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Attentional demand: validation of a new paradigm to quantify the use of attentional resources

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ABSTRACT

This work explores the interaction between two attentional processes, selective attention, and divided attention, while also assessing the cognitive costs associated with their switching in different contexts. Despite the number of studies on task-switching, there is no data in the literature concerning the cognitive impact of switching between components of the same domain.
In this study, therefore, an attempt was made to fill this gap by developing and validating the Attentional Demands Task (AD-Task). The instrument proved effective in measuring selective and divided attention, given the high correlations with established paradigms such as the Oddball task for selective attention and the Dual-Task task for divided attention. Initial results from the application of the instrument confirmed that divided attention leads to slower reaction times and less attention than selective attention due to a saturation of perceptual resources due to the concurrent processing of multiple stimuli. The innovative aspect of this research, the investigation of switching costs between different attentional states, showed that selective attention tasks, contrary to what might be expected, involve higher switching costs.

Within the same work, the Revised Sleep, Circadian Rhythms, and Mood Questionnaire (rSCRAM) was validated to give more consistency in the assessment of the different samples under study, to allow reliable measurement of participants' sleep quality, chronotype, and mood by greatly reducing the battery of questionnaires.

Evaluation of circadian and homeostatic variables revealed that attention is particularly vulnerable to these factors. Selective attention is more susceptible to circadian phenomena and shows greater deterioration in performance throughout the day. Divided attention and switching, on the other hand, are more vulnerable to homeostatic effects. Sleep deprivation amplifies the cognitive costs of switching, leading to prolonged reaction times and reduced accuracy, probably because prolonged wakefulness causes impairments in the functioning of the prefrontal cortex and executive processes.

In addition, age-related changes in attentional capacity, a decline in attention, and greater divided attention tasks due to the increased cognitive load these tasks impose have been shown and confirmed in comparison with previous findings in the literature. This decline is related to reduced prefrontal cortex function and weakened brain connection.

Overall, the results of this work contribute to the study of aging-related processes and circadian and homeostatic rhythms in the modulation of attentional components and switching ability, highlighting their impact on both short-term and long-term cognitive performance.

BACKGROUND

Famous is the phrase of James (1980), 'Everyone knows what attention is', less obvious is the real understanding of what it represents in everyday life. Indeed, even today, work continues to find the most effective and reliable method of measuring attention. What, for James (1980), was 'a condition that has a real opposite in the state of confusion, dizziness and scattering', for Rafael and Posner (1987), it consisted of several components. Various models for attention have been proposed since the 1950s (Burk et al., 2018). To date, an acceptable definition is to consider it a cognitive process that adapts data from the environment to the organism's needs (Ben Azouz et al., 2009).

Attention differs in several processes. Alertness can be tonic in nature when it represents a state of intrinsic arousal that can last from a few minutes to hours, or phasic when it involves a rapid change in attention following a stimulus of short duration (Degutis, 2010; Schmidt et al., 2007). Selective attention refers to focusing on relevant information while ignoring irrelevant information. Sustained attention refers to the ability to maintain a continuous effort and response over time. Divided attention can be defined as the ability to focus on two or more tasks simultaneously (Ko et al., 2017; Johnston & Dark, 1986).

The orientation of attention can be considered 'bottom-up' when external stimuli guide attention, and 'top-down' if the guidance comes from internal factors related to prior knowledge (Katsuki & Constantinidis, 2014). It is generally accepted that attention can be focused voluntarily through 'top-down' cues, which arise from awareness of the task at hand, or automatically through 'bottom-up' cues, which are evoked by relevant sensory events (Buschman & Miller, 2007; Bowling et al., 2020).

Given these theoretical foundations, we will now focus on two key components of attention: selective and divided attention. Selective attention allows individuals to focus on specific stimuli while ignoring others, understood as irrelevant information that may occur either externally (auditory or visual stimuli in the environment) or internally (thoughts) that hinder the performance of the task at hand (Stevens & Bavelier, 2012). We know from the large body of studies in the literature that selective attention is driven by both bottom-up cues from salient stimuli and top-down cues from participants' goals. These two processes constantly interact through partially overlapping networks of brain areas operating separately but collaborating to determine the allocation of attention (Buschman & Miller, 2007; Corbetta & Shulman, 2002; Desimone & Duncan, 1995). At the neural level, top-down signals involve the dorsal frontoparietal network (including the dorsolateral prefrontal cortex and intraparietal sulcus) to voluntarily direct attention

to relevant stimuli (Corbetta & Shulman, 2002; Hopfinger et al., 2000). Bottom-up signals, on the other hand, are mediated by the ventral network (temporoparietal cortex and inferior frontal gyrus), which redirects attention toward external events (Corbetta et al., 2008). These processes allow modulation of the activity of sensory areas, facilitating target processing and inhibiting distractions, while the anterior cingulate cortex (ACC) and other frontal regions manage response conflicts when competing stimuli compete for processing (Botvinick et al., 2004; Fan et al., 2005). Divided attention relates to the ability to handle multiple tasks simultaneously, distributed over several cognitive resources. This ability requires the involvement of executive functions, such as working memory, inhibitory control, and cognitive flexibility (Redick et al., 2016; Diamond, 2013). A concept closely related to divided attention is multitasking which is a relevant aspect of modern life (Broccia et al., 2019; Madore & Wagner 2019). Although multitasking is perceived as an important and desirable skill (Srna et al., 2018) and is becoming increasingly present in daily life (Malkoc & Tonietto, 2019), research shows how this ability to multitask has limitations (Madore & Wagner 2019). Some useful skills in performing multiple tasks together can improve with practice but often this comes at the cost of cognitive resources (Madore & Wagner 2019). Multitasking is a complex cognitive skill involving the simultaneous performance of multiple tasks, which may require considerable effort from various mental functions. Among the cognitive skills crucial for effective multitasking, recent research cites executive functions such as working memory, inhibitory control and cognitive flexibility (Redick et al., 2016; Diamond, 2013). Inhibitory control is coordinated by a series of processes that allow individuals to regulate their thoughts and actions to achieve specific goals, enabling them to resist distractions and suppress inappropriate responses (Bari & Robbins, 2013; Miller & Cohen, 2001). Working memory consists of the ability to retain and manipulate information that is no longer perceptually available; it is essential for processing sequences of stimuli and solving complex problems (Baddeley & Hitch, 1994). Finally, cognitive flexibility allows one to adapt quickly to new rules or perspectives and is the most crucially exploited capacity in multitasking (Miyake et al., 2000). In the experimental sphere, the effects of multitasking are studied using task-switching protocols, which involve rapidly switching from one task to another. This process involves the subject having to reorganize cognitive resources, known as (task-set reconfiguration) and this occurs, causing cognitive costs (switch cost), usually in the slowing down of responses and the increase in errors immediately after a task change compared to task repetition. (Rogers & Monsell, 1995). In task-switching, various cognitive processes are involved, as it requires modulating attention to prioritize relevant stimulus features and inhibiting information from the previous task to prevent stimuli associated with the previous task from triggering competition with the new task (Allport et al., 1994). At the

neural level, task-switching activates a broad brain network, including the dorsolateral prefrontal cortex, responsible for executive control and task-set reorganization; the anterior cingulate cortex, implicated in error monitoring and conflict resolution, and the posterior parietal regions, which are involved in attentional modulation and the selection of stimulus-specific attributes (Monsell, 2003).

There are several methodologies to assess this ability, with established tests measuring selective and divided attention in different populations and conditions (Nasiri et al., 2023).
For example, for selective attention, the Stroop Color and Word Test is one of the most accepted methods and allows for the measurement of the ability to inhibit cognitive interference from competing stimuli, an indicator of selective attention ability (Stroop, 1935; Scarpina & Tagini, 2017; Zonneveld et al., 2023). Another method used to study selective attention experimentally is the dichotic listening test, in which participants listen to different stimuli in each ear and are instructed to focus on one. This test assesses various cognitive processes, such as attention control, language lateralization, and neural mechanisms of auditory processing (Ball & Zuckerman, 1992; Ross et al., 2010; Gadea et al., 2016). One of the most famous tasks used in this field is the Continuous Performance Test (CPT, Conners et al., 1995; Conners et al., 2000), based on the Go-NoGo paradigm, where in its initial version, different letters are visually presented, and the participant is asked to respond to the appearance of the letter "X", either alone or when preceded by the letter "A". Over the years, several versions have been created to adapt it to different experimental contexts and populations (Tinius, 2003). Finally, among these, the oddball paradigm should be mentioned. It is an experimental method used to study selective attention, where a participant is presented with a sequence of repetitive stimuli, occasionally interrupted by an unexpected or "target" stimulus (Squires et al., 1975). To assess divided attention, tasks such as the PASAT (Paced Auditory Serial Addition Task, Gronwall, 1977) are well-known, where the participant is asked to mentally add verbally presented numbers, adding each number to the previous result. The Trail Making Test (Reitan, 1958) consists of two sections: Part A, where the subject connects 25 numbers in ascending order, and Part B, where they alternate between numbers and letters in a specific order (1-A-2-B, etc.). It is used to study divided attention, as Part B requires the subject to alternate between numbers and letters sequentially (1-A-2-B, etc.), testing the ability to manage multiple pieces of information and tasks simultaneously. In this section, the subject must maintain attention on two separate sequences (numbers and letters), thus evaluating their ability to manage and coordinate attention across multiple stimuli. The time taken to complete both sections indicates the efficiency of divided attention. However, it is more common to use Dual-

Task paradigms, where the efficiency of divided attention is evaluated as the result of a true division of concentration on two tasks of different nature, such as performing a visual search task (e.g., the barrage task) while listening to a voice that pronounces numbers, and the subject must respond when a number is repeated twice consecutively.
There are also tasks in the literature that measure different dimensions of attention, such as sustained, selective and divided attention, in everyday contexts. The Test of Everyday Attention (TEA) includes eight subtests that simulate real-world tasks, such as counting floors in a lift and searching for telephone numbers, allowing the ability to maintain attention and manage distractions to be measured (Avirame et al., 2022; Bak et al., 2014).

Additionally, several experimental paradigms exist in the literature for studying task switching and its effects. Among these, it is important to highlight the paradigm used by Rogers & Monsell (1995), where participants see a letter and a number appear in one of the four screen quadrants. If the symbol appears above the midline, they must indicate whether the letter is a vowel or a consonant; if it appears below, they need to determine whether the number is even or odd. The task changes predictably every two rehearsals, demonstrating that change costs occur even with early preparation. In a study by Mayr & Bryck (2005), they used a task (*Spatial Rules Task*) in which participants had to apply a specific spatial rule to respond to a stimulus that appeared in a quadrant of the screen, with a cue indicating which spatial rule to apply. Costs emerged even when stimulus and response remained unchanged, suggesting that it was not only the change in stimulus that affected performance but also the need to adapt to a new rule, a crucial factor in the slowdown in responses. In Arrington & Logan's (2004) *Voluntary Task Switching,* on the other hand, participants were free to choose which of the two available tasks to perform, but a clear preference was observed for repeating the previous task, indicating a strong tendency for task persistence, reflecting the difficulty or psychological burden in making a voluntary switch. Dykstra and colleagues (2022) used a task that explored the situation in which stimuli and responses between two tasks were completely distinct and did not overlap, and change costs were still observed, suggesting that the brain not only adapts to external changes (stimuli) but also to the internal organization of actions, treating the tasks as distinct and separate groups.

Despite the wide diversity of instruments used to assess attention and the considerable advantages in their application, it is fair to consider the existence of several limitations, including the difficulty of comparing the results obtained due to differences in protocols and modes of administration. These aspects introduce significant bias, as variations in stimuli, response times and instructions

make it complex to compare both data between different studies and performance between different attentional components. Furthermore, the assessment of attentional processes is complicated by the interaction with other cognitive processes, such as working memory, which influence test performance and make it difficult to isolate attention specifically. Furthermore, many tests require motor or language skills, excluding subjects with specific deficits and reducing the generalizability of the results. As for switching tasks, there are no tasks that specifically allow the evaluation of the switch between two exclusively attentional components. In fact, in the existing tasks, the switching costs always arise from the alternation between two tasks of different perceptual nature (auditory stimuli versus visual stimuli) or involving different cognitive processes (working memory task versus selective attention task), obscuring what happens daily when switching from one attentional demand to another (Liebehrr et al., 2019).

Typically, to assess performance in an attentional task, several variables derived from Signal Detection Theory (SDT, Stanislaw & Todorov, 1999) and response time analysis are used. The main ones are:

Hit Rate (H): proportion of correctly identified targets compared to the total number of targets presented. It is calculated as:

$$H=Hit/Hit+Miss$$

where hit (correct hit) occurs when the observer correctly recognizes a target and responds appropriately and miss (failure to recognize) occurs when the observer does not detect a target present and does not respond. This indicates a possible lack of attention or too conservative a decision threshold.

False Alarm Rate (FA): proportion of non-target stimuli erroneously reported as targets. It is calculated as:

$$FA = False\ Alarm / False\ Alarm+Correct\ Rejection$$

False alarm occurs when the observer responds incorrectly to a stimulus that is not a target, and correct rejection occurs when the observer does not respond to an irrelevant stimulus, correctly recognizing that it is not a target.

d' (d-prime): a measure of the sensitivity of the observer in discriminating between target and non-target signals. It is calculated as:

$$d' = Z(H) - Z(FA)$$

where Z is the inverse transform of the standard cumulative normal function. Higher values of d' indicate a better ability to distinguish target stimuli from noise. However, computational problems arise when H=1 or FA=0, since:

$$Z(1) = +\infty, Z(0) = -\infty$$

This situation arises in the case of near-perfect performance, such as in experiments with a limited number of trials or with highly sensitive observers.

To avoid infinite values in the calculation of d', a continuity correction is applied that stabilizes the estimates of H and FA. Among the most widely used methods is the one proposed by Macmillan & Kaplan (1985), which corrects the boundary rates as follows:

$$H' = 1 - 1/(2*N)$$

$$FA' = 1/(2*N)$$

where N represents the total number of trials for each rate (N_H for hits e N_{FA} for false alarms). Using these corrected values, d' can be recalculated as:

$$d' = Z(H') - Z(FA').$$

Reaction Time (RT): average response time to target stimuli. Lower values indicate quick responses but may be associated with increased errors, and longer times may reflect a more cautious strategy or attentional difficulties.

These variables, used and analyzed together, provide insight into the trade-off between accuracy and speed, highlighting individual differences or experimental effects on attentional performance.

Attention and executive functions are fundamental cognitive processes that regulate our ability to concentrate, make decisions, and adapt to complex situations. However, these mechanisms are not static but are influenced by several biological factors, including circadian rhythms, sleep quality, and aging.

Circadian rhythms are regulated by the suprachiasmatic nucleus (CNS) and allow for the synchronization of physiological functions, also leading to variations in cognitive performance throughout the day, with maximum levels of attention during the daytime hours and major declines during the night (Valdéz et al., 2012; Logan & McClung, 2019). A factor that influences a lot of cognitive performance is the chronotype, performing tasks in alignment with it allows for better performance (Singh et al., 2016; Holding et al., 2021). Monitoring the chronotype is therefore a

very important aspect in the assessment of circadian fluctuations in the experimental environment. In addition to attentional performance, circadian rhythms also modulate the ability to switch between tasks, as they affect executive functions such as cognitive flexibility and inhibitory control, which are essential in task switching (Bratzke et al., 2012; Cheng et al., 2017). Indeed, circadian misalignment, such as social jet lag or shift work, reduces attention and increases fatigue (Wittmann et al., 2006; Lahti et al., 2010; Lee, 2022).

Sleep quality also plays a crucial role in attentional processes and executive functions. Sleep deprivation can cause significant declines in cognitive performance even after only 24 hours; equivalent attentional deficits occur even when chronic restriction occurs (with sleep periods of 4-6 hours per night for 14 days, Dodds et al., 2011; Deliens et al., 2015). Lack of sleep results in performance decrements in executive functions, especially in cognitive flexibility, resulting in greater difficulty in task-switching and divided attention (Couyoumdjian et al., 2010; Murphy & Castel, 2022; Gaspelin et al., 2013). These deficits stem from altered cortical activation and reduced connectivity in attentional networks that can lead to slowed reaction time and impaired executive control (Chee et al., 2011; Honn et al., 2018) and impaired prefrontal cortex that can increase task-switching costs and reduce adaptability in task switching (Lo et al., 2012; Varga et al., 2014).

