the P3 delay seem to lack accordance with some studies that suggest that it is the lateralized readiness potential which is delayed (Arnell et al., 2004).

Figure 4

P3 component analysis for a dual task.



Note. Results of the subtraction of single-task's P3 beta weights from task 1/task 2 beta weights in dual-tasks. Colored arrows and vertical bars illustrate the temporal delay of P3 responses in task 2. Red lines indicate SOA 100, green lines SOA 300, and blue lines SOA 800. From Probing the cortical network underlying the psychological refractory period: A combined EEG–fMRI study, by G. Hesselmann, G. Flandin, and S. Dehaene, 2011, Elsevier. *Copyright © 2011 Elsevier Inc.*

The amplitude of the P3 has been assumed to be related to the intensity of processing (Coles et al., 1986). A correlation between P3 amplitude and task complexity has been demonstrated in both single and dual-task paradigms (Kok, 2001). In single-task experiments, increasing the working memory load and manipulating task difficulty (Scharinger et al., 2017; Spencer & Polich, 1999) reduced P3 amplitude. Dual-task designs produced smaller P3 amplitudes compared to their single-task counterparts (Watter et al., 2001). One interpretation of the reduction in P3 amplitude is that the reduction of perceptual-cognitive resources occurs as task demands mount, resulting in correspondingly fewer resources available for P3-related processes (Kok, 2001). This aligns well with the intent of dual-task designs to approach full utilization of central processing capacity (Richardson et al., 2022).

Given the task used in this study (MEMO) compromises encoding and retrieval, a useful paradigm of interest is the subsequent memory effect (SME), which allows a comparison of the encoding activity associated with successful or unsuccessful retrieval performance. In the case of EEG, it refers to a greater ERP signal found during encoding for stimuli that are successfully retrieved later compared to items that are not. Semantic studies focusing on P3 found that presenting words that deviated from others in a physical manner (font size) elicited a P3 and that those distinctive words that were later on recalled elicited a larger P3 than those that were not (Karis et al., 1984) Meaning, distinctive features of events attracts attention and that this additional allocation of attention leads to deeper processing of the event (Craik and Lockhart, 1972). To note, the SME is studied not only through the P3 component but through many different types of ERPs elicited during encoding. For example, in one study, participants studied words that were either congruent or incongruent with a category. Congruent words were remembered better than incongruent ones and an SME emerged at 300 ms whereby a frontal SME occurred for both but a parietal SME was evident only for congruent words (Holtje et al. 2019).

In a review, Mecklinger and Kamp (2023), suggested that the stimulus-elicited SME can be categorized into three components, reflecting the different processing factors that support successful encoding. First, the early frontal SME elicited around 300-600 ms post-stimulus reflects the semantic processing of a stimulus event, indicating that the brain is engaging in understanding semantic attributes of a stimulus. Second, the early parietal SME emerges 350-500 ms post-stimulus and indicates the binding of multiple features of an event into a single item representation. It shows the integration of various aspects of the event into a cohesive memory trace. Third, the sustained late frontal SME starting around 550 ms post-stimulus reflects continued processing of associative and conceptual event features, suggesting ongoing elaboration of the memory information to secure encoding and enhance recall. However, all of these three noteworthy components were realized by the results of hundreds of studies that had adult participants. Hence a disparity in either latency or localization may occur when studying older individuals.

Chapter 2: Experimental Study

2.1 Objectives and Hypotheses

This study aimed to explore how digital tasks can be used to monitor individual cognitive trajectories and investigate multitasking as a potential indicator for identifying individuals at risk of Mild Cognitive Impairment (MCI) and dementia. More specifically, in order to understand cognitive trajectories, we investigated the impact of aging and cognitive levels on performance in dual-tasking scenarios. Furthermore, EEG recordings were collected during task execution in order to identify how dual-tasking manifests as a neural process in older individuals.