Aging further contributes to cognitive decline with major implications in executive and attentional functions, evolving following an “inverted U-shaped” trajectory, in which there is a peak in young adulthood and a subsequent progressive decline (Simon et al., 2023). With advancing age, there is a decline at the level of the frontal lobe, which results in a performance impairment in the ability to filter out irrelevant stimuli or divide attention (Geerlings et al., 2014; Craik et al., 2010). Moreover, poor prefrontal cortex inefficiency in older adults deteriorates the ability to switch between tasks deteriorates, with slower response times and higher cognitive costs, (Lacreuse et al., 2020; Wilson et al., 2017). Although older adults may implement compensatory strategies, reduced processing speed and increased cognitive load negatively affect multitasking performance (Fellows et al., 2014; Nóbrega-Sousa et al., 2020).

This scientific evidence shows how attention and executive functions are profoundly influenced by circadian rhythms, sleep quality, and aging, necessitating studies that can investigate their implication in everyday contexts.

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STUDY 1: Development and validation of Attentional Demands Task with evaluation of possible learning effects

1.1 INTRODUCTION

Knowledge about attention has evolved, revealing that this process is fundamental to human behavior and interaction with the environment (Peterson & Posner, 2012). A relevant aspect of modern life is the prevalence of multitasking, which significantly influences attentional processes and cognitive performance (Broccia et al., 2020; Madore & Wagner 2019). Although multitasking is perceived as an important and desirable skill (Srna et al., 2018) and is becoming increasingly present in daily life (Malkoc & Tonietto, 2019), research shows how this ability to multitask has limitations (Madore & Wagner 2019). Some useful skills in performing multiple tasks together can improve with practice, but often this comes at the cost of cognitive resources (Madore & Wagner, 2019). Multitasking is a complex cognitive skill that involves the simultaneous performance of multiple tasks and may require considerable effort from various mental functions (Redick et al., 2016). Among the cognitive skills crucial for effective multitasking, recent research mentions executive functions such as working memory and inhibitory and attentional control (Diamond, 2013).

The ability to switch from performing one task to another is generally studied using task-switching tasks (Monsell,2003). *Task switching* is an executive function that automatically shifts attention from one task to another. This paradigm, introduced by Jersild (1927), allows for analyzing control processes that organize and reallocate mental resources during task switching, revealing the mechanisms underlying our cognitive adaptability and operational efficiency in complex, dynamic contexts.

Attentional resources are limited, so they must be divided among various tasks, often leading to decreased overall performance. For example, the quality or speed with which a task is completed may decrease when attempting to perform multiple tasks simultaneously. This phenomenon is particularly evident in complex tasks requiring a high concentration level (Owsley, 2011). Despite the strong involvement of attentional processes in multitasking ability, the shift between different attentional demands has been largely overlooked. It was only in 2019 that Liebherr et al., introduced a task aimed at investigating the ability to transition between different tasks by specifically stressing the cognitive domain of attention, focusing on the interaction between two components of this process: selective attention and divided attention. Thus, the Switching

Attentional Demands Task (SwAD-Task) was developed to study the capacity to adapt to varying attentional demands, such as selective and divided attention, with a focus on task switching. The task comprises three phases: training, single demand, and switching demand. The task involves the presentation of a stimulus composed of a figure (e.g., a triangle) and a number (e.g., three). In the selective attention condition, participants must focus on one element, ignore the other, and respond using a predefined button. In the divided attention condition, they must respond to both elements with separate buttons. The task consists of three phases: training (ten trial blocks, one for selective attention and one for divided attention, with feedback on correct or incorrect responses), single demand (four blocks of selective attention and four of divided attention, with two-minute breaks between blocks), and switching (four blocks of selective attention and four of divided attention presented alternately). Each block contains 26 trials, with target stimuli (between 5 and 8) randomly presented. The stimuli are displayed at the center of the screen for 250 milliseconds, with a maximum response time of 1,800 milliseconds. The interval between stimuli randomly varies between 500 and 2,300 milliseconds. Performance is evaluated primarily through response times and the entire task takes approximately 20 minutes (Liebherr et al., 2019).

The Switching Attentional Demands Task (SwAD-Task), as designed by Liebherr et al. (2019), effectively evaluates participants' ability to manage attentional flexibility between selective attention and divided attention. However, several limitations inherent in this task design may impact the robustness and breadth of the cognitive processes examined. Specifically, the task presents a restricted number of stimuli, both target and nontarget, which may hinder the generalizability of findings to more complex real-world contexts. Additionally, the predefined response times and interstimulus intervals, ranging from 500 to 2,300 milliseconds, could be too long, potentially diminishing the urgency and dynamics of the task and making it challenging for participants to maintain a high level of attention and engagement. Finally, with a total duration of only 20 minutes, the SwAD-Task may not capture long-term adaptability or the effects of fatigue, which are critical to understanding sustained attentional control. These limitations suggest a need for a revised experimental design that improves the ecological validity and comprehensiveness of the task.

Learning from practice is a key element in attentional tasks, as it contributes to improved cognitive performance and the ability to adapt strategies in response to varying demands (Bell et al., 2018; Liao et al., 2019; Yokoyama et al., 2015). The effects of practice consist of improvements in performance on cognitive tests resulting from repeated assessments, Bell et al. (2018) highlighted that the effects of practice are evident in cognitive tasks even when alternative forms of the same functions are used, suggesting that familiarity and repeated exposure can contribute to improved

performance (Bell et al., 2018). This finding is consistent with the broader literature indicating that cognitive training improves attention and executive functions (Liao et al., 2019; Yokoyama et al., 2015). In the context of task switching, training in performing two attention-demanding tasks simultaneously has been found to produce greater improvements than training on a single task (Worden & Vallis, 2014), due to better integration and coordination of cognitive resources (Strobach, 2019).

Even in the Switching Attentional Demands Task (SwAD-Task), the effects of practice may be a crucial element that requires further investigation. Although Liebherr et al. (2019) did not conduct specific studies on learning effects, the literature suggests that continuous practice could significantly influence performance, representing a limitation for using the task in protocols that require multiple measurements (Bell et al., 2018; Liao et al., 2019; Yokoyama et al., 2015). Therefore, it is essential to explore this dimension further to rule out possible learning effects that may limit the applicability of the task in contexts requiring multiple measurements.

1.2 PHASE 1: CREATION AND VALIDATION OF THE NEW ATTENTIONAL DEMANDS TASK (AD-TASK).

1.2.1 AIM

To develop and validate a revised experimental paradigm version of the Switching Attentional Demand (SwAD), called Attentional Demands Task (AD-Task), which measures selective and divided attention and the 'cognitive cost' due to switching between them.

1.2.2 MATERIALS AND METHODS

Participants

Forty-one participants (age: 21.0±2.25; 33 F) completed the AD-Task, a selective attention task (Oddball-Task, OD), and a divided attention task (Dual-Task, DT). No participant reported a history of neurological or psychological disorders, and all indicated that they had normal or corrected vision and hearing. All participants were bachelor students from the University of L'Aquila. Before the experiment, all participants provided their informed consent in writing and were told that they could withdraw from the study at any time without facing consequences.

Pittsburgh Sleep Quality Index (PSQI)

The Pittsburgh Sleep Quality Index (PSQI), developed by researchers at the University of Pittsburgh (Buysse et al., 1989) in its Italian version (Curcio et al., 2013), was used to assess sleep quality in the previous month. The questionnaire was completed digitally (or on paper when requested, before the experimental phase to select a sample of subjects with good sleep quality). It is a self-assessment test that the subject completes independently between 5 and 10 minutes. The questionnaire consists of 19 items with different subscales for assessment: subjective sleep quality, sleep latency, sleep duration, habitual sleep efficiency, sleep disturbances, use of sleep medication, and daily dysfunctions. Each item is rated on a scale of 0-3 and an overall score greater than 5 indicates a sleep disorder. The Italian version (Curcio et al., 2013) achieved significant internal consistency (Cronbach's α of 0.83).

Karolinska Sleep Diary (KSD)

Introduced in 1994 by researchers at the Karolinska Institute (Åkerstedt et al.,1994), this instrument assesses sleep quality. Available in digital form (or on paper when requested), it must be completed by subjects within 30 minutes of awakening to increase the reliability and accuracy of responses. The questionnaire takes about 5 minutes to complete. It is a self-assessment tool that examines the previous night's sleep. Specifically, it investigates several components that contribute to sleep quality, such as continuity, depth, awakenings, degree of sleep refreshment, final awakening, and any events that may have altered sleep quality.

Karolinska Sleepiness Scale (KSS)

The Karolinska Sleepiness Scale (KSS; Kaida et al., 2006) measures the subjective level of sleepiness at a specific time of day based on the individual's psychophysical state in the past 10 minutes. This self-report scale, sensitive to situational fluctuations, is used in studies on shift work, jetlag, driving abilities, attention, performance, and clinical settings and applies to both men and women. It helps to assess changes due to environmental factors, circadian rhythm, and drug effects but is not widely used clinically because it does not measure 'trait' sleepiness. Completing the KSS takes about 5 minutes. Studies by Kaida et al. (2006) indicate high validity, showing strong correlations with EEG and behavioral variables, though test-retest reliability is challenging due to score variability. The KSS uses a 9-point scale (1=extremely alert, 9=extremely sleepy). Scores increase with the duration of wakefulness and correlate with the time of day (Åkerstedt & Gillberg, 1990).

Epworth Sleepiness Scale (ESS)

The Epworth Sleepiness Scale (ESS) was used to assess daytime sleepiness. This scale was introduced by Murray Johns in 1991 at the Epworth Hospital in Melbourne, Australia. It is a tool for evaluating sleep and can be useful in diagnosing related disorders. The questionnaire presents subjects with everyday situations that most people encounter over time. For each situation, the subject is asked to rate their likelihood of falling asleep on a scale from 0 to 3. A total score from 0 to 9 is considered normal, while a score from 10 to 24 indicates dysfunctional sleep that needs to be examined more closely.

Global Vigor-Affect Scale (G-VAS)

The Global Vigor-Affect Scale (GVAS), introduced by T.H. Monk in 1989, is a psychometric tool developed to measure an individual's perceived vigor and affect at a given time. Comprising eight items, the GVAS evaluates two main dimensions: *vigor*, reflecting perceived energy and vitality, with high scores indicative of elevated levels of positive activation; and *affect*, capturing current positive or negative emotions, with high scores associated with positive feelings such as joy and satisfaction. Used in various research contexts, including sports psychology, mental health, and general well-being studies, the GVAS is completed on paper before specific tasks, inviting participants to assess their current state using a Likert scale to gauge the intensity of perceived emotions and vigor.

Attentional Demands-Task (AD-Task)

The SwAD task (Libherr et al., 2019) was developed to measure two different attentional processes: selective attention and divided attention. Additionally, this tool allows for the assessment of the "cognitive cost" due to switching between the two different attentional demands. In this revised version, called Attentional Demands Task (AD-Task) each stimulus consists of two features: geometric shape (circle, square, triangle, and diamond) and color (red, blue, green, yellow). The use of figures and colors makes it more applicable to a broad population from infancy to old age than the version by Liebherr et al. (2019) in which the use of numbers limited the use of the task to a schooled population.

Each stimulus (target or nontarget) had the same size and appeared at the center of a black screen for 250 ms, followed by a black screen (up to 900 ms) during which the participant could respond

by pressing a key. The inter-stimulus interval was randomized between 250 and 1000 ms and featured a black screen with a white fixation point ("+").

The task is composed of 16 blocks (8 blocks for selective attention and 8 blocks for divided attention), each consisting of 60 trials, preceded by a training phase with two blocks of 15 trials, one for each attentional demand. As in the version developed by Libherr et al. (2019), the task used is composed of two conditions: in the first condition, four blocks of a single attentional demand (either selective attention or divided attention) are presented, allowing for the evaluation of only one attentional component at a time. In the second condition, the four blocks of selective attention and the four blocks of divided attention are alternated, allowing the measurement of the cognitive costs associated with switching between different attentional demands. The difference between selective and divided attention tasks was explained through detailed instructions at the beginning of each block, specifying the target(s) to search for and the key(s) to press in response. In selective attention tasks, participants were instructed to press the "L" key when a green circle appeared, as for every selective attention trial. In the divided attention tasks, participants were asked to press the 'L' or 'S' key when a specific color appeared (both the key and the color varied from block to block, as indicated in the instructions before the test), regardless of the shape. They were also asked to press the 'L' or 'S' key when a specific shape appeared (key and shape varied from block to block, as indicated in the instructions before the test), regardless of color. For more details, see Figures 1.1 and 1.2.

Selective Attention: The task consists of 4 blocks, for a total of 240 stimuli, including 174 no-target and 66 target stimuli. Specifically:

- In the first block, 45 nontarget stimuli are presented (18.5% no target for the shape; 18.5% no target for the color; 38% nontarget for both characteristics) and 15 target stimuli.
- In the second block, 42 nontarget stimuli are presented (17.5% nontarget for the shape; 17.5% nontarget for the color; 35% nontarget for both characteristics) and 18 target stimuli.
- In the third block, 42 non-target stimuli are presented (17.5% non-target for the shape; 17.5% non-target for the color; 35% non-target for both characteristics) and 18 target stimuli.
- In the fourth and final block, 45 nontarget stimuli are presented (18.5% nontarget for the shape, 18.5% nontarget for the color; 38% nontarget for both characteristics) and 15 target stimuli.

Divided Attention: The task consists of 4 blocks, for a total of 240 stimuli, including 174 nontarget and 66 target stimuli. Specifically:

- In the first block, 42 non-target and 18 target stimuli are presented (50% target for the shape; 50% target for the color).
- In the second block, 45 nontarget and 15 target stimuli are presented (58.3% target for the shape; 46.7% target for the color).
- In the third block, 42 nontarget and 18 target stimuli are presented (50% target for the shape; 50% target for the color).
- In the fourth block, 45 non-target and 15 target stimuli are presented (53.3% target for the shape; 46.7% target for the color).

***Switching*:** The test consists of 8 blocks (the same 4 for selective attention and the same 4 for divided attention already specified), for 624 stimuli, including 468 non-target and 156 target stimuli. To avoid a sequence effect among the different conditions presented in the task, six different sequences were created: selective/divided/switching; selective/switching/divided; divided/selective/switching; divided/switching/selective; switching/selective/divided; switching/divided/selective. These sequences were administered to participants in a randomized order. The total duration of the task was 50 minutes, and the performance was assessed by measuring reaction times and accuracy.