As put forward in Chapter 1, a cost is expected to occur in transitioning from the single-task condition to the dual-task condition given the nature of limited processing resources for multitasking. Furthermore, despite the findings in previous research regarding a higher cost, or lower multitasking performance as age increases, Contemori et al. (2022) have found that in regards to the MEMO task, this was not the case. Hence, an age-related increase in cost is not expected. However, a correlation between cost and cognitive screening tests, namely the auto-GEMS, MoCA, and CRIq is expected.

Moreover, the results by Contemori et al. (2022) indicate that there were more correct than incorrect responses in each condition in the MEMO task. Hence the number of epochs for incorrectly reported images is likely too low to produce comparable ERPs. Therefore, the focus was exclusively on the encoding stage for correctly reported images for ERP analyses. There is expected to be a significant difference between the late waveforms that are elicited in the image encoding phase in the single versus dual condition. Further, an SME effect, as indexed by a difference in a sustained waveform between dual and single conditions, was expected to predict the behavioral cost.

2.2 Methods and Procedure

Data collection capitalized on online tools to administer a total of 6 questionnaires where the participants answered the questions digitally at home. Specifically:

- Beck Anxiety Inventory (BAI) (Beck et al., 1988)
- Beck Depression Inventory-II (BDI-II) (Beck et al., 1996)

- World Health Organization Quality-of-Life Scale (WHOQOL-BREF) (World Health Organization. Division of Mental Health, 1996)
- Dual-task Impact on Daily-living Activities Questionnaire (DIDA-Q) (Cock et al., 2003)
- Motor Reserve Index Questionnaire (MRIq) (Pucci et al., 2023)
- Auto- Global Examination of Mental State (auto-GEMS) (Contemori et al., 2021)

These were completed online on the platform Qualtrics (except auto-GEMS which was done on Jatos) along with questions related to the inclusion criteria (Chapter 2.2.2) and some anagraphic information (name, last name, date of birth, age, gender, years of schooling). Further, a total of 3 questionnaires were administered in the presence at the labroatory, namely:

- Montreal Cognitive Assessment (MoCA) (Nasreddine et al., 2005),
- Cognitive Reserve Index questionnaire (CRIq) (Nucci et al., 2012),
- UCLA Loneliness Scale (Russell, 1996).

Once the participants arrived at the laboratory, they were given a description of the study along with an informed consent form. Then the task and procedures were explained as a high-density geodesic EEG cap was immersed in the solution. After placing the EEG cap and adjusting for proper fit, the participant was then seated in front of a 24-inch screen (resolution of 1280 × 1024 pixels) to perform the task. A computer keyboard was used to record the task responses. Recommendations were given on the importance of minimizing body movements to avoid muscular artifacts. The first phase was ten minutes of resting state, followed by a practice version comprising the two blocks (load and no-load conditions), then the actual execution of the dual mnemonic task (MEMO with), and a final resting state of another ten minutes. After the removal of the EEG cap, the responsible research administered the MoCA and CRIq, followed by a self-administration of the UCLA Loneliness Scale.

2.2.2 Participants

Participants were recruited through public advertisements (posters, social media posts) but mainly through meetings with some nonprofit organizations (rights, welfare). There was no monetary compensation. Participation in the study was voluntary. The inclusion criteria were:

- Age greater than or equal to 50 years

- Achieved an auto-GEMS cognitive screening score of no lower than a score of 67/100. The cut-off was calculated by subtracting two standard deviations from the mean score
- Do not suffer from a neurological disorder or have been diagnosed with mild cognitive impairment or dementia
- Do not take drugs with effects on the central nervous system
- Do not suffer from particular dermatological diseases or potential allergic reactions that could create problems with the use of the EEG cap
- Have normal vision and hearing following correction via tools such as glasses or hearing aids.

50 participants met the inclusion criteria and carried out the study. After the preprocessing of the EEG data, some subjects (N= 11) who presented excessively noisy data were discarded from the sample.

2.2.3 EEG Recording Procedure

For recording electric scalp potentials generated by brain activity during the resting state and task performance, EEG was recorded at a 500 Hz sampling rate through a pre-cabled 128-channel HydroGel Geodesic Sensor Net (HCGSN-128), using a Geodesic high-density EEG System (EGI® GES-300). All electrodes were referenced online to the vertex, and scalp voltages were amplified through a 24-bit DC amplifier (Net Amps™ 300). The impedance was kept below 60 kΩ for each sensor. A high-density EEG provides the advantage of obtaining better spatial resolution and localizing cortical sources of scalp-recorded activity more accurately. This type of setup is also much quicker and more comfortable for the participant compared to an EEG cap requiring gel application for each electrode or skin abrasion. Instead, in order to increase conductivity and thus reduce impedance, the cap is immersed in a bucket containing a solution of water, potassium or sodium chloride, and shampoo, which is absorbed into the sponges located at each electrode site. Finally, all participants were informed about the cap preparation and application procedure.

2.2.4 EEG pre-processing and analysis description

Subsampling was performed at 250Hz, and a notch filter was applied to power line frequencies (50Hz) using the EEGLab Zapline plugin. A high-pass filter at 0.1Hz was applied. The data was epoched from 500 ms before the onset of the image to 2000 ms after the onset. Data cleaning for artifacts was performed by means of an Independent Component

Analysis (ICA) and visual inspection. Independent components (ICs) were automatically classified with the IClabel plugin (Pion-Tonachini et al., 2019). IClabel is based on a trained neural network classifying ICs according to the category they most likely belong to. It flags each IC indicating the category and a percentage displaying the confidence level of IC category recognition. ICs identified as artifacts by ICLabel were visually inspected, and those related to eye blinks, eye movements, muscular and cardiac activity according to the visual inspection of their time course, and scalp distribution were removed. Epochs with large artifacts exceeding a threshold value of 100mV were discarded. Bad channels for more than 20% of epochs were interpolated. A low-pass filter at 30Hz was applied. Finally, the data was re-referenced to the average of all electrodes.

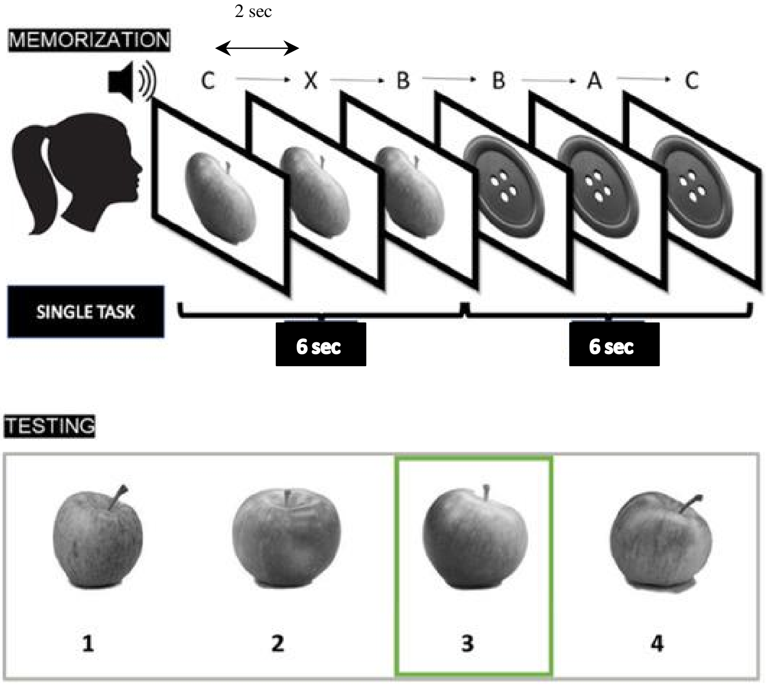
The ERP statistical analysis was performed via Brainstorm software. A paired *t*-test ($\alpha = .05$) permutation approach (Luck et al., 2017) was used, with cluster-based correction, performing 5000 iterations over the parietal electrode region. The permutations were computed over 6 a priori time windows: 80-140 ms, 140-200 ms, 200-300 ms, 500-600 ms, 700-1100 ms, and 1100-1500 ms.