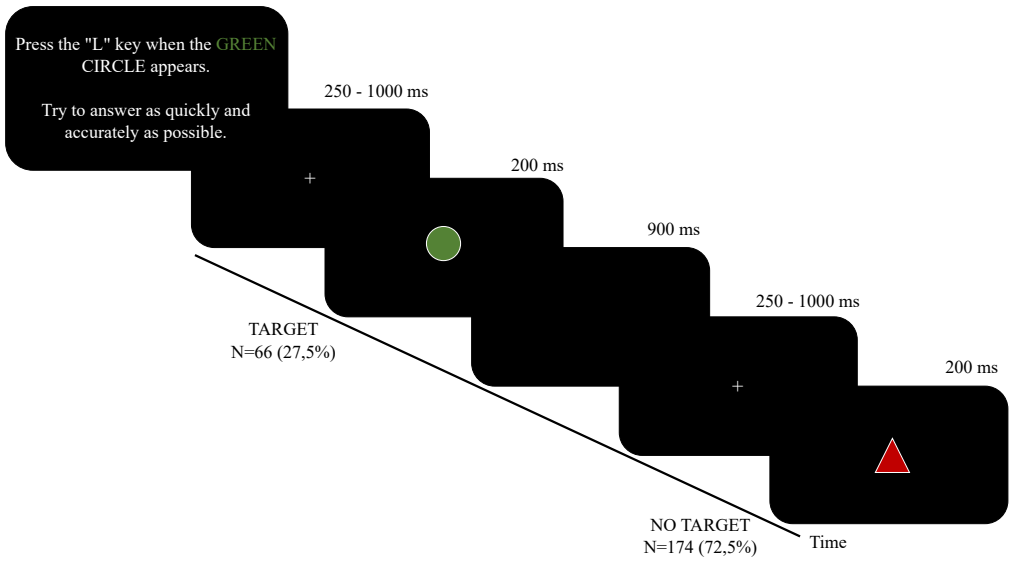


Figure 1.1- The instructions and the sequence of exposure with the timing of the task execution with selective attention

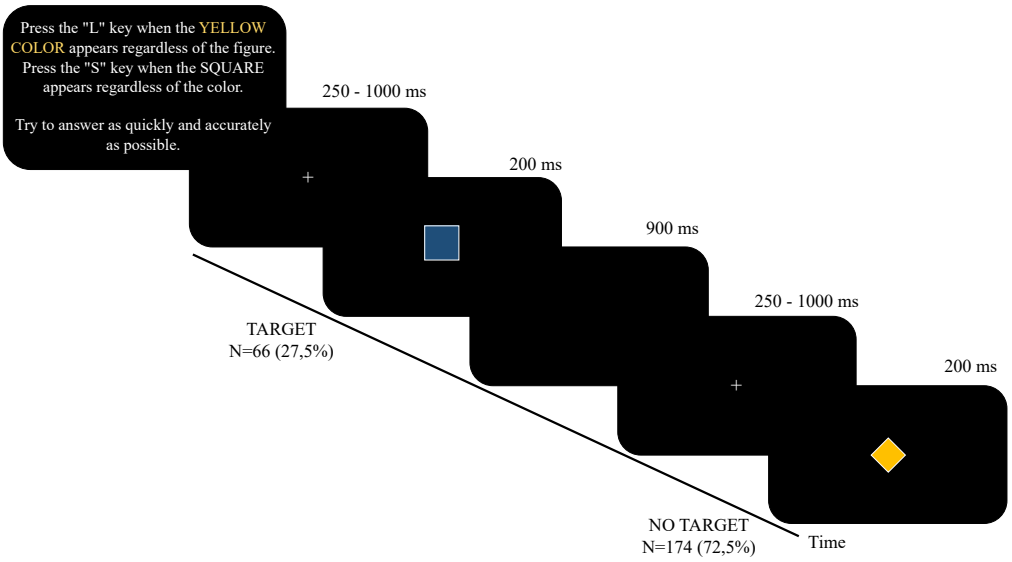


Figure 1.2 - Instructions and sequence of exposure with the timing of the task execution in divided attention

Oddball-Task, OD

The experimental session included two different task types, each containing 360 stimuli. In one task, circles served as the target stimuli and squares as distractors (Fig.1.3), while in the other, the roles were reversed: squares were the targets and circles were the distractors (Fig.1.4; Bocquillon et al., 2012). The order of task presentation was counterbalanced, with half of the participants completing the circle task first and the other half the square task. Figures 1.3 and 1.4 show that the stimuli were solid blue shapes, presented in random order for 900 ms each, with an interstimulus interval ranging from 800 to 1200 ms (Sanger & Dorjee, 2016; Cai et al., 2023).

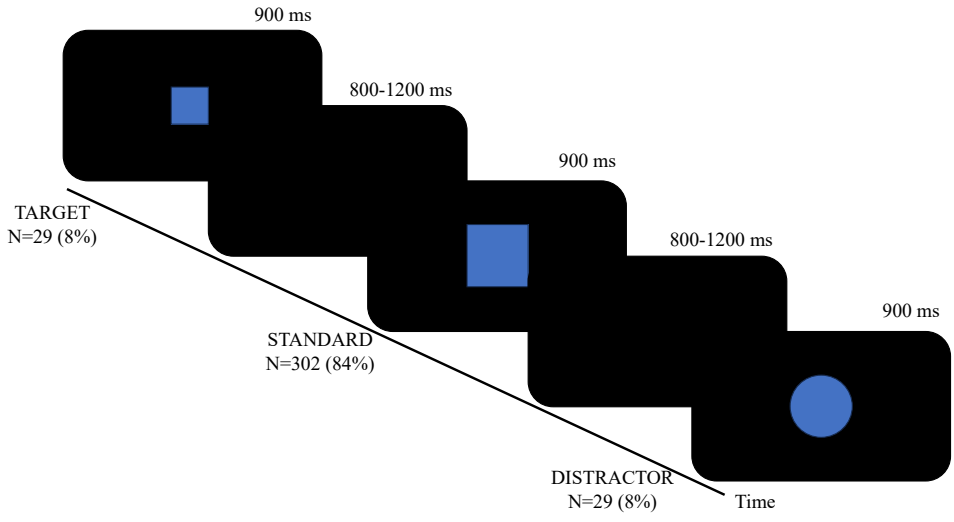


Figure 1.3 - Schematic representation of the three-stimulus visual oddball paradigm (square task).

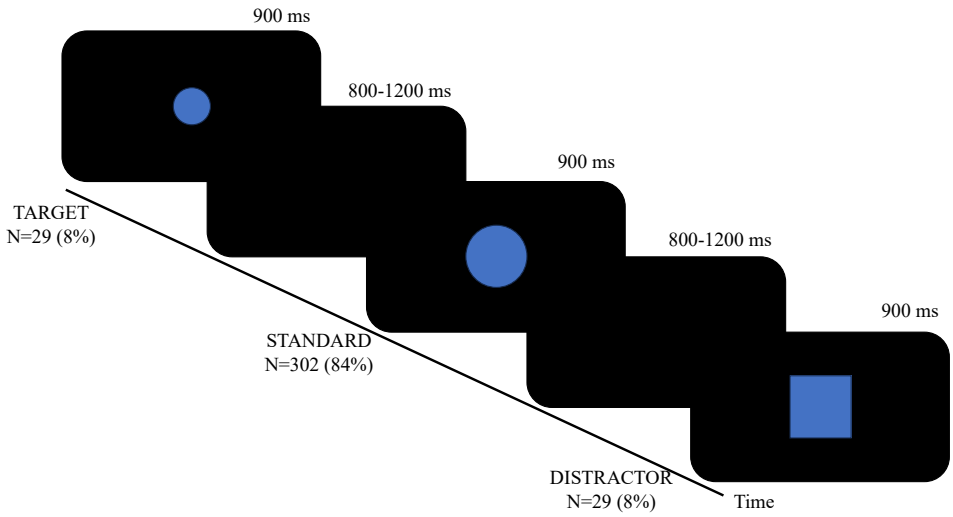


Figure 1.4 - Schematic representation of the three-stimulus visual oddball paradigm (circle task).

The stimuli were divided into three categories: standard no-target shapes (circles with a diameter of 6.66 cm or squares with sides of 6.66 cm), distractors (the opposite shape from the standard: squares or circles of the same dimensions), and target shapes (smaller versions of the standard shapes: circles with a diameter of 4.44 cm or squares with sides of 4.44 cm).

The presentation probabilities were 0.84 for standard no-target shapes, 0.08 for distractors, and 0.08 for target shapes. Before each task, participants received verbal and written instructions to respond as quickly and accurately as possible by pressing the spacebar when the target shape appeared, either a small square or a small circle, depending on the task (Bocquillon et al., 2012). The task lasted 20 minutes in total and the performance was assessed by measuring reaction times and accuracy.

Dual-Task, DT

To validate the divided attention condition of the AD-Task, we used a dual-task paradigm based on a standard Go-NoGo task (modified version of Chua et al., 2017), involving two concurrent visual stimuli. Unlike conventional dual-task paradigms that combine visual and auditory cues to engage separate sensory channels, our version used only visual stimuli, focusing on a single sensory modality. Before the main test, participants completed a brief training session to familiarize themselves with the task.

The task involved two visual elements: a white square and a white circle, both displayed on a black background. Following an initial display period of 2750 ms (pre-target phase), the square changed color, and the circle was replaced by a number from 1 to 6 (see Figure 1.5). Participants were instructed to respond by pressing the "C" key if the square turned orange and the "N" key if the circle displayed an even number (2, 4, or 6). Participants were also required to inhibit responses if the square turned any color other than orange (eg, blue, red, or green) or if the circle displayed an odd number (1, 3, or 5). As with other attention tasks, participants were encouraged to respond as quickly and accurately as possible.

The task included 50 target stimuli:

- 25 color-Go stimuli (displayed for 750 ms each),
- 25 number-Go stimuli (displayed for 750 ms each), as well as 50 No-Go stimuli (750 ms each).

The task lasted 20 minutes in total and the performance was assessed by measuring reaction times and accuracy.

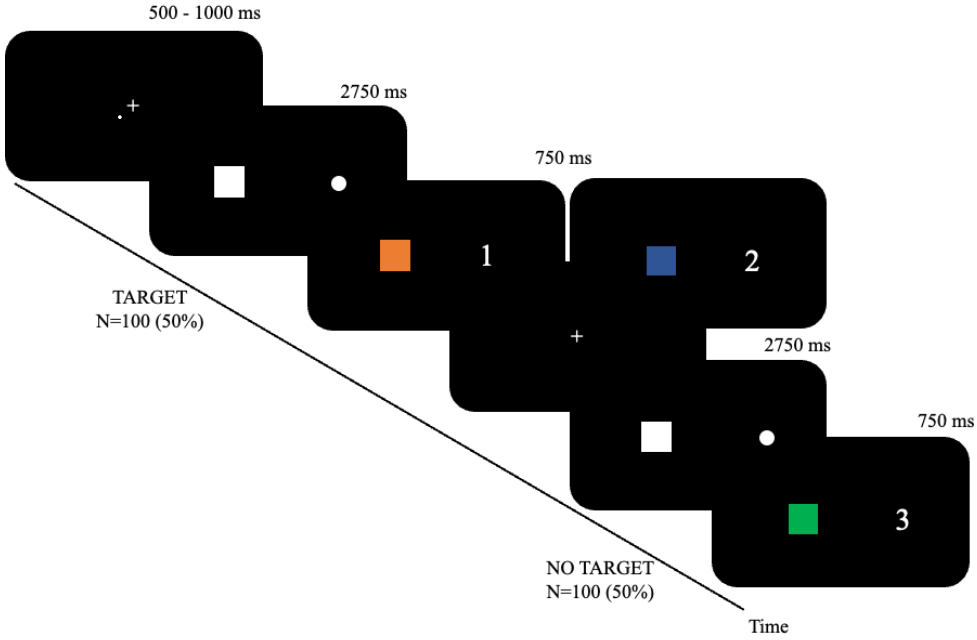


Figure 1.5 - Sequence of stimuli in the dual-task paradigm

1.2.3 PROCEDURE

The study, conducted in the Laboratory of Cognitive and Behavioral Sciences at the University of L'Aquila involved participants selected according to the Pittsburgh Sleep Quality Index (PSQI) scores, excluding those with poor sleep quality to avoid possible confounding effects. The selected

participants completed the Karolinska Sleep Diary (KSD) throughout the experimental week to monitor the quality and duration of their sleep.
For experimental purposes, the most suitable room was initially chosen to create an optimal experimental environment, isolated from outside distractions and interference, and participants were seated at a 35.4x19.9-cm computer station. The protocol took place over three consecutive days at the same time each day. Before each session, participants completed the Epworth Sleepiness Scale (ESS), the Karolinska Sleepiness Scale (KSS), and the Global-Vigor and Affect Scale (G-VAS) to measure, respectively, daytime sleepiness, current sleepiness, and vigor-affect. Participants were then randomly assigned to one of three computerized attentional tasks: the Attentional Demands Task (AD-Task) to assess selective and divided attention and switching between them; the Oddball Paradigm to measure selective attention and response to rare stimuli; and the Dual-Task Paradigm to evaluate the efficiency of performing two simultaneous tasks.

Before starting each experimental session, the participants were instructed verbally and with written instructions about the nature of the experiment in which they participated. In addition, it was made clear to them that this was a test for evaluating attention and that they were required to maintain attention and concentration to their full potential throughout the experiment. For performance assessment, accuracy was measured using the Signal Detection Theory (SDT; Stanislaw & Todorov, 1999), calculating the hit rate (H), false alarm rate (FA), and sensitivity (d'), with possible extreme value correction according to Macmillan & Kaplan (1985), while speed was assessed based on reaction times (RTs).

The protocol for each day lasted approximately 40 minutes. The investigation was approved by the Internal Review Board of the University of L'Aquila (#61/2021-2022) and was conducted according to the principles established in the Declaration of Helsinki.

1.2.4 DATA ANALYSIS

Descriptive statistics of the investigated sample were conducted on age, gender, and the participants' indices of sleep quality (PSQI, KSD). To assess the stability of the index of sleepiness, vigor and affect, a repeated measures ANOVA was performed in which DAY was included as a factor within the scores obtained on the ESS and GVAS questionnaires (vigor and affect). A nonparametric repeated measure ANOVA (Friedman) was performed on the KSS scores because the data did not have a distribution consistent with that of a normal (DAY1: Shapiro Wilk

W=0.864, p<.001; DAY2: Shapiro Wilk W=0.942, p=0.033 DAY3: Shapiro Wilk W=0.925, p=0.009).

To assess the presence of correlations in the reaction times (RTs) of the AD-Task in the individual attentional components with the other measures used in the study for selective attention, the Oddball task paradigm and the Dual-Task for divided attention, Pearson's r was used. A non-parametric (Spearman) correlation was performed for the HIT RATE scores of both divided and selective attention because the data did not have a distribution consistent with that of a normal (AD-Task selective: Shapiro Wilk W=0.568, p<. 001; Odd-ball: Shapiro Wilk W=0.560, p>.001; AD-Task divided: Shapiro Wilk W=0.936, p=0.022; Dual Task: Shapiro Wilk W=0.715, p<.001).

To perform the analyses, average reaction times were calculated for each attentional demand investigated (selective/divided) in each condition considered (single demand/switching). Incorrect responses and nonresponses were excluded from the calculation of average reaction times. Subjects with a performance below 75% were identified as outliers. HIT RATE, d', and FA RATE indices were considered to assess accuracy. For the single demand condition, the mean reaction times were calculated for all four blocks, while in the switching condition only blocks 2 to 4 were included to exclude the first two blocks per demand, which were exempt from switching effects.

For the AD-Task task, reaction times and accuracy (d') in the three different attentional demands were evaluated using a repeated-measures ANOVA in which CONDITION (selective attention, divided attention, and switching) was entered as an internal factor. The repeated-measures ANOVA was used to analyze reaction time and accuracy (d') in the single demand and switching conditions, using “TYPE OF ATTENTIONAL DEMAND” (selective/divided) and “CONDITION” (single-demand/switching) as factors within.

In addition, to assess how much its “costs” to switch in the two attentional demands investigated, switching costs for selective and divided attention were calculated as the difference between the demand switching and single demand conditions. The resulting switching costs were analyzed by a repeated-measures ANOVA in which “ATTENTIONAL DEMAND TYPE” was included as a within factor.

To assess the differences between selective, divided attention and switching on performance (HIT RATE, FA RATE), a nonparametric repeated-measures ANOVA (Friedman) was performed on

the accuracy indices HIT RATE and FA RATE because the data did not have a distribution conforming to the normal distribution (HIT RATE selective: Shapiro Wilk W=0.568, p<. 001; HIT RATE divided: Shapiro Wilk W=0.936, p=.022; p<.001; HIT RATE switching: Shapiro Wilk W=0.802, p<.001; HIT RATE switching selective: Shapiro Wilk W=0.280, p<.001; HIT RATE switching divided: Shapiro Wilk W=0.906, p=.002; FA RATE selective: Shapiro Wilk W=0.692, p<. 001; FA RATE divided: Shapiro Wilk W=0.358, p<. 001; p<.001; FA RATE switching: Shapiro Wilk W=0.758, p<.001; FA RATE switching selective: Shapiro Wilk W=0.779, p<.001; FA RATE switching divided: Shapiro Wilk W=0.683, p<. 001). The same statistical test was also applied to the same performance variables to assess the differences between performance in single demand and switching conditions for selective and divided attention.

Post-hoc comparisons were performed if statistical significance was reached (p <.05).
All analyses were conducted using the Jamovi program, and the level of statistical significance was set at p<.05.

1.2.5 RESULTS

Descriptives

The 41 participants (age: 21.0±2.25; 33 F) who participated in the study reported good sleep quality in the last month as assessed by PSQI (5.45±2.67, min 1 max 12) which remained stable during the week of the trial, monitored by filling out sleep diary (KSD, as highlighted in Table 1.1 regarding sleep quality and Table 1.2 regarding restorativeness of sleep).