2.2.5 Experimental Task: MEMO

The experimental task that was presented to participants during the EEG recording, was an adaptation, for feasibility in an EEG recording setting, of the MEMO task (Contemori et al., 2022), consisting of a dual-modal mnemonic-attentional task. The task had two phases: encoding and recognition. During the encoding phase, participants were asked to memorize 15 sequentially presented black-and-white images of inanimate objects. Participants were informed they would be later asked to recognize the correct stimulus among four alternatives. Images were randomly shuffled between participants and counterbalanced across conditions. Each image was presented centrally on the location of the fixation cross for 6 seconds. Simultaneously, a series of forty-five sounds (of the letters A, B, C, D, and X) was played, where each letter would be audibly presented every two seconds. In the recognition (or testing) phase, four different images were shown simultaneously, with one being the image previously presented in the encoding phase, while the other three were distractors, similar but different images. Participants were asked to indicate which of the four images was the one presented in the previous encoding phase, using keyboard numbers (1 to 4). Figure 5 illustrates the administered task. After responding to all image recognition questions of the block, they were asked how many times they heard the letter “X”, and could respond by selecting an option from 3 multiple choices. After each response, participants were asked to estimate their confidence level, on a scale from 0 to 9 (0: completely uncertain, 9: completely confident) about their given response. This was used to assess their response confidence in selecting the image among the four options.

Figure 5

Representation of the MEMO task.



Note. A representative sequence of the memory task. The encoding phase (upper panel) and testing (lower panel) and examples of the stimuli (visual and auditory). This figure was adjusted from "Multitasking Effects on Perception and Memory in Older Adults", by Contemori et al., (2022).

2.2.6 Questionnaires

Auto-Global Examination of Mental State

The auto-Global Examination of Mental (auto-GEMS) State is a novel tool designed for self-administered online cognitive screening (Contemori et al., 2021). It is a computerized test to assess overall cognitive function and is derived from the tele-GEMS, an assessment battery crafted for remote administration via telephone, and which originally stemmed from GEMS, a paper-and-pencil screening (which requires the presence of an examiner) recently described in the literature (Mondini et al., 2022). The auto-GEMS test is tailored for self-administration, enabling participants to autonomously take the test using only a computer and benefit from automated scoring thereafter. The ten tasks that make up auto-GEMS encompass structured tests and multiple-choice questions probing domains such as short and long-term memory, spatial and temporal orientation, spatial and verbal skills, and executive functions.

The Cognitive Reserve Index questionnaire

The Cognitive Reserve Index questionnaire (CRIq) developed by Nucci et al. (2012), estimates an individual's cognitive reserve (CR) through a collection of information regarding their entire adult life. The CRIq was conceived based on the cognitive reserve construct proposed by Yackob Stern (2009). Completing the CRIq requires the ability of the administrator to conduct a semi-structured interview and to possess the skills to actively guide a conversation. The CRIq encompasses all three possible sources of cognitive reserve, namely education, work, and participation in cognitively demanding activities, whilst considering the amount of time spent on each activity. In the CRI-School section, the number of years of schooling and attendance for any non-work-related training is calculated. In the CRI-Work section, different jobs are divided into five categories, and the participant is to indicate the years for which each job has been performed. The CRI-Leisure Time section, which includes a series of cognitively stimulating activities that can be done in leisure time (e.g., playing sports, going to the cinema or theater, practicing a hobby, etc.), participants are asked to indicate if each activity is (or has been) performed less than or equal to two, or greater than or equal to three times over the course of either week, month, or year. A final overall score calculated as the average of the three sections indicates the individual's general CR.

Montreal Cognitive Assessment

The Montreal Cognitive Assessment (MoCA) is a widely used screening tool developed in 2005 by Nasreddine et al. to detect individuals’ cognitive impairment and is typically used for diagnosing Mild Cognitive Impairment (MCI). It consists of a one-page, 30-point test covering various cognitive domains such as memory, visuospatial abilities, orientation, executive function, attention, concentration, working memory, and language. It has been extensively validated and is particularly effective in distinguishing between normal cognition, MCI, and dementia. MoCA demonstrates consistently higher sensitivity in detecting cognitive deficits, making it a useful tool in clinical practice. It is scored by obtaining an item total and the authors recommend a clinical cutoff score of 26, and takes around 10 minutes to complete. The normative data has wide variability and individuals’ scores are considered within the norm depending on age and of years of schooling, and in some cases nationalities, that fall well below the cut-off value intended by the original test.

Chapter 3: Data Analysis and Results

3.1 Data Analysis

Outliers were detected through median absolute deviation (MAD) on image accuracy (Leys et al., 2019), 1 participant was discarded and the total number of participants became 38 with a mean age of 61.8 (SD = 5.59) and the youngest participant being 52 and the oldest being 72. 15 of them were male and 23 of them were female. Analysis was conducted using RStudio (Rstudio Team, 2020).

Cost was calculated as *((mean single condition score - mean dual condition score) / mean single condition score) x 100.*

3.2 Behavioral Results

A generalized linear model (GLM) was fitted to evaluate the effect of load (i.e. whether the condition was single or dual) on image accuracy using binomial logistic regression. The model indicated a significant impact of load on image accuracy ($\beta = 0.75704$, SE = 0.11154, z = 6.787, $p < 0.001$).

As expected there was no significant interaction between age and cost (β=0.425, $t(36)=1.342$, p=.188, R^2=.048). However, contrary to expectations, correlations of cost with CRIq scores (r (36) = .12, p = .45), MoCA (r (36) = -.07, p = .65), and auto-GEMS (r (36) = -0.007, p = .96) were not significant.

The effect of age on image recognition accuracy was tested by a generalized linear model (GLM) using logistic regression given the binomial nature of task accuracy data, and while accounting for individual variability. The model revealed that age significantly predicted image accuracy, $\beta = -0.063$, SE = 0.026, $z = -2.359$, $p < .018$.

To see how auto-GEMS scores predicted image accuracy in both conditions, a logistic regression analysis was performed for exploratory purposes. It revealed that the auto-GEMS score significantly predicts image accuracy, (β=0.81, SE=0.008, z= 2.199, p=.027). The same was done to predict MoCA scores, which was significant (β= 0.11, SE= 0.017, z= *2.199*, p<.001), and to CRIq scores, which on the other hand, was not significant (β=0.001, SE=0.003, z=*.38*, p=.704).

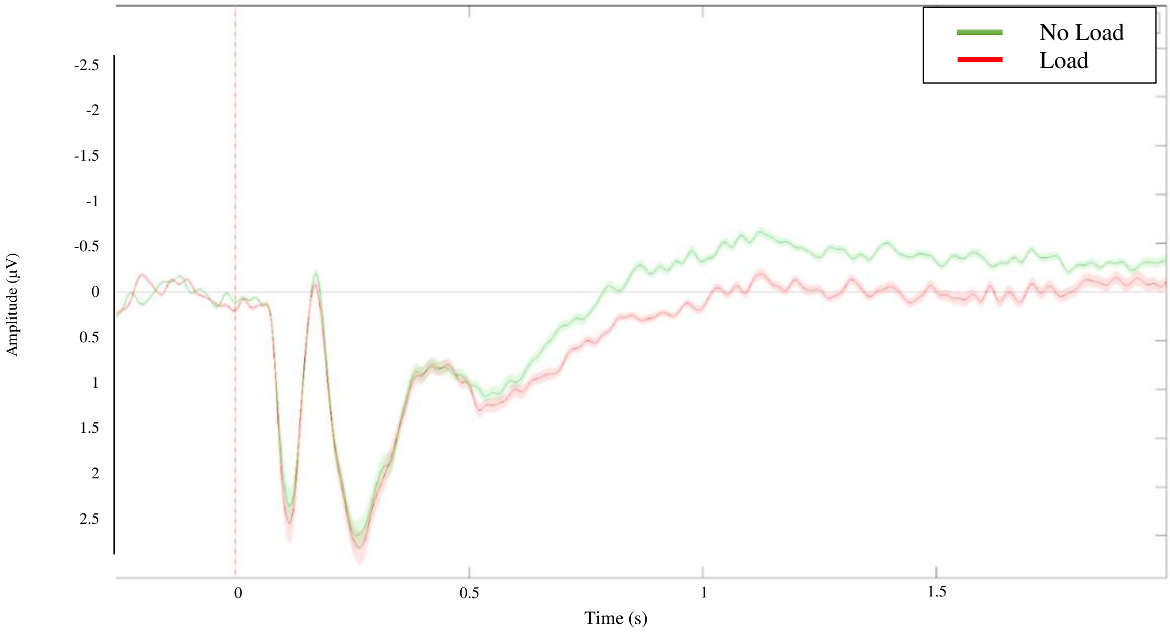
Further explaratory analysis revealed that MoCA scores also correlated with auto-GEMS scores (*r* (36) = .54, *p* <.001) and CRIq scores (*r* (36) = .35, *p* = .03). As did CRIq with auto-GEMS scores (*r* (36) = .49, *p* = .001).