Descriptives - Sleep Quality measured using the Karolinska Sleep Diary								
	DAY 1	DAY 2	DAY 3	DAY 4	DAY 5	DAY 6	DAY 7	DAY 8
N	40	40	41	41	41	41	41	40
Missing	1	1	0	0	0	0	0	1
Mean	4.45	4.38	4.30	4.20	4.23	4.22	4.10	4.44
Median	4.75	4.50	4.50	4.25	4.50	4.25	4.25	4.50
SD	0.513	0.499	0.706	0.736	0.717	0.628	0.733	0.539
Minimum	3.00	3.33	2.33	1.75	2.00	2.67	1.67	2.50
Maximum	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00

Table 1.1- Assessment of sleep quality evaluated by filling in the KSD sleep diary

Descriptives - Restorative sleep measured using the Karolinska Sleep Diary								
	DAY 1	DAY 2	DAY 3	DAY 4	DAY 5	DAY 6	DAY 7	DAY 8
N	40	40	41	41	41	41	41	39
Missing	1	1	0	0	0	0	0	2
Mean	3.57	3.67	3.73	3.11	3.62	3.48	3.73	3.44
Median	3.33	3.67	4.00	3.33	3.33	3.33	3.67	3.33
SD	0.771	0.769	0.962	0.914	0.820	0.850	0.756	0.773
Minimum	2.00	2.33	1.00	1.33	1.33	2.00	1.67	1.33
Maximum	5.00	5.00	5.00	4.67	5.00	5.00	5.00	5.00

Table 1.2 - Assessment of restorative sleep evaluated by filling in the KSD sleep diary

The indices of sleepiness, vigor, and affect were maintained on the experimental days, as evidenced by the absence of statistically significant differences in the ESS scores ($F_{(2,80)}$=0.526, p=0.593, η^2p = 0.013); in the GVAS_vigor ($F_{(2,80)}$=0.272, p=0.763, η^2p = 0.007) and affect scores ($F_{(2,80)}$=0.0344, p=0.966, η^2p = 0.001) and in the KSS scores ($\chi^2_{(2)}$ =0.438, p=0.804).

Correlations with common measures of selective and divided attention

Correlations between the AD-Task and commonly used measures of selective attention and divided attention showed high correlations in reaction time and moderate overall performance in both single-demand and switching conditions (as shown in Tables 1.3 and 1.4).

Correlation Matrix – HIT RATE					
		ADT_SELECTIVE	ADT_DIVIDED	ODDBALL	DUAL TASK
ADT_SELECTIVE	Spearman's rho	—			
ADT_DIVIDED	Spearman's rho	0.246	—		
ODDBALL	Spearman's rho	0.453**	0.254	—	
DUAL TASK	Spearman's rho	0.070	0.485**	0.528***	—
Note. * p < .05, ** p < .01, *** p < .001					

Table 1.2 – Correlations between the selective attention component of the AD-Task and the oddball task

Correlation Matrix - RTs					
		ADT_SELECTIVE	ADT_DIVIDED	ODDBALL	DUAL TASK
ADT_SELECTIVE	Pearson's r	—			
ADT_DIVIDED	Pearson's r	0.813***	—		
ODDBALL	Pearson's r	0.723***	0.585***	—	
DUAL TASK	Pearson's r	0.685***	0.696***	0.653***	—

*Table 1.3 - Correlations between the divided attention component of the AD-Task and the dual task. *p<.05, ** p<01, ***p<.00*

Evaluation of differences between single demand blocks and switching conditions

Repeated measures ANOVA with CONDITION (selective / divided / switching) entered as an internal factor showed a significant main effect of the condition type on speed in responding to stimuli ($F_{(2,80)} = 331$, $p<.001$, $\eta^2p = 0.892$, Figure 1.6) and ability to discriminate the target stimulus ($F_{(2,80)} = 44.5$, $p<.001$, $\eta^2p = 0.320$, Figure 1.7). Post-hoc comparisons show that divided attention predicts slower reaction times and lower ability to discriminate the target stimulus than selective attention ($t_{(40,0)} = 20.7$, $M_{dif}=0.480$, $p<.001$; $t_{(40,0)} = -9.09$, $M_{dif}=-0.952$, $p<.001$) and switching attention ($t_{(40,0)} = 13.3$, $M_{dif}=0.214$, $p<.001$; $t_{(40,0)} = -5.02$, $M_{dif}=-0.494$; $p<.001$). Selective attention, on the other hand, seems to be characterized by better speed and ability to discriminate the target stimulus even compared to switching ($t_{(40.0)} = -16.7$, $M_{dif}=-0.266$, $p<.001$; $t_{(7,0)} = 4.60$, $M_{dif}=0.08$, $p<.001$).

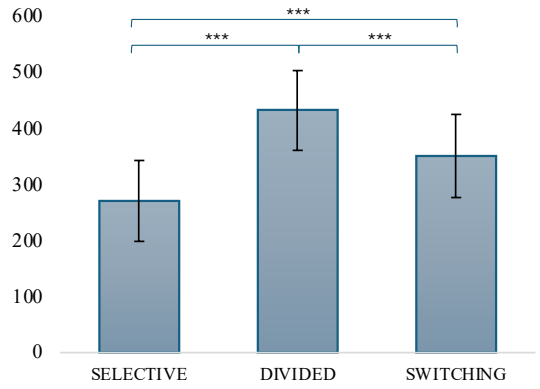


*Figure 1.6 – RTs in different conditions of AD-Task. *p<.05, ** p<01, ***p<.001*

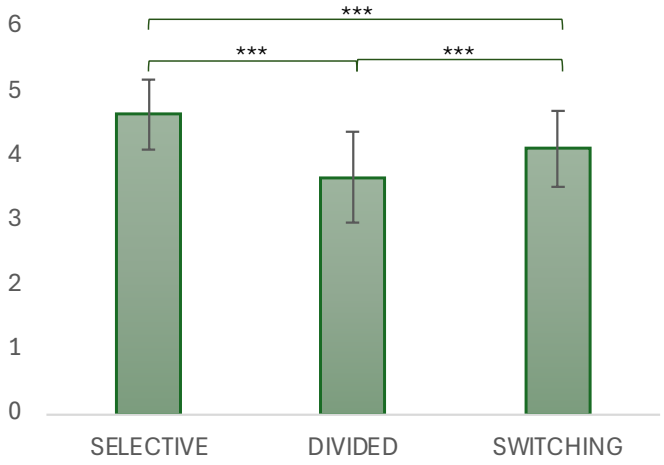


*Figure 1.7 – d' in different conditions of AD-Task. *p<.05, ** p<01, ***p<.001*

Repeated-measures ANOVA with “ATTENTIONAL DEMAND TYPE” (selective/divided) and “CONDITION” (single/switching demand) as factors within showed an interaction effect between ATTENTIONAL DEMAND TYPE and CONDITION ($F_{(1,40)} = 5.87$, $p=0.020$, $\eta^2p = 0.128$) and posthoc comparisons show that in selective attention there is a worsening in reaction time in the switching condition compared with the single demand condition ($t_{(40.0)} =-3.788$, $M_{dif}=-12.44$, $p=0.003$). In addition, it also emerges that selective attention predicts better reaction times than selective attention in both the single demand ($t_{(40.0)} =-21.246$, $M_{dif}=-160.48$, $p<.001$) and switching ($t_{(40.0)} =-24.108$, $M_{dif}=-144.34$; $p<.001$) conditions. For details, see Figure 1.8.

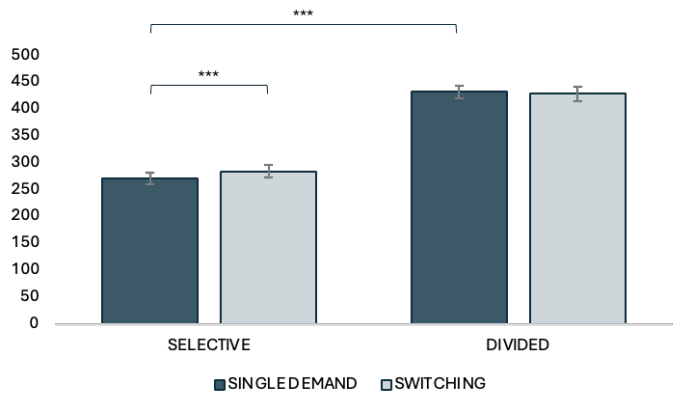


*Figure 1.8 – RTs in selective and divided attention in single and switching conditions. *p<.05, ** p<01, ***p<.001*

Repeated-measures ANOVA with “ATTENTIONAL DEMAND TYPE” (selective/divided) and “CONDITION” (single demand/switching) as within factors on the discrimination index of target stimulus from no target showed a main effect of “ATTENTIONAL DEMAND TYPE” ($F_{(1,40)} = 103.031$, $p<. 001$, $\eta^2p = 0.720$), showing that in general, in both the single demand and switching conditions, selective attention predicts a better ability to discriminate the target stimulus than divided attention ($t_{(40,0)} = 10.2$, Mdif=-0.744, $p<.001$, figure 1.9).

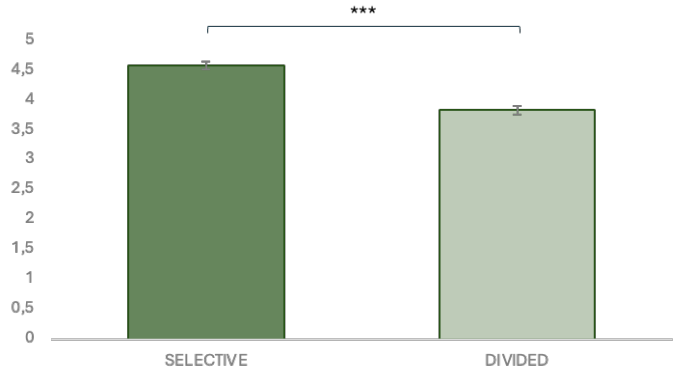


*Figure 1.9 – d' in selective and divided attention in single and switching conditions. *p<.05, ** p<01, ***p<.001*

Repeated-measures ANOVA on switching costs revealed a main effect of ATTENTIONAL DEMAND TYPE ($F_{(1,40)} = 5.87$, p=0.020, $\eta^2p = 0.128$), post hoc comparisons showing that selective attention is more sensitive to switching than divided attention ($t_{(40.0)} = 2.42$, $M_{dif} = 16.1$, p=0.020, figure 1.10).

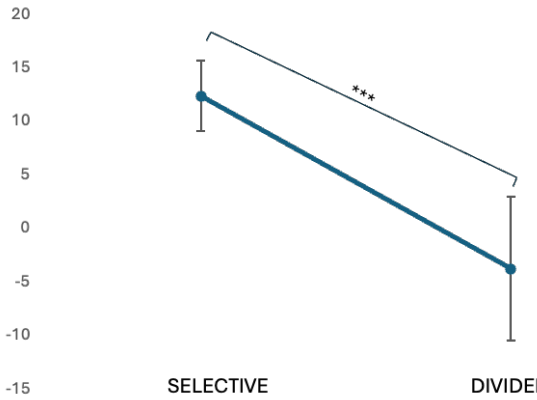


*Figure 1.10 – Switch cost difference between selective and divided attention. *p<.05, ** p<01, ***p<.001*

Friedman's test results on performance (HIT RATE) in the different conditions (sel/div/sw) showed a significant effect ($\chi^2_{(3)} = 62.0$, p<.001), and post hoc successes show that performance in divided attention is worse than both selective attention (d = 15.73, p<.001) and switching (d = 8.53, p<.001). Selective attention also predicts better performance than switching (d = 7.20, p<.001). See Figure 1.11 for more details.

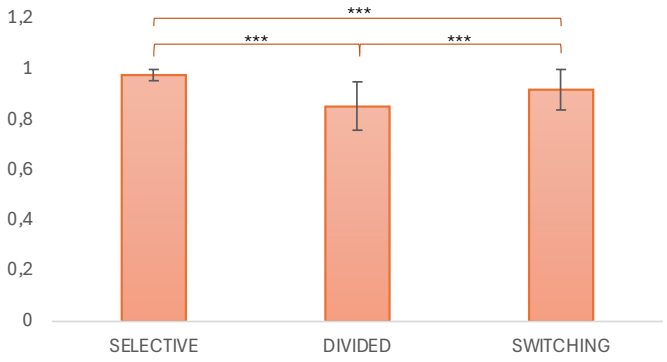


*Figure 1.11 – Hit Rate in different conditions of AD-Task. *p<.05, ** p<01, ***p<.001*

The results of Friedman's test used to evaluate the differences between performance in the single demand and switching conditions for selective and divided attention showed a significant effect of attentional demand type on HIT RATE performance ($\chi^2_{(3)} = 81.6$, p<.001). Next, a post-hoc analysis was performed using the Durbin-Cover test to compare condition (single

demand/switching) and attentional components (selective/divided). The results of the post-hoc analysis showed a significant decrease in performance between selective and divided attention in both the single demand (d = 12.29, p<.001) and switching (d = 9.25, p<.001) conditions, see figure 1.12. No significant difference was observed between selective attention in the single demand and switching condition and between divided attention in single demand and switching.

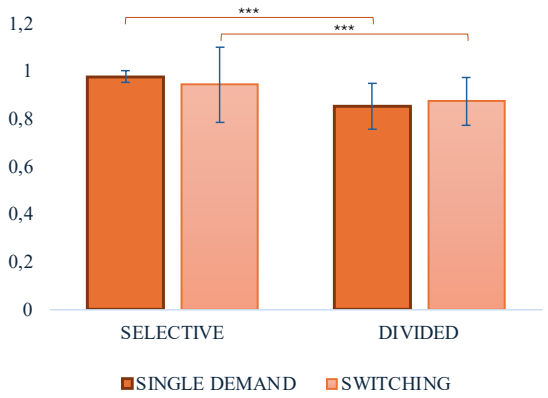


*Figure 1.12 – Performance on selective and divided attention in single demand and switching conditions. *p<.05, ** p<01, ***p<.001*

The results of Friedman's test on the number of commission errors in the different conditions (sel/div/sw) showed no statistically significant difference. The results of Friedman's test used to evaluate the differences between performance in the single demand and switching conditions for selective and divided attention showed a significant effect of attentional demand type on the number of commission errors in the switching condition ($\chi^2_{(3)} = 12.1$, p=0.007, see Figure 1.13). Post-hoc findings using the Durbin-Cover test to compare the conditions (single/intermittent demand) and attentional components (selective/divided) showed a significant increase in committing errors between selective and divided attention in the switching demand condition (d = 3.179, p=0.002). No other statistically significant differences were found.

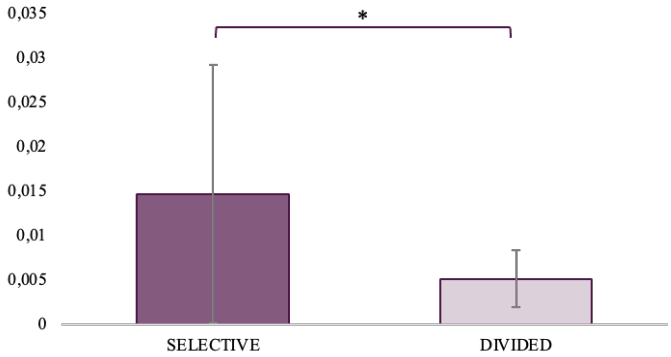


*Figure 1.13 – Fa Rate on selective and divided attention in single demand and switching conditions. *p<.05, ** p<01, ***p<.001*

1.3 PHASE 2: EVALUATION OF PRACTICE OR LEARNING EFFECTS ON THE PERFORMANCE OF THE ATTENTIONAL DEMANDS TASK

1.3.1 AIM

Evaluate possible learning effects from intensive task execution to consider its application in multiple measurement protocols.

1.3.2 MATERIALS AND METHODS

Participants

The learning effect was evaluated on 25 subjects, 3 of whom were excluded as outliers. The 22 participants resulting (age: 22.5±2.89; 16 F) were divided into an experimental group consisting of 11 subjects (age: 21.8±3.22; 8F) and a control group comprised of 11 subjects (23.2± 2.48; 8F). The participating subjects were recruited from bachelor students at the University of L'Aquila. No participant reported a history of neurological or psychological disorders, and all indicated that they had normal or corrected vision and hearing. All participants provided their written informed consent and were told that they could discontinue participation.

Materials

In Phase 2, the Pittsburgh Sleep Quality Index (PSQI), the Karolinska Sleep Diary (KSD), the Karolinska Sleepiness Scale (KSS), the Epworth Sleepiness Scale (ESS), the Global Vigor-Affect Scale (G-VAS) and the Attentional Demands Task (AD-Task) were used, described in detail in the Materials and Methods section of Study 1.

1.3.3 PROCEDURE

This study was also conducted at the Laboratory of Cognitive and Behavioral Sciences of the University of L'Aquila. The entire protocol was performed over two consecutive days. The sample was selected based on scores obtained on the Pittsburgh Sleep Quality Index (PSQI) to exclude

subjects with poor sleep quality. The quality and duration of sleep were monitored by filling out the Karolinska Sleep Diary (KSD) for four consecutive days (including the two experimental days). To obtain an appropriate experimental setting, a well-insulated classroom was selected from external noise and interference, and lighting conditions were controlled. The stations, equipped with a 35.4x19.9-cm computer, were spaced to isolate each subject as much as possible.

The protocol required the completion of questionnaires to assess drowsiness (ESS, KSS) and vigor/affect (G-VAS) before performing the computerized task (AD-Task) on both experimental days. After completing the questionnaires (KSS, VAS, ESS), both groups performed a familiarization trial of the Attentional Demands Task on the first day of the experiment. Subsequently, unlike the control group, the experimental group underwent an intensive training session on the AD-Task, which concluded once they achieved a performance level of over 85% correct responses. On the second day of the experiment, after completing the same questionnaires (KSS, VAS, ESS), both groups performed the full version of the Attentional Demands Task. On the first experimental day, the procedure required different time commitments for each group: the control group completed the trial in approximately 5 minutes, while the experimental group completed the training in a variable time range of 1 to 3 hours. On the second day, since both groups followed the same procedure, they completed the task in 40 minutes.

The investigation was approved by the Internal Review Board of the University of L'Aquila (#61/2021-2022) and was conducted according to the principles established in the Declaration of Helsinki.

1.3.4 DATA ANALYSIS

Descriptive statistics on the sample under investigation were performed on participants' age, sex, and sleep quality indices (PSQI, KSD), alertness, and drowsiness (GVAS, KSS, ESS). Subsequently, a t-test was performed to compare the two groups (1, 2) on demographic variables (age and gender). To examine possible differences between the groups in sleep quality and daytime drowsiness, a t-test was also conducted on the scores obtained in the relevant questionnaires (PSQI, ESS, KSD) administered during the sample selection phase.

The performance achieved by the two groups in the Day 2 AD-Task was compared using a T-Test for independent samples in which GROUP (1,2) was entered as a grouping variable on all variables investigated for both speed of execution (RTs) and performance (HIT RATE, d' and FA RATE). An independent sample t-test, with GROUP (1,2) as the grouping variable, was applied to the variables d' and RTs for selective attention and to d', RTs and HIT RATE for divided attention, under both single demand and switching conditions, to assess potential differences between the group exposed to intensive training (Group 2) and the unexposed group (Group 1).
The Mann-Whitney test was used to determine whether the success rate (HIT RATE) and the failure rate (FA RATE) in the AD-Tak, for selective attention under single demand and switching conditions, differed between the two groups (control and experimental). This choice was motivated by the non-normal distribution of the data (Group 1: HIT RATE Single demand: Shapiro-Wilk W=0.362; p<.001; HIT RATE Switching: Shapiro-Wilk W=0.734; p<.001; FA RATE Single demand: Shapiro-Wilk W=0.791; p=0.007; FA RATE Switching: Shapiro-Wilk W=0.855; p=0.049 / Group 2: HIT RATE Single demand: Shapiro-Wilk W=0.572; p=0.001; HIT RATE Switching: Shapiro-Wilk W=0.625; p<.001; FA RATE Single demand: Shapiro-Wilk W=0.779; p=0.005; FA RATE Switching: Shapiro-Wilk W=0.670; p<.001). The Mann-Whitney test was also used to evaluate the failure rate (FA RATE) in performing the AD-Tak for divided attention under single demand and switching conditions to compare the two groups (control and experimental). This choice was also motivated by the non-normal distribution of the data (Group 1: FA RATE single demand: Shapiro-Wilk W=0.650; p<.001; Switching: Shapiro-Wilk W=0.711; p<.001 / Group 2: FA RATE single demand: Shapiro-Wilk W=0.463; p<.001; Switching: Shapiro-Wilk W=0.625; p<.001).

The significance level was established at p<.05. All analyses were performed using the statistical software Jamovi 2.4.

1.3.5 RESULTS

Descriptives

Participants in both groups reported relatively good sleep quality (group 1: M 7.55±2.70; group 2: M 6.73±2.53). The descriptive statistics revealed stable indices of both sleep quality and sleep restorativeness for the two groups, assessed by filling out KSD sleep diaries (see Tables 1.5 and 1.6).

Descriptives - SLEEP QUALITY (KSD)					
	group	KSD_1_Q	KSD_2_Q	KSD_3_Q	KSD_4_Q
N	1	11	11	11	11
	2	11	11	11	11
Mean	1	4.23	4.20	4.02	4.16
	2	4.14	4.16	4.18	4.05
Median	1	4.50	4.25	4.00	4.25
	2	4.50	4.50	4.50	4.00
Standard deviation	1	0.666	0.472	0.745	0.785
	2	0.710	0.635	0.845	0.678

Table 1.5 - Sleep quality in the two groups in the experimental week

Descriptives - SLEEP RESTORATIVENESS (KSD)					
	group	KSD_1_R	KSD_2_R	KSD_3_R	KSD_4_R
N	1	11	11	11	11
	2	11	11	11	11
Mean	1	3.77	3.36	3.21	3.36
	2	3.69	3.24	3.35	3.43
Median	1	3.67	3.33	3.00	3.33
	2	4.00	3.33	3.33	3.33
Standard deviation	1	0.772	0.849	1.00	0.767
	2	0.817	0.685	0.754	0.544

Table 1.6 - Sleep restorativeness in the two groups in the experimental week

Descriptive statistics of the indices of sleepiness, vigor and affect on the two experimental days are shown in Table 1.7.

Descriptives - Indices of sleepiness, vigor, and affect									
	group	KSS_1	GVAS_1_V	GVAS_1_A	ESS_1	KSS_3	GVAS_3_V	GVAS_3_A	ESS_3
N	1	11	11	11	11	11	11	11	11
	2	11	11	11	11	11	11	11	11
Mean	1	3.45	60.8	62.5	7.64	3.91	63.7	61.3	7.55
	2	4.27	61.0	62.5	8.09	3.73	60.5	65.9	8.45
Median	1	3	60.0	65.8	7	3	66.8	60.3	7
	2	4	54.5	65.0	7	3	64.8	71.8	7
SD	1	2.16	15.9	18.5	3.61	1.70	21.9	17.1	3.05
	2	1.79	13.0	16.1	2.98	1.42	16.7	15.5	3.64

Table 1.7 - indices of sleepiness, vigor, and affect in the two groups during the two experimental days in the moments before the behavioral task was performed

The t-test for independent samples showed no statistically significant differences in the two groups in age ($t_{(20.0)}$ =1.112, p=0.279) and scores obtained on the PSQI sleep quality assessment questionnaires ($t_{(20.0)}$ =0.73, p=0.472), KSD (see table 1.8) and on the two experimental days on the sleepiness and vigor indices (see table 1.9).

Independent Samples T-Test				
		Statistic	df	p
KSD_1_Q	Student's t	0.310	20.0	0.760
KSD_2_Q	Student's t	0.191	20.0	0.851
KSD_3_Q	Student's t	-0.468	20.0	0.645
KSD_4_Q	Student's t	0.363	20.0	0.720
KSD_1_R	Student's t	0.224	20.0	0.825
KSD_2_R	Student's t	0.369	20.0	0.716
KSD_3_R	Student's t	-0.360	20.0	0.722
KSD_4_R	Student's t	-0.241	20.0	0.812
Note. H_a $\mu_1 \neq \mu_2$				

Independent Samples T-Test				
		Statistic	df	p
KSS_1	Student's t	-0.96601	20.0	0.346
GVAS_1_V	Student's t	-0.03667	20.0	0.971
GVAS_1_A	Student's t	-0.00614	20.0	0.995
ESS_1	Student's t	-0.32181	20.0	0.751
KSS_2	Student's t	0.27217	20.0	0.788
GVAS_2_V	Student's t	0.38332	20.0	0.706
GVAS_2_A	Student's t	-0.66926	20.0	0.511
ESS_2	Student's t	-0.63500	20.0	0.533
Note. H_a $\mu_1 \neq \mu_2$				

Tables 1.8 and 1.9 - Differences between the two groups in indices of sleep quality, sleepiness, vigor and affect

Evaluation of possible effects of practice or learning on performance at the AD-Task

The independent-samples t-test used for comparison between the experimental group and the control group showed no statistically significant differences in the performance of the whole task, neither in reaction time (RTs: $t_{(20.0)}$=-0.0850, p=0.279), nor performance (HIT RATE: $t_{(20.0)}$=-1.0923, p=0.288) nor discrimination indices (d': $t_{(20.0)}$=-1.0492, p=0.307) of the target stimulus. In selective attention, the independent samples t-test did not reveal statistically significant differences in speed, either in the single demand condition (RTs: $t_{(20.0)}$=-0.220, p=0.828) or in the switching condition (RTs: $t_{(20.0)}$=0.799, p=0.434). In selective attention, the independent samples t-test did not reveal statistically significant differences in speed, either in the single demand condition (RTs: $t_{(20.0)}$ =0.456, p=0.653) or in the switching condition (RTs: $t_{(20.0)}$ =0.427, p=0.674). However, a statistically significant difference was found between the training-exposed group and the unexposed group in the discrimination index for the target stimulus in the switching condition (d': $t_{(20.0)}$ =2.143, p=0.045, as shown in fig.1.14), but not in the single demand condition (d': $t_{(20.0)}$ =1.136, p=0.269). The Mann-Whitney test performed on performance in selective attention found no statistically significant differences between the two groups in either the success rate in the single demand condition (HIT RATE: Mann- Whitney's U = 56.5, p = 0. 753) and in the switching condition (HIT RATE: U of Mann- Whitney = 47.5, p = 0.350) or the failure rate in

the single demand condition (FA RATE: U of Mann- Whitney = 50.5, p = 0.513) or in the switching condition (FA RATE: U of Mann- Whitney = 37.0, p = 0.118).

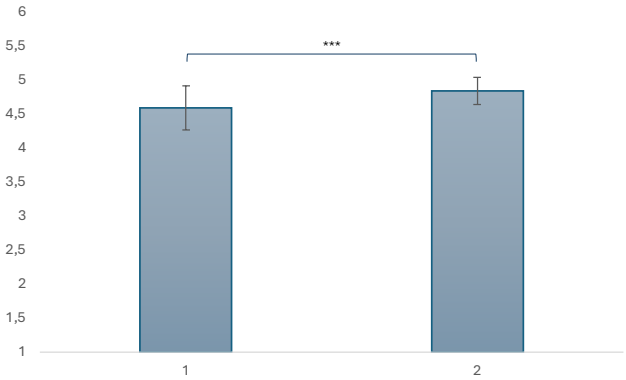


*Figure 1.14 – d' in control and experimental groups. *p<.05, ** p<01, ***p<.001*

Similarly, no statistically significant differences were found in divided attention when examined in the single demand condition (RTs: $t_{(20.0)}$=0.456, p=0.653/ HIT RATE: $t_{(20.0)}$=1.059, p=0.302/ d': $t_{(20.0)}$=-0.320, p=0.752) and in the switching condition (RTs: $t_{(20.0)}$=0.427, p=0.674/ HIT RATE: $t_{(20.0)}$=0.412, p=0.685 /d': $t_{(20.0)}$=-0.181, p=0.858). The Mann-Whitney test found no statistically significant differences between the two groups in the number of committing errors either in the single demand condition (FA RATE: U of Mann- Whitney = 58.0, p = 0.878) or in the switching condition (FA RATE: U of Mann- Whitney = 51.0, p = 0.498).

1.4 DISCUSSION

This study aimed to design a new task, inspired by the original Switching Attentional Demands Task (SwAD-Task, Liebherr et al., 2019) for the study of selective and divided attention, which also offered the possibility of evaluating the switching costs resulting from the alternation of the two attentional components under investigation. To this end, an instrument capable of overcoming the limitations of the SwAD-Task called the Attentional Demands Task, was developed and validated. In the same study, the influence of intensive exposure to the task was also evaluated to consider the possible existence of learning effects that could limit the application of the tool in contexts in which several exposures to the task are required. The task was tested on 41 young, healthy individuals and compared with two widely used measures to assess the same constructs. The learning effects, on the other hand, were studied in a sample of 24 subjects divided into two groups, in which the experimental group, in contrast to the control group, was subjected to intensive AD-Task training.

The results of this work can be discussed in four main sections:
- Correlations between AD-Task and measures commonly used to assess selective and divided attention
- Differences between selective and divided attention
- Assessment of switching costs in the two attentional components
- The presence of learning or practice affects the performance of the AD-Task.

Regarding the results of the comparison between AD-Task and commonly used measures of selective and divided attention, significant correlations were found in terms of speed and accuracy. These results can be considered reliable since, in the case of selective attention, an Oddball task, widely considered an effective paradigm for measuring this type of attention, was used as a concurrent measure. It involves the presentation of frequent (standard) stimuli interspersed with infrequent (target) stimuli for participants to detect and is often associated with studies evaluating the event-related potential (ERP) P300 component, which corroborates its reliability (Warren et al., 2020; Ogawa et al., 2022). Indeed, the P300 occurs approximately 300 ms after the stimulus and is a key indicator of attentional allocation and cognitive processing (Gray et al., 2004; Demirayac et al., 2023; Pavarini et al., 2018). The amplitude of the P300 is greater for rare (target) stimuli, reflecting greater attention to meaningful stimuli (Verleger & Śmigasiewicz, 2016; Ciria et al., 2017). This parameter is influenced by stimulus rarity and cognitive load (Alexander et al., 2005). The methodological limitations highlighted in Liebherr's (2019) work, which used a dual-task paradigm with stimuli belonging to different sensory domains (e.g., visual and auditory) as a competing measure for divided attention, were overcome. Unlike their Switching Attentional Demand Task, which consisted of visual stimuli only, the dual task was susceptible to interference due to switching between different demands that could generate residual effects, complicating the interpretation of results (Hsieh and Yu, 2003; Monsell, 2003; Hsieh and Liu, 2005). To address this critical issue, a dual-task paradigm with only visual stimuli, such as the attentional demands task, was adopted. This approach made it possible to avoid variability due to the transfer of cognitive resources between different sensory domains, ensuring greater consistency in cognitive demands and more accurate assessment in the measurement of divided attention, without introducing confounding effects related to the change of sensory domain (Hsieh and Yu, 2003; Monsell, 2003; Hsieh and Liu, 2005).
To understand cognitive performance in the two attentional components, it is important to emphasize the distinction between selective and divided attention. Selective attention consists of

the ability to focus on a specific stimulus while ignoring others, whereas divided attention requires the simultaneous processing of multiple stimuli. The results of this work showed that divided attention involves slower reaction times and worse performance than selective attention. One explanation for this phenomenon could be related to the use of visual stimuli alone, which may saturate available cognitive resources (Sutton et al., 1965; Wickens et al., 1983). As pointed out by Talsma et al. (2006), the processing of stimuli in the same modality is driven by reduced attentional capacity compared to processing in different modalities. Such assumptions would explain why motor and cognitive modalities beneficial effects on cognitive performance in some tasks may have where motor and cognitive modalities alternate (Liebherr et al., 2018). From the literature, we know that integrating simple motor demands into cognitive tasks, known as (cognitive-motor interference, CMI), can improve cognitive performance (Al-Yahya et al., 2011). Indeed, well-practiced motor skills reduce interference with cognitive tasks, improving both domains (Schaefer & Lindenberger, 2013). In the case of two stimuli of the same modality, on the other hand, several empirical evidence support the idea that dividing attention between stimuli incurs perceptual costs, Niebergall and colleagues (2010) demonstrated that dividing attention between visual targets reduces perception compared to when focused on a single stimulus, reinforcing the idea that attentional resources are limited (Niebergall et al., 2010). Pestilli and co-workers (2011) also assessed that cortical responses are enhanced in early visual areas if attention is focused on a single target stimulus, compared to when it is divided over multiple stimuli (Pestilli et al., 2011). This leads to and explains reduced processing efficiency and increased cognitive load in divided attention tasks compared to selective attention tasks.

Additional explanations regarding the differences in reaction times between selective and divided attention come from neuroimaging studies, which have shown that these two attentional components activate distinct but overlapping neural networks that would explain the variations in reaction times (Liehberr et al., 2019; Moisala et al., 2015). Dual-task conditions can lead to increases in activation in brain regions already involved in single tasks, indicating that divided attention does not recruit new areas, but intensifies demands on existing networks (Moisala et al., 2015). Gharahi and colleagues (2021) assessed the presence of a positive correlation in reaction times between selective and divided attention tasks, where increasing demands on divided attention also predicted an increase in reaction times, reflecting the cognitive load imposed by handling multiple streams of information. The explanation may be that the right temporal hemisphere shows increased activation during divided attention tasks, underlining the implication of distinct neural pathways activated when attention is divided versus when it is selectively focused (Tomita et al., 2017). Other evidence confirming what has been argued in this section comes from

studies by Weerda et al. (2006) who find greater activity in areas involved in top-down control (lateral prefrontal cortex and posterior parietal cortex (Buschman and Miller, 2007) during divided attention tasks compared to selective attention tasks, which would confirm the hypothesis of greater top-down control contributing to a prolongation of reaction time.