3.3 EEG Results

ERPs time-locked to image encoding were analyzed, focusing exclusively on correctly recognized pictures. Comparisons were made between single (no load) and dual (load) conditions (Figure 6). The cluster-based permutation identified a significant difference between single and dual conditions was observed in a posterior cluster of electrodes (E50, E51, E52, E53, E58, E59, E60, E61, E62, E65, E66, E67, E70, E71, E72, E75, E76, E77, E78, E83, E84, E85, E86, E90, E91, E92, E96, E97, E101), during the 700-1100 msec time window after image onset (*p* = .018, cluster statistic = -1683, cluster size = 663) and the 1100-1500 msec time window (*p* = .027, cluster statistic = -1477, cluster size = 574). Specifically, the dual condition exhibited a more positive sustained SME-like component compared to the single condition (Figure 6). The topographical distribution of the SME-like effect for the single versus dual condition contrast that was statistically significant shows a centro-parietal distribution in the right hemisphere for the 700 - 1100 ms slot and a centro-parietal distribution in right hemispheres with a slight distribution towards the left for the 1100 – 1500 ms slot (Figure 7).

Figure 6

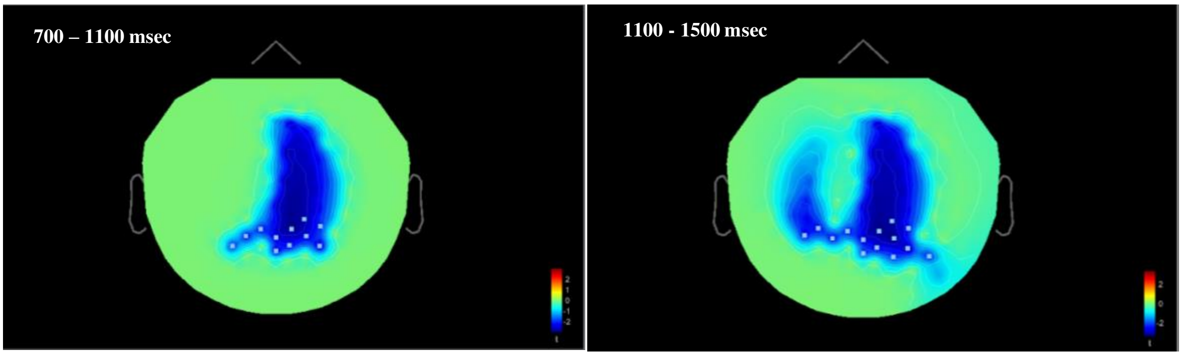
Event-related potential results.