Finally, from the motor response point of view, as Liebherr et al. (2019) suggested, the different number of response buttons (one in the selective attention task and two in the divided attention task) could affect reaction times. This aspect, related to motor actions, might require more attention when more complex responses are needed.

The lack of significant differences in reaction time and performance between the group exposed to intensive training of the AD-Task and the unexposed group allowed us to exclude the presence of learning or fatigue effects. The only significant difference was found in the stimulus discrimination index (d') in the switching condition for the group subjected to intensive training. This could suggest a possible sensitivity to discriminative skill practice effects. From the literature, we know that repeated exposure to cognitive tasks can improve discriminative ability (Vékony et al., 2018; Marsevani, 2022; Russo et al., 2017) but, in this case, they may be neglected as they are so marginally related to only one performance parameter and condition.

Regarding the effects of switching between attentional demands, our results show that selective attention, which involves a lower cognitive load than divided attention (Madden and Plude, 1993), is more sensitive to switching costs. Increased attentional demand slows the response time to the target stimulus in selective attention, which is affected by switching with divided attention. The latter, on the contrary, although not significantly, tends to improve when switched to the simpler attentional component. Some work shows that engaging in simpler attentional tasks before more complex ones can improve execution speed, reduce cognitive overload, improve attentional capacity and facilitate better cognitive planning (Richter & Yeung, 2015). One explanation could be related to attentional filters that adapt to better allocate resources, allowing a smooth transition to complex tasks after performing simpler ones (Wearden et al., 2010). Furthermore, mindfulness meditation, considered a simple attentional task, has been proposed in some studies as a strategy to improve attention under stress and reduce cognitive load in complex tasks (Jankowski & Holas, 2020). In support of these considerations, Nonnekes and colleagues (2020) highlight the importance of preparing and allocating attentional resources for performance in dual tasks.

Another explanation for our results can be traced back to inhibition theory. It has been shown in several previous studies that a reduction in the need for inhibition in divided attention can result in less effective inhibitory control in selective attention tasks (Monsell 2003). Furthermore, the level of inhibition may depend on the degree of conflict in the response, in functions with a larger

number of response options, as in divided attention, lower levels of inhibition may be required (Goschke, 2000). Based on these considerations, it is important to point out that proactive interference, resulting from persistent activation of the previous task and suppression of the current task, maybe a key factor in switching costs (e.g., Allport et al., 1994; Yeung et al., 2006). Indeed, the capacity-sharing model supports this relationship, arguing that when two tasks share similar attentional resources, performance on both can suffer (Patel & Bhatt, 2015). The limited capacity model suggests that attention is a limited resource and that competing tasks may impair performance in one or both tasks (Yang et al., 2018; Swerdloff & Hargrove, 2023). However, in our results switching costs are not symmetrical, switching between selective and divided attention generates different effects for each modality with selective attention being more sensitive to switching costs despite being the least complex attentional demand. This phenomenon is at odds with the hypothesis of similar costs in both tasks under switching conditions and could be explained by Allport's (1994) concept of 'asymmetries in switching costs,' in which it is observed that when tasks of different difficulty are alternated, the switching cost is higher for the easier task. The sequential effects of difficulty probably cause a reduction in performance after a difficult task, regardless of whether one switches to another task or repeats the same one (Schneider and Anderson, 2010).

1.5 CONCLUSIONS

In this work, the Attentional Demands Task (AD-Task), a new instrument for assessing selective and divided attention and associated switching costs, was developed and successfully validated. The AD-Task showed significant correlations with established measures, such as the Oddball task for selective attention and the Dual-Task for divided attention, confirming its reliability in analyzing the attentional constructs for which it was designed. The exclusive use of visual stimuli made it possible to overcome the limitations related to sensory domain switching of previous switching tasks, ensuring greater consistency in cognitive loadings.

The results show important differences between selective and divided attention, with the latter resulting in slower reaction times and reduced performance compared to selective attention, probably due to the increased cognitive load required to process multiple stimuli within the same sensory domain. Neuroimaging studies and theoretical models support these findings, indicating greater involvement of top-down control networks and limited attentional resources during divided attention tasks.

Regarding switching costs, an asymmetry emerged in which selective attention showed greater sensitivity. This asymmetry was explained by the concept of ‘asymmetry in switching costs’, in which the transition from complex to simpler tasks disproportionately influences the simpler task. Furthermore, the absence of significant learning or fatigue effects, except for marginal improvements in stimulus discrimination in the experimental group, suggests the robustness of the AD-Task for repeated use without compromising validity.

1.6 LIMITATIONS

Despite the promising results, this study has some limitations that reduce its generalizability and applicability. First, the sample size is relatively small, which may limit statistical robustness. In addition, despite important evidence in the literature, the neural and cognitive mechanisms underlying switching costs have not been directly investigated, future research could further investigate through neuroimaging techniques. The ecological validity of the AD-Task could be improved by evaluating it in applied contexts, such as work or clinical settings, to test its usefulness in real-life situations. Finally, the modest learning effects observed suggest the need to explore further training protocols to better capture possible performance improvements.

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STUDY 2: Validation of the revised version of the SCRAM questionnaire for the assessment of sleep quality, chronotype, and mood characteristics

2.1 INTRODUCTION

The existence of an interdependent relationship between sleep quality, circadian preference, and mood is evidenced by several findings. Sleep quality refers to an individual's self-satisfaction with different components of sleep experience. The four main components for assessing sleep quality are sleep efficiency, sleep frequency, sleep duration, and wakefulness after sleep onset. Sleep quality is critical, and poor sleep quality is detrimental to health (Nelson et al., 2022). Chronotype refers to the time of day when an individual feels most alert and active or most prone to sleep (Kerkhof & Van Dongen, 1996; Lavie, 2001). It can be classified into "morning type," "middle type," or "evening type," based on preferences for morning, midday, or evening activities, respectively. It can be measured by the Morningness-Eveningness Questionnaire (MEQ), which gives an estimate of diurnal preference for activities (Horne & Östberg, 1976, which will be referred to in this paper) or the Munich Chronotype Questionnaire (MCTQ, Roenneberg et al., 2003), which uses mean point of sleep on non-working days (adjusted for sleep debt accumulated during workdays) to refer to sleep timing. These are reliable subjective measures that correlate with objective stage markers such as melatonin onset or minimum body temperature (Bauducco et al., 2020).

Depression, classified as a mood disorder, is characterized by persistent feelings of sadness and disinterest, which have a significant impact on daily functioning. Symptoms vary in severity and may include mood alterations, decreased interest in usual activities, sleep disturbances, impaired cognitive function, and vegetative symptoms. It is more prevalent in women, being about twice as frequent than in men, and it is estimated to affect 6 percent of the world's adult population each year (Otte et al., 2016). Etiologically, depression results from a complex interaction of biological, psychological, and environmental factors, and its onset is possible at any stage of life (de Zwart et al., 2019; Kanter et al., 2008).

Anxiety is a natural and widespread human response to threatening situations. To determine when anxiety becomes clinically problematic interferes with daily functioning, or warrants a diagnosis of anxiety disorder, two key factors must be assessed: intensity (the level of distress experienced) and frequency/duration (how often anxiety occurs and how long it persists beyond what is typical for the situation). According to the Diagnostic and Statistical Manual of Mental Disorders, Fifth

Edition (DSM-5), the diagnosis of an anxiety disorder requires the presence of a specific symptom profile that causes significant distress or impairment. Therefore, it is clinically critical to be able to accurately measure both the intensity and frequency of anxiety symptoms over a defined period and to track changes over time (Kessler et al., 2005; American Psychiatric Association, 2013; Baker et al. 2020).

Chronotype and sleep quality are two highly interconnected aspects. Individual preferences for activities (morning or evening) can significantly influence sleep quality.
In modern society, it can be difficult for some people to stay aligned with their chronotype; in fact, the presence of fixed schedules for work and social activities can create a phenomenon known as circadian misalignment or social jet lag (SJL, Wittmann et al., 2006), which can disrupt the normal circadian rhythm (Zou et al., 2022), particularly in individuals with early or late chronotypes. In addition, work schedules may have an even greater impact on sleep timing in shift workers than in regular day workers (Roenneberg et al., 2019). This discrepancy between socially determined and intrinsically/biologically determined sleep schedules may lead to health implications, including reduced sleep quality and depressive symptoms (von Gall et al., 2023; Sudy et al., 2019; Van den Berg et al., 2018). Another important aspect of this relationship between externally and internally determined sleep schedules concerns sleep architecture: a significant discrepancy between these factors can affect REM sleep, making it highly fragmented (von Gall et al., 2023).
In addition to sleep quality, chronotype is also related to the development of psychophysical disorders. An evening-type chronotype is at increased risk for illness, as well as depression, anxiety, insomnia, and sleep apnea (Knutson et al., 2018). In turn, sleep quality is also related to depressive symptoms and anxiety disorders. In this case, it is a bidirectional relationship (Riemann et al., 2001). Comorbidity between sleep disorders (such as insomnia, narcolepsy, and sleep apnea), depression, and anxiety has been found in several studies (Baglioni et al., 2011; Fichter et al., 2009). The best available evidence suggests that poor sleep quality and the presence of sleep disorders, such as insomnia, are bidirectionally related to anxiety and depression (Kaneita et al., 2009; Jansson-Fröjmark et al., 2008; Morphy et al., 2007). Given this, treatment of insomnia could prevent the development of anxiety and depressive disorders and vice versa (Alvaro et al., 2013).

In the literature, these four aforementioned factors (i.e, sleep quality, chronotype, anxiety and depression) are studied individually using self-assessment questionnaires, which are then correlated to investigate their intrinsic relationships.

For the assessment of sleep quality in most studies, the Pittsburgh Sleep Quality Index (PSQI, Buysse et al., 1989) is administered, and for the measurement of insomnia, the Insomnia Severity Index (ISI, Bastien et al., 2001). For chronotype, the Morningness-Eveningness Questionnaire (MEQ, Horne & Östberg,1976) and the Munich ChronoType Questionnaire are usually cited in the literature (Roenneberg et al., 2003). For the study of depression, questionnaires such as the Beck Depression Inventory or the Center for Epidemiologic Studies Depression (CES-D, Radloff, 1977) and the Geriatric Depression Scale (GDS; Yesavage, 1988) for elderly populations are known. For the assessment of anxiety, the State and Trait Anxiety Inventory (STAI; Spielberger et al., 1970), the General Anxiety Disorder-7 (GAD-7, Spitzer et al., 2006), and the Depression and Anxiety Stress Scale (DASS; Lovibond & Lovibond 1995), which allows for the measurement of both anxiety and depression, are available. The limitation of these questionnaires lies in the absence of their ability to measure briefly and immediately the constructs discussed so far. To investigate the relationships between sleep quality, chronotype, anxiety, and depression, it would be necessary to use a battery of questionnaires that includes most of the questionnaires just mentioned. This would involve using a very long battery that could compromise the response rate to the questions and their veracity (Sahlqvist et al., 2011).

However, given the importance of the intrinsic and often bidirectional relationships between sleep quality, chronotype, depression, and anxiety, there is a need for a short self-assessment instrument that can measure the four constructs and the relationships among them. Byrne et al. (2017) created and validated the Sleep, Circadian Rhythms, and Mood (SCRAM) questionnaire that measures sleep quality, chronotype, and depressed mood. The questionnaire consists of fifteen items (five for each scale) that were selected and adapted to a uniform Likert scale from established and well-validated self-report questionnaires on sleep (e.g., PSQI, Buysse et al., 1989), depression (e.g., BDI, Beck et al., 1996), and circadian rhythms (e.g., MEQ, Horne & Östberg, 1976).

Initially, the authors conducted an exploratory factor analysis (EFA) on a sample of students (n = 720, mean age 33.32 (10.11), 82.4% female) to reduce the number of items and identified three separate but related factor scales, named Depressive Mood, Good Sleep, and Morning Mood. Then, through confirmatory factor analysis (CFA) on another sample of students (n = 462, mean age 33.82 (10.11), 79.2% female), they obtained an acceptable fit to the 15-item questionnaire model (Byrne et al., 2017).

In subsequent studies, the same authors tested and confirmed good validity using convergent and divergent measures and excellent test-retest reliability (rs .73 to .86) for the SCRAM across two

weeks (Byrne et al., 2019). Considering the results obtained by Byrne and colleagues (2017, 2019), the SCRAM questionnaire emerges as an excellent tool for assessing sleep, chronotype, and mood, while also offering the opportunity to investigate the relationships between these constructs without employing an excessive number of items. However, despite its strengths, it does not consider anxiety, which has effects on the other four constructs, and therefore its exclusion could have significant implications in the assessment of sleep quality, chronotype, and depressive mood.

Given that the SCRAM questionnaire appears to be a promising tool, this study aims to validate a revised and translated version of it in an Italian sample of healthy individuals. Compared with the original version, the rSCRAM proposed in this work includes an additional subscale to measure anxious mood. In the initial phase of the study, using principal component analysis, items for the assessment of anxiety were selected and adapted from well-validated and widely used self-report questionnaires (GAD-7, DASS, STAI). Once the most representative items for anxiety assessment were identified, the SCRAM questionnaire was subjected to item reduction through principal component analysis to prevent the addition of anxiety-related items from overloading the structure designed by Byrne et al. (2017). After the creation of this new version, called rSCRAM, consisting of 4 items for each subscale (Good Sleep, Morning, Depressed Mood, and Anxious Mood), an EFA was conducted to develop hypotheses about its basic factor structure, followed by a CFA. To best validate the rSCRAM questionnaire, several psychometric aspects were considered, such as internal consistency, reliability, construct validity, and stability over two weeks.

2.2 PHASE 1: SELECTION AND INTEGRATION OF ITEMS TO ASSESS ANXIETY.

2.2.1 AIM

Since the original SCRAM questionnaire measures the "mood" domain by assessing only depressive symptoms, here we tried to add a new subscale for assessing anxiety symptoms to make the description of the mood domain more complete.

2.2.2 MATERIALS AND METHODS

Participants

The study involved 239 Italian participants (148 F, Age M = 29.0 ± 8.6, age range 19-67 years). Regarding educational qualifications, 2.1% had a secondary school leaving certificate, 37.2% a diploma, 52.7% a degree, and 7.9% a post-graduate degree.

State and Trait Anxiety Inventory (STAI)

State and Trait Anxiety Inventory (STAI; Spielberger, 1970) is a questionnaire consisting of 40 self-report items on a 4-point Likert scale, validated in several languages including Italian. This instrument is used to measure anxiety and to distinguish it from depressive syndromes.

The STAI-X version is widely used, like the original version, it consists of two parts, each of which includes 20 items. Specifically, it is designed to measure anxiety both of a transient nature (state anxiety, STAI-X1), assessing people's emotional state at the time they fill out the questionnaire, and in its more generalized and persistent aspect (trait anxiety, STAI-X2), considering people's emotional state in terms of how they feel in general.

Each item is rated on a 4-point Likert scale where 1 indicates "not at all" and 4 "very much" in the subscale of state anxiety (X1), and "rarely" to "almost always" in the subscale of trait anxiety (X2). The level of anxiety is defined by the total score derived from the sum of the scores for each subscale.

The scores for each subscale can range from 20 (low anxiety) to 80 (severe anxiety). A total score of 40 or higher indicates the presence of anxiety. The higher the score, the more significant the anxiety. Regarding psychometric characteristics, the STAI-X showed good test-retest reliability (coefficients ranged from 0.31 to 0.86), the alpha coefficients of internal consistency were also high (0.86 to 0.95), and finally, correlations with competing measures were high (0.73 to 0.85). The main strengths of the STAI are its wide use for the study of general anxiety and its availability in many different languages (Spielberger, 1970; Julian, 2011).

In this study we were only interested in using items related to state anxiety, so only the X1 subscale was used.

The Depression and Anxiety Stress Scale (DASS)

The Depression and Anxiety Stress Scale (DASS; developed by Lovibond & Lovibond, 1995, translated into Italian) is composed of 42 self-report items, each reflecting a negative emotional symptom. Specifically, this instrument consists of three 14-item self-report scales measuring depression, anxiety, and stress. Each item is scored on a 4-point Likert scale that allows participants to rate the frequency or severity of their experiences over the past week. Scores range from 0 where the subject feels the item “does not apply at all,” to 3, which means the subject feels the item “applies a lot or almost all the time”. The Italian version (Bottesi et al., 2015) of the Depression Anxiety Stress Scales 21 (DASS-21), a 21-item short form of Lovibond and Lovibond's (1995) self-report measure of depression, anxiety and stress (DASS), was used in this study. Regarding psychometric characteristics, the reliability of the DASS-21 scales was .88 for

Depression, .82 for Anxiety, .90 for Stress, and .93 for the Total scale. In addition, the measure possesses adequate convergent and discriminant validity (Henry & Crawford, 2003, Henry & Crawford, 2005).

The Generalized Anxiety Disorder 7 (GAD-7)

Another scale that has been used to select anxiety items is the Generalized Anxiety Disorder -7 (GAD- 7; Spitzer et al., 2006) in the Italian version. It is a self-reported questionnaire useful in screening and measuring the severity of Generalized Anxiety Disorder (GAD). The questionnaire consists of 7 items scored on a 4-point Likert response scale from 0 = Never to 3 = Almost every day. The sum of the scores leads to a total between 0 and 21. Higher scores indicate higher levels of anxiety, with a score of 10 or above indicating a possible diagnosis. Concerning psychometric variables, the GAD-7 has a sensitivity value of 0.89 and a specificity value of 0.82 for identifying GAD. These indices remain acceptable even when the questionnaire is administered to identify other types of anxiety disorder (score ≥ 8: sensitivity: 0.77, specificity: 0.82). In addition, the GAD-7 demonstrated excellent internal consistency (α =.92) and good convergent validity with commonly used measures of anxiety (r =.72).

2.2.3 PROCEDURE

A battery of questionnaires was developed and administered via an online survey to involve many participants. To participate, subjects had to be over 18 years old and sign both a written and digital informed consent form describing the nature and objectives of the study. The questionnaire was completed voluntarily and anonymously; participants were only asked for demographic information such as age, gender, nationality, and education to adequately describe the sample. The study data were collected and managed using REDCap electronic data capture tools hosted at the University of L'Aquila. REDCap (Research Electronic Data Capture) is a secure, web-based software platform designed to support data capture for research studies by providing 1) an intuitive interface for validated data capture; 2) audit trails to track data manipulation and export procedures; 3) automated export procedures to seamlessly download data into common statistical packages; and 4) procedures for data integration and interoperability with external sources (Harris et al., 2009; Harris et al., 2019). The investigation was approved by the Internal Review Board of the University of L'Aquila (#24/2023) and was conducted according to the principles established in the Declaration of Helsinki.

2.2.4 DATA ANALYSIS

Descriptive statistics were performed on age, sex, and years of education, as reported in the participants' section. To identify the most representative items for ANXIETY factor, a principal component analysis (PCA) was conducted to reduce the number of components underlying the measurement of anxiety and lose as little information as possible. All items related to the measurement of anxiety are present in the questionnaires (STAI-X: questions 1 to 20; DASS-21: questions 2,4,7,9,15,19,20, and GAD-7: questions 1 to 7). Given the important psychometric characteristics confirming the effectiveness of anxiety measurement of the questionnaires used and their wide use in the literature, the number of factors was forced to one component. The solution was rotated using orthogonal rotation (varimax) to obtain the simplest structure. The items factorizability was assessed through the Kaiser-Meier-Olkin measure of sampling adequacy, known to be ≥.60 when acceptable and ≥.80 when ideal (Kaiser, 1974) and Bartlett's test of sphericity (null hypothesis: variables are uncorrelated and not ideal for factor analysis) which should be significant (Swami and Barron, 2019).

Then, the content of the items to generate the anxiety scale was devised from the remaining 21 items considering that this scale should have the same number of items as the three existing scales including a reverse-coded item; furthermore, efforts were made to ensure heterogeneity of meaning among the items to cover the breadth of the measured domain. Finally, when items had comparable loadings and similar meanings, preference was given to brevity and face validity.

2.2.5 RESULTS

The sample size was found to be adequate. PCA results indicate that the Kaiser-Meyer-Olkin (KMO) measure of sampling adequacy (KMO = .93) and Bartlett's test of sphericity ($\chi 2_{(561)}$ = 5241, $p < .001$) revealed good factorization. The results of PCA indicate that the items of the analyzed questionnaires have high loadings on the first factor. The eigenvalue of this factor was 13.6 and explained 40.1% of the variance. The highest loading was 0.77 for item 9 of the STAI-X (i.e., "I feel anxious"), while the lowest loading was 0.35 for item 2 of the DASS-21 (i.e., "I noticed I have a dry mouth"). After the initial removal of items according to the criteria described above, 21 items remained on a provisional anxiety scale. Applying the principles described above to select the final items, the scale was designed considering items 1, 2, and 4 of the GAD-7 and items 6 and 13 of the STAI-X1, which were combined into one item to make it more comprehensive. As shown in Table 2.1, these items had moderate to large loadings on the factor considered.

Questionnaire	Item		Factor Loading
STAI_X	9	I feel anxious	0.774
STAI_X	14	I feel "high strong"	0.773
STAI_X	15*	I am relaxed	0.761
STAI_X	13	I am jittery	0.760
STAI_X	12	I feel nervous	0.758
STAI_X	6	I fell upset	0.739
STAI_X	5*	I feel at ease	0.724
STAI_X	3	I'm tense	0.723
GAD_7	2	Not being able to stop or control worry	0.701
STAI_X	17	I am worried	0.689
GAD_7	3	Worrying too much about different thing	0.687
GAD_7	1	Feeling nervous, anxious, or on edge	0.684
GAD_7	4	Trouble relaxing	0.675
STAI_X	1*	I feel calm	0.668
STAI_X	20*	I feel pleasant	0.658
STAI_X	10*	I feel confortable	0.654
DASS_21	15	I felt I was close to panic	0.628
STAI_X	2*	I feel secure	0.623
DASS_21	20	I felt scared without any good reason	0.617
DASS_21	4	I experienced breathing difficulty (eg, excessively rapid breathing, breathlessness in the absence of physical exertion)	0.615
DASS_21	9	I was worried about situations in which I might panic and make a fool of myself	0.603
GAD_7	7	Feeling afraid as if something awful might happen	0.589
STAI_X	11*	I feel confident.	0.589
DASS_21	7	I experienced trembling (eg, in the hands)	0.557
GAD_7	5	Being so restless that it is hard to sit still	0.552
STAI_X	19*	I feel joyful	0.552
STAI_X	18	I feel over-excited and rattled	0.534
GAD_7	6	Becoming easily annoyed or irritable	0.534
DASS_21	19	I was aware of the action of my heart in the absence of physical exertion (eg,sense of heart rate increase, heart missing a beat)	0.534
STAI_X	16*	I feel content	0.524
STAI_X	4	I am regretful	0.506
STAI_X	7	I'm presently worring about possible misfortunes	0.466
STAI_X	8*	I feel rested	0.451
DASS_21	2	I was aware of dryness of my mouth	0.349

Table 2.1 - Factorial loadings of the items of the different questionnaires for the assessment of anxiety in PCA (indicate reverse items)*

2.3 PHASE 2: VALIDATION OF RSCRAM

2.3.1 AIM

To validate a revised and translated version of the first self-report instrument that can reliably measure individual differences in sleep quality, chronotype (diurnal preference), and depressed and anxious mood. An inherent goal is to provide a brief, easy-to-complete instrument that allows four constructs and the relationships among them to be assessed.

2.3.2 MATERIALS AND METHODS

Participants

The study involved 486 Italian participants (343 F, Age M = 26.9 ± 10.1, age range 18-77 years). 272 participants (56%, 195 F, Age M = 26.7 ± 9.85) of the initial sample filled in the rSCRAM questionnaire two weeks later, to allow the assessment of the temporal stability of the instrument translated into Italian. Regarding educational qualifications, 0.6% had a secondary school leaving certificate, 57.4% a diploma, 21.2% a bachelor's degree, 14.8% a master's degree and 6.0% a post-graduate degree.

Beck Depression Inventory-II (BDI-II)

The Beck Depression Inventory-II (BDI-II, Beck et al., 1996), created by Aaron T. Beck and then validated in several languages and cultures, is a self-report questionnaire consisting of 21 multiple-choice questions. In the field of depressive symptom assessment, the Beck Depression Inventory. (BDI) is among the most widely used measures of depressive symptoms worldwide. Items presented in the form of statements assess the severity of common major depressive symptoms: Respondents are asked to select the most appropriate statement to describe their mood over the past 2 weeks on a point scale (0 to 3). Total scores range from 0 to 63; higher scores reflect higher levels of depression. The Italian version of the BDI-II (Ghisi et al., 2006) was used in this study, which reports excellent psychometric properties with an $\alpha = 0.80$; valid test-retest correlation (r=.76) and satisfactory convergent validity (r=.77; Sica & Ghisi, 2007).

The Insomnia Severity Index (ISI)

The Insomnia Severity Index (ISI, Bastien et al., 2001) is a self-report instrument useful for assessing the perception of insomnia. It consists of seven items, scored on a 5-point Likert scale (0-4), that address subjective symptoms and daytime consequences of insomnia, as well as the degree of distress caused by these difficulties. The score ranges from 0 to 28, the cut-off as a threshold for clinically relevant insomnia is 15, and gradually higher scores indicate more severe insomnia. The questionnaire is short and easy to assess. The Italian version of the ISI, validated by Castronovo et al. (2016) showed excellent psychometric properties with an internal reliability coefficient, measured by ordinal alpha, of 0.75.

The reduced Morningness-Eveningness Questionnaire (rMEQ)

The chronotype represents a diurnal preference for sleep, wakefulness, and activity, placing it on a continuum between morning and evening. It is assessed through subjectively reported measures, in which respondents report morning and evening preferences and the effect on daytime function. The Reduced Morningness-Eveningness Questionnaire (rMEQ, Adan and Almirall, 1991), consisting of 5 items extracted from the MEQ (Horne & Östberg, 1976), ranks among the available instruments used to measure subjective chronotype. The minimum score is 4 and the maximum score is 25. The cutoff scores outlined by Adan and Almirall (1991) were used in the Italian version (4-10 evening type; 11-18 intermediate type; 19-25 morning type). Cronbach's 'alpha is ever very high including in its Italian version (i.e, 0.71; Natale et al., 2006).

STAI-X1

Also here, we used the X1 subscale of the State and Trait Anxiety Inventory (STAI), already described in Study 1.

Pittsburgh Sleep Quality Index (PSQI)

Pittsburgh Sleep Quality Index (PSQI) was described in detail in Study 1 and therefore is not discussed in detail here.

SCRAM

The SCRAM questionnaire, developed by Byrne et al. (2017), through 15 items allows the assessment of sleep, circadian rhythm, and mood. It consists of three subscales composed of 5 items each, the "Good Sleep" designed to investigate sleep quality, the "Morningness" to delineate a morning or evening chronotype, and the "Mood" to assess the presence of depressive symptoms.

The score for each subscale ranges from a minimum of 5 to a maximum of 30 and is derived by rating each item on a 6-point Likert scale where 1 indicates "strongly disagree" and 6 "strongly agree." Concerning psychometric characteristics, the original version of this questionnaire has good test-retest reliability (r=.72 to .86) and a Cronbach's alpha of .76 to .85 (Byrne et al., 2019). In the revised version that we propose in this paper, the rSCRAM questionnaire in addition to the three subscales just mentioned and described, includes an "Anxious Mood" subscale to consider the anxious state to better delineate the mood of the subject filling it out. The version used therefore includes a total of 19 items on a Likert scale of 1 to 6 each.

SCRAM translation into Italian

Following recommended guidelines (Swami and Barron, 2019), at first, the SCRAM questionnaire was translated from English to Italian independently by two authors. As a second step, a third person analyzed the discrepancies between the two translations to create an unambiguous version of the translated questionnaire. This version was then back-translated from Italian to English by a native English speaker. Finally, the discrepancies between the forward and backward translations were analyzed and discussed by all translators mentioned above.

The Personality Inventory for DSM-5 - Short Version (PID-5-BF) - Adult

The Personality Inventory for DSM-5 - Short Version (PID-5-BF, Krueger et al., 2013) is a self-report questionnaire useful for assessing personality traits. It measures five domains of personality traits (Negative Affectivity, Detachment, Antagonism, Disinhibition, and Psychoticism) through 25 items, scored on a 4-point scale (0-3) in which each trait domain consists of 5 items. The total score can range from 0 to 75, and greater overall personality dysfunction is delineated by higher scores. Even within each trait domain, the higher the scores (0 to 15), the greater the dysfunction in the specific personality trait domain.

Barratt Impulsiveness Scale-11 (BIS-11)

The self-report questionnaire BIS-11 is among the most widely used to measure impulsivity (Patton et al., 1995). It is composed of 30 items measured on a 4-point scale (1=Rarely/Never; 2=Occasionally; 3=Often; 4=Somewhat Always/Forever). Reverse scales are also included in the questionnaire to avoid response bias. The scores of the BIS-11 are summed and used to calculate the level of impulsive behavior adopted by the individual. The internal consistency and test-retest reliability of both the English and Italian versions of the BIS-11 is very high (0.79 and 0.89, respectively; Fossati et al., 2001).

The Short Form Health Survey 36 (SF-36)

The Short Form Health Survey 36 (SF-36; Ware et al., 1992) is a generic, multidimensional instrument that aims to quantify health status and measure the resulting quality of life. It consists of 36 questions divided into eight scales: Physical functioning; Limitations due to physical health; Limitations due to emotional problems; Energy and fatigue; Emotional well-being; Social activities; Pain; and General health perception. All Items are rated on a Likert scale, which has variable and weighted values for each item. A score is derived from each subscale that can range from a minimum of 0 (negative health) to a maximum of 100 (positive health) and can be considered independently. As in the original version, the Italian translation (Apolone & Mosconi, 1998) is characterized by a very good Cronbach's alpha coefficient (ranging between 0.77 and 0.93 in different subscales).

2.3.3 PROCEDURE

The administration of the questionnaire was identical to that of Study 1: participants signed the informed consent, answered the demographic questions, and then the battery of questionnaires on REDCap. Unlike in Study 1, in this second phase participants were asked for their telephone number to be contacted again after two weeks for a new completion of the rSCRAM questionnaire to be able to assess its test-retest reliability. The investigation was approved by the Internal Review Board of the University of L'Aquila (#24/2023) and was conducted according to the principles established in the Declaration of Helsinki.

2.3.4 DATA ANALYSIS

At first, descriptive analyses were conducted on the characteristics of the sample (gender, age, educational qualification).

For the sample size, the criteria of the most used guideline, which suggests a participant/item ratio of 10:1 (Nunnally & Bernstein, 1995; Tabachnick & Fidell, 2013) were considered and met.

To identify the most representative items of each factor considered in the original SCRAM questionnaire, a principal component analysis (PCA) was conducted. Subsequently, EFA was conducted on the rSCRAM version that included the anxiety assessment items. Again, as in Study 1, the factorizability of the items was assessed using the Kaiser-Meier-Olkin measure of sampling adequacy and Bartlett's test of sphericity. An oblique rotation (oblimin) was used. Given the most suitable method (Swami and Barron, 2019), parallel analysis was performed to retain factors (Horn, 1965). Items with fair factorial loadings ≥ .33 were retained, and in the PCA those with lower factorial loadings were eliminated (Comrey & Lee, 1992).

A confirmatory factor analysis with maximum likelihood estimation was then conducted to analyze the four-factor model found with the EFA. The fit of the model was studied using the normalized chi-square (which should be less than 3 for an acceptable fit, Hu & Bentler, 1999), the Standardized Root Mean Square Residual (SRMSR), and the Root Mean Square Residual (RMSEA), whose values must be small if the model is to fit; values less than .08 are considered acceptable. For the RMSEA, values below .06 or .05 delineate a good fit, and a 90% confidence interval was also calculated to ensure a better evaluation of the index. In addition, the comparative goodness-of-fit index (CFI) and the Tucker-Lewis index (TLI) were considered, which must be greater than 1 to indicate an adequate fit, and indices greater than or equal to 0.95 are considered satisfactory. Correlations between the four factors were also considered.

In addition, Pearson correlations were performed between the four SCRAM subscales and the well-validated measures to examine criterion validity.

Test-retest reliability was investigated using Pearson's correlations between the first and second administration of the rSCRAM questionnaire occurring 2 weeks apart.