Note. Grand averaged ERPs after image presentation at 0s, from a parieto-occipital cluster of electrodes (E50, E51, E52, E53, E58, E59, E60, E61, E62, E65, E66, E67, E70, E71, E72, E75, E76, E77, E78, E83, E84, E85, E86, E90, E91, E92, E96, E97, E101), according to the condition (single/no load in green and dual/load in red). Bands represent standard error.

Figure 7.

Spline map on the significant sustained component.



Note. Topographical distribution of the SME-like effect where the blue areas indicate regions exceeding the critical t-score threshold for statistical significance for the contrast single versus dual in the 700-1100 msec (on the left) and 1100-1500 msec (on the right) time window.

A linear regression analysis was conducted to examine the effect of early SME (between 700 – 1100 ms) and late SME (between 1100 – 1500 ms) on cost. The regression was not significant, F (2,35) = 0.80, p = .457, indicating that the predictors did not explain a significant amount of variance in cost ($R^2 = 0.044$, Adjusted $R^2 = -0.011$).

Chapter 4: Conclusions

4.1 Discussion

As expected the cost remained consistent across the age cohort, aligning with the findings of a previous study by Contemori et al. (2022). Even though this study focused on global cognitive function tasks and cognitive reserve to offer a perspective on the relationship between multitasking and cognitive performance, the results did not find a significant relation between the costs of multitasking and cognitive screening test scores (MOCA and auto-GEMS) and compensation mechanisms (CRIq). The results from this study and the one by Contemori et al. (2022) differ from findings from many studies that have revealed an age-related impairment in dual-tasking (Riby, 2004). However, most of these studies which found an age-related effect on cost or cognitive load involved cognitive-motor dual-task. It also appears that if there needs to be a trade-off between cognitive vs. motor domains, older adults tend to prioritize the motor task (Schaefer, 2014). Hence when both tasks engage the attention and memory domain (image and auditory encoding) finding age or global cognitive-level-related effects on cost may be more nuanced since prioritizing one task over the other is not typically observed. Moreover, Ben-Shakhar and Sheffer (2001) concluded that performing two simultaneous tasks is a stable and distinct cognitive ability after finding that performance on the single task could not predict cost. Thus, explaining cost in terms of task difficulty becomes less sensible.

Nevertheless, the finding that task accuracy is significantly interacted with MoCA and auto-GEMS scores suggests that performance in visual and auditory encoding, a memory process that brings sensory input from short-term to long-term memory, and retrieval, is related to global levels of cognitive functioning, in accordance with many previous models (Dudukovic & Kuhl, 2017; Mungas et al., 2003). The same can be said about age predicting task accuracy. The most simple conclusion is that performance in a visual-mnestic task decreases with age due to the effects of aging on a specific memory process, though it is unclear which process exactly. However, relying only on mnemonic indices is inadequate for studying characteristics indicative of the prodromal phase of cognitive decline.

Furthermore, in the exploratory phase, the significant correlations between MoCA, auto-GEMS, and CRIq evidenced the convergent validity of the tests.

Given the lack of cost-related findings, can we claim that the MEMO task is a robust multitasking task? Kerr (1973) claimed that encoding does not require the central mechanism and hence will not interfere with simultaneous processing. This idea came from a study by Posner and Boies (1971) in which a warning signal was presented, followed by a letter, followed by another letter. The participants had to indicate whether the letters were the same or different with one hand and responded to a noise probe, presented on half the trials with the other hand. Reaction times to the noise when it was presented in a time frame whereby the participant was still encoding the first letter, were equal (even less than) to reaction times to the probe when it was presented in the intertrial interval. The lack of an increase in reaction time implies that encoding can occur concurrently with auditory processing and without interference.

Regarding psychophysiological aspects, results indicate that the late difference waveform could not explain the cost in the behavioral domain. Even though we aimed for an interpretation of the two different waveforms using the framework of SME, it becomes challenging to interpret due to the lack of interaction with the behavioral outcome. Furthermore, a parietal SME is nuanced and quite conceptual since in most studies, a sustained late component related to the SME is observed frontally. However, according to Mecklinger, A., & Kamp, S. (2023), the parietal SME may be observed when different features of an item are effectively bound together so that a rich and detailed item representation can be subsequently retrieved as a whole. This is a well-suited explanation for the closely similar visual stimuli in the MEMO task that can only be differentiated through detailed inspection and not merely semantic differentiation. In addition, there is often a deviation between parietal SME elicited in conditions that require more shallow processing, compared to more elaborate conditions in which associative information is processed (Schott et al., 2002). Considering the parietal SME in terms of the amount of available cognitive resources, we can claim that participants had more cognitive resources in the single condition which allowed them to process items more elaborately. As opposed to in the dual condition whereby their cognitive resources were limited due to the second task. However, this difference was not deep enough to produce an effect in behavior as evidenced by a lack of interaction between the waveforms and the cost.

Moreover, the topographical map demonstrates a right-distributed activation. The popular notion by Corbetta and Shulman (2002) suggests that a right-lateralized network might act as a bottom-up “circuit breaker” and detect behaviourally relevant stimuli for another network responsible for top-down selection. In other words, they suggest this mainly right-sided network seems to interrupt ongoing cognitive activity when a stimulus that might be behaviourally important is detected. However, this process may not necessarily be bottom-up. Fassbender et al. (2006) argue that the right fronto-parietal network is involved in allocating attentional resources when they are required during behavior and is involved in monitoring situations where this control needs to be implemented. This challenges the traditional view of separate bottom-up and top-down processes because monitoring for behavior-relevant stimuli can be considered both bottom-up and top-down.

Additionally, given there is a significant difference in waveform but no significant interaction with the cost, it can be interpreted that the waveform difference is simply the effect of sustained auditory attention, independent of dual-task interference or the cost of multitasking.

However, the ERP analysis concerned itself only with image-evoked potentials, even though the task consisted of an auditory component as well. This was a decision made due to the noisy and disrupted signal when time-locked for the auditory stimuli. Given that sustained attention to the auditory stimuli was the differentiating factor between the single and dual conditions, performing ERP analysis time-locked to the auditory stimuli might have revealed results regarding the attentional process that gives rise to multitasking.

Lastly, a shortcoming in all studies with older adults is that in the recruitment, the sample may lack a representation of individuals who have limited social interactions, financial support, exposure to university settings or researchers, and suffer from non-cognitive illnesses. This recruitment bias tends to underestimate the degree of cognitive decline seen with aging and may have occurred in this study as well.

4.2 Conclusion

This study aimed to explore how the increase in cognitive demand from multitasking affects task performance, and how it varies with different cognitive levels as measured by different screening tests. The task employed consisted of memorizing images while concurrently performing an additional task (dual condition) or without (single condition), whereby accuracy was measured by how well participants recognized images. The findings confirm a decline in performance in the dual as opposed to the single condition, however, neither age (between 52 and 72), nor cognitive levels, were predictive of performance cost.

Psychophysiologically, the late difference waveform failed to explain behavioral costs, with no interaction observed. The parietal SME, linked to the effective binding of item features suggests that cognitive resources in the single condition enabled more elaborate processing. The study's focus on image-evoked potentials, despite the auditory component, highlights a limitation. Future ERP analyses time-locked to auditory stimuli in the MEMO might better reveal the attentional processes underlying multitasking.

Further research should employ longitudinal study designs to explore how deficits in multitasking predict or uncover cognitive decline, or recruit younger participants to compare the psychophysiological indices across different ages.

In conclusion, this research highlights the necessity of further studies to comprehensively understand the true nature of multitasking and its complex relationship with age, cognitive functioning, cognitive load, and compensation mechanisms. Insights into these areas could have significant implications in the realms of prevention and clinical practice of cognitive aging. Moreover, it hints at a positive clinical potential in using online or computer-based tools for assessing cognitive decline as it may be useful in reaching more individuals to create normative data on how performance varies across individual differences.

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