2.3.5 RESULTS

The sample size was found to be adequate. PCA results report that the Kaiser-Meyer-Olkin (KMO) measure of sampling adequacy (KMO = .82) and Bartlett's test of sphericity ($\chi^2_{(105)} = 2175$, $p < .001$) revealed good factoring. The parallel analysis that created a random dataset confirmed the 3 factors from the original version by Byrne et al. 2017. These 3 factors explained 53.8% of the common variance. The items with the lowest loadings for each factor considered were eliminated (item 5 for the subscale "Depressed mood", item 3 for the subscale "Morning") and in the case of similar saturations, the lexically most confusing item was eliminated (item 5 for the subscale "Good sleep"), see Table 2.2.

As shown in Table 2.3, EFA results report that the Kaiser-Meyer-Olkin (KMO) measure of sampling adequacy (KMO = .88) and Bartlett's test of sphericity ($\chi^2_{(120)} = 3457$, $p < .001$) revealed good factoring. The parallel analysis that created a random dataset confirmed the 4 factors in rSCRAM. This structure explained 54.5 percent of the common variance.

	Component		
	1	**2**	**3**
scram1			0.758
scram2		0.844	
scram3	0.756		
scram4		0.669	
scram5*	0.705		
scram6			0.607
scram7	0.756		
scram8			0.810
scram9	0.794		
scram10*		0.537	
scram11		0.703	
scram12*			0.617
scram13	0.664		
scram14		0.809	
scram15			0.607

Table 2.2 - Factor loadings of original SCRAM items in the PCA (indicate reverse items)*

Scale		Item	Factor Loading
Anxious Mood	AM1	I felt nervous, anxious and/or tense	0.930
	AM3	I felt agitated and/or upset	0.825
	AM2	I could not stop worrying or keep my worries under control	0.753
	AM4	I felt I had difficulty relaxing	0.662
Morningness	M1	People talk about "morning" and "evening" people, I'm a morning person	0.874
	M4	Waking up at 7am or earlier works really well for my natural body clock	0.724
	M3	I work most efficiently before midday	0.648
	M2	I get very tired by 11 pm	0.557
Good Sleep	GS3	I get the amount of slept hat I need	0.829
	GS2	I week up feeling refreshed, like I've had enough sleep	0.634
	GS1	I sleep soundly through the night	0.552
	GS4	If I slept better at night my life would be drastically different	0.475
Depressed Mood	DM1	I have lost interest in things that I used to enjoy	0.706
	DM4	Everything is going from bad to worse	0.517
	DM2	I can laugh and see the funny side of things	0.464
	DM3	All I want to do is cry	0.419

Table 2.3 - Items and Factor Loadings for each scale of rSCRAM

The results of the CFA are detailed in Figure 2.1. The model fit was acceptable for all fit indices. The analyses indicated the following fit indices: $\chi^2_{(98)} = 225$, CFI = 0.96, TLI = 0.95, RMSEA = 0.052 (90% CI [0.043,0.060]), and SRMSR = 0.057. The latent structure of rSCRAM was

supported by this model. For each subscale, the four items were significantly loaded on a single latent variable. The scores of the rSCRAM Good Sleep, Good Sleep and Anxious Mood scales appear relatively normally distributed, whereas a non-significant positive skewness was observed for the Depressed Mood scale scores (see Figure 2). The Morningness scale had a weak positive relationship with good sleep ($r = 0.21$; $p<.001$); the Good Sleep scale had moderate negative associations with both depression ($r = -0.36$; $p<.001$) and anxiety ($r= -0.36$; $p<.001$); finally, anxiety and depression had a strong positive relationship ($r = -0.72$; $p<.001$), as shown in Table 2.4.

Scale	Good Sleep	Morningness	Depressed Mood	Anxious Mood
Good Sleep	—			
Morningness	0.206***	—		
Depressed Mood	-0.361***	-0.047	—	
Anxious Mood	-0.360***	0.014	0.723***	—
Mean	14.8	14.1	9.69	13.6
SD	3.71	4.48	3.89	4.81
Skewness	-0.27	0.02	0.55	0.05
Kurtosis	-0.17	-0.62	-0.26	-0.54

*Table 2.4 - Correlations, Descriptive Statistics for the Morningness, Good Sleep, Depressed and Anxious Mood Scales. N=484, theoretical range for each scale is 4-24, ***p<.001*

The reliability indices for the internal consistency of the rSCRAM were acceptable for all subscales (from $\alpha = 0.90$ to $\alpha = 0.72$). Details, also concerning Cronbach's α if the item was eliminated, are given in Table 2.5.

SCALE	Cronbach's α	Cronbach's α if item is dropped			
		ITEM 1	ITEM 2	ITEM 3	ITEM 4
GOOD SLEEP	0.723	0.697	0.623	0.592	0.726
MORNINGNESS	0.788	0.665	0.794	0.746	0.726
DEPRESSED MOOD	0.786	0.757	0.761	0.717	0.694
ANXIOUS MOOD	0.901	0.858	0.873	0.868	0.886

Table 2.5 - Cronbach's Alpha for the Morningness, Good Sleep and Depressed and Anxious Mood Scale

The criterion validity of the rSCRAM questionnaire is strong, with significant correlations between its subscales and relevant convergent measures. In particular:

- The subscale Good Sleep shows high negative correlations with both the PSQI (r = -0.645) and the ISI (r = -0.713).
- The subscale Morningness shows a strong positive correlation with the MEQr (r = 0.814).
- The depressed mood and anxious mood subscales are positively correlated with mood-related measures such as the BDI-II (depressed mood: r = -0.738) and the STAI-X1 (anxious mood: r = -0.789).

The divergence measures show weaker correlations with the subscales of the rSCRAM, indicating good discriminant validity.

For detailed correlations of convergent and divergent measures, please refer to the supplementary materials.

Considering test-retest reliability, the rSCRAM subscales showed good temporal stability over 2 weeks. The Pearson correlations performed are excellent and statistically significant (Good Sleep: r=.733/p<.001; Morningness: r=.824/p<.001; Depressed Mood: r=.798/p<.001; Anxious Mood: r=.729/p<.001

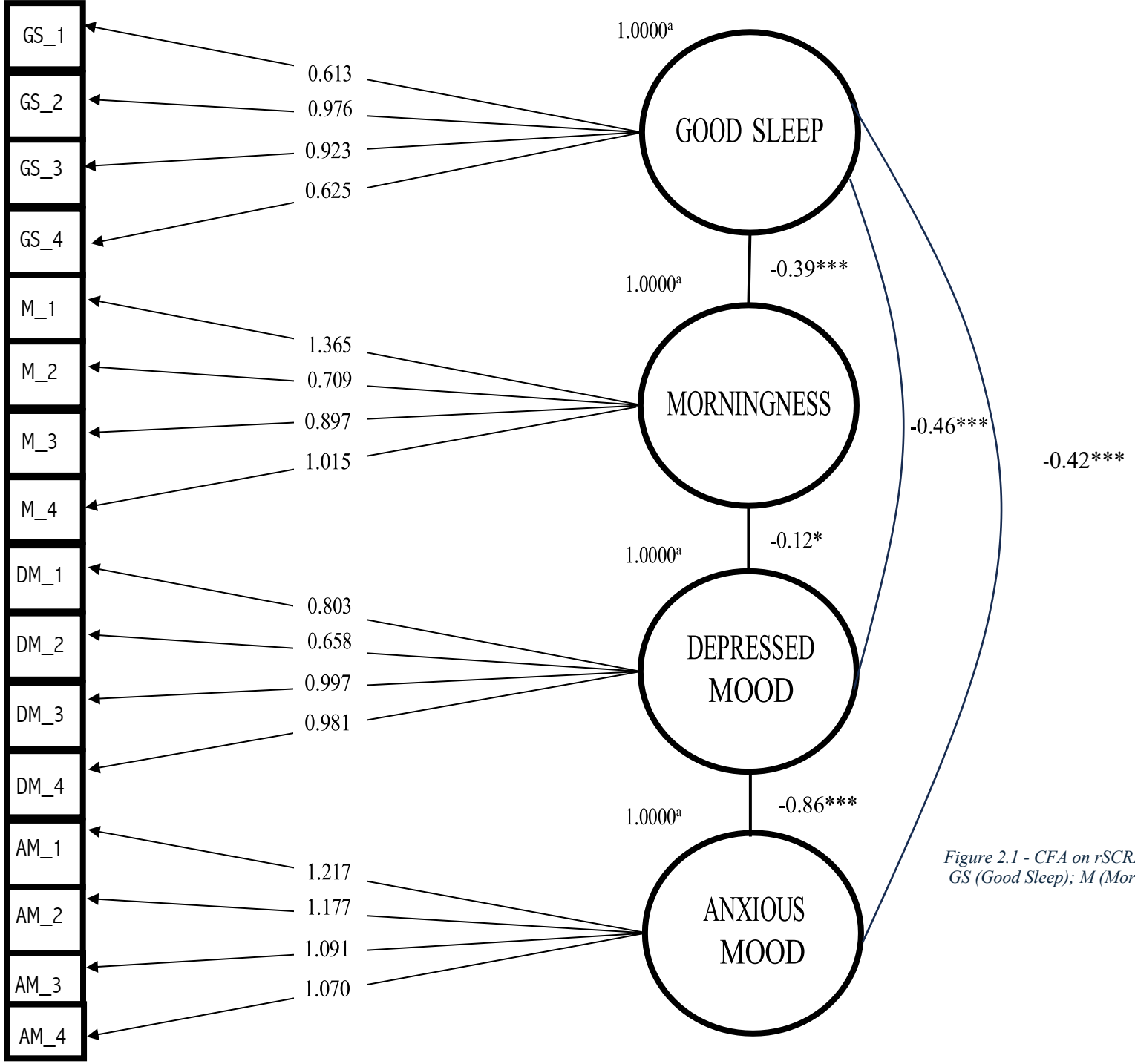


*Figure 2.1 - CFA on rSCRAM . *p<.05, **p<.01, ***p<.001*
GS (Good Sleep); M (Morningness); DM (Depressed Mood); AM (Anxious Mood)

2.4 DISCUSSION

This project aimed to validate a revised version of the first self-report instrument able to provide a reliable measure of individual differences in sleep quality, chronotype (diurnal preference), and mood. Compared to the original version of the SCRAM questionnaire, the assessment of anxiety was introduced in this study to offer a more precise measurement of mood.

From the one-dimensional factorial structure of questionnaires commonly used to measure anxiety, obtained through PCA, four items were chosen for inclusion in the rSCRAM instrument.

To keep the structure short and of immediate relevance to the factors considered, a strength of the original instrument proposed by Byrne et al. (2017), 3 items from the SCRAM were excluded to add the four items for anxiety without extending the questionnaire significantly. After eliminating the 3 items from the original SCRAM questionnaire, considering through PCA which ones saturated less for each appropriately identified membership factor (one item for Good Sleep, one item for Morningness, and one item for Depressed Mood) the four items for the anxiety assessment were included in the rSCRAM scale. As hypothesized the EFA conducted on the new version rSCRAM returned a 4-factor structure. This structure was satisfactorily confirmed by the CFA, with good fit indices.

In general, good psychometric properties of the rSCRAM questionnaire were obtained. As hypothesized, test-retest reliability and internal consistency were acceptable for each scale, with significant correlations considering a two-week interval between the first and second administration of the questionnaire and with Cronbach's α values ranging from 0.72 to 0.90.

Correlations performed to investigate convergent validity were highly significant when comparing the subscales of the rSCRAM questionnaire with commonly used measures of sleep quality, chronotype, and depressed and anxious mood. Indeed, analyses show that higher scores on the Good Sleep subscale are associated with worse sleep quality as assessed by PSQI and greater presence of insomnia symptoms as measured by the ISI questionnaire. The Morningness subscale was found to be reliable in measuring chronotype, correlating highly significantly with the MEQr questionnaire, thus effectively discriminating between subjects with morning, intermediate, or evening chronotype. Depressed mood was effectively measured by the Depressed Mood subscale, as evidenced by the high correlations with the BDI-II scale, likewise the high positive correlations between the Anxious

Mood subscale and the STAI-X scale, ensure that the rSCRAM instrument can measure anxiety independently. In this work, divergent validity was also investigated, using commonly used measures to measure constructs other than those studied by the rSCRAM. In this work, divergent validity was also investigated, using commonly used methods to measure constructs other than those studied by the rSCRAM. For this purpose, a PID-5-BF personality scale, an impulsivity trait rating scale (BIS-11) and a general health scale (SF-36) were used. In general, low correlations were shown between these scales and the rSCRAM, confirming the latter's ability to measure the constructs for which it was created without interference in other domains. In addition, the high correlations between the Depressed Mood and Anxious Mood subscales and the Affectivity and Detachment subscales of the PID-5-BF questionnaire confirm their ability to assess the affective states for which they were designed.

The intrinsic relationships found in-between the four scales of the rSCRAM questionnaire were generally found to be corroborated by the existing literature. From our results, it appears that higher levels of depressed mood are associated with lower sleep quality. In this bidirectional relationship, it is known that poor sleep quality can negatively affect brain chemical and metabolic balance by increasing the risk of developing depressive symptoms (Medic et al., 2017; Alrousan et al., 2022). Moreover, sleep plays a crucial role in the regulation and processing of emotions. Insufficient sleep duration or poor sleep quality can impair emotional regulation, increasing vulnerability to mood disorders such as depression (Vandekerckhove & Wang, 2018). Depression can also affect sleep quality; negative thoughts can create difficulty in falling asleep or maintaining sleep. Depressive symptoms, therefore, impair sleep quality by causing frequent awakenings during the night, early awakening in the morning, altered sleep patterns, and generally less restorative sleep (Jiang et al., 2022; Murphy & Peterson, 2015).

Given the known correlations between depressed and anxious mood - also confirmed in this study - as well as their frequent comorbidity (Groen et al., 2020), it is evident that there is also a relationship between an anxious mood and sleep quality, again a bidirectional one (Jansson-Fröjmark & Lindblom, 2008). Our results show that higher levels of anxiety are related to worse sleep quality for various reasons. Consistent with the existing literature, it can be inferred that anxious people derive less benefit from sleep episodes either because of difficulty in falling asleep due to anxious thoughts that persist in the mind, making it difficult to achieve the relaxation necessary for sleep, or because of nighttime awakenings caused by worries or anxieties that interrupt sleep and reduce the overall quality of rest. Vice-versa, poor-quality sleep may also increase susceptibility to anxiety. Lack of rest may increase reactivity to negative stimuli and reduce the ability to suppress intense emotional

responses, thus increasing the risk of developing anxiety or reacting anxiously to stressful situations. It follows that sleep quality and anxiety may interact in a negative cycle, in which anxiety affects sleep and sleep affects anxiety (Ohayon & Roth, 2003; Staner, 2003; Bragantini et al., 2019).

Morningness and Good Sleep had a moderately positive correlation, consistent with evidence that having a later chronotype is associated with higher levels of insomnia complaints. People with an evening chronotype may have difficulty adjusting to social sleep schedules, such as those imposed by work or family commitments. This can lead to reduced sleep duration and impaired sleep quality. (Wittmann et al., 2006; Chan et al., 2014).
In contrast to the existing literature (Au & Reece, 2017; Chan et al., 2014; Kivelä et al., 2018), no correlations have been found between chronotype and depressed or anxious mood. This finding can be explained by considering that 59% of the sample had an intermediate chronotype and the corresponding absence of a clear clustering of the sample into morning and evening chronotypes.

Given the validated capabilities of the rSCRAM questionnaire to distinguish between the four strongly interrelated factors, it is an excellent candidate as a tool in research. The rSCRAM questionnaire could be applied in the research assessment of the four domains investigated. Moreover, it could also be used in clinical settings: sleep quality, circadian phase-shifts, and mood fluctuations are early risk-factors for some mood disorders and are often underestimated (Malhi & Kuiper, 2013). To this end, a possible future development of the tool could be its use on clinical populations affected with neurodegenerative or psychiatric disorders. Given the brief nature of the rSCRAM questionnaire to analyze four different constructs, it can be considered useful in large-scale studies where the aim is to collect large amounts of data while minimizing the burden on subjects. This would avoid the use of long batteries of questionnaires to measure sleep quality, chronotype, depressed mood and anxious mood, which could be time-consuming for participants to complete.

2.5 CONCLUSIONS

This study validated a revised version of the first self-assessment tool capable of reliably measuring individual differences in sleep quality, chronotype, and mood, by introducing anxiety for a more precise measurement of mood compared to the original SCRAM questionnaire. The 4-factor structure of the rSCRAM questionnaire was successfully confirmed by CFA, demonstrating good psychometric properties. Significant correlations with common measures of sleep quality, chronotype, and depressed and anxious mood confirm the convergent validity of the rSCRAM.

Divergent validity was also confirmed, showing low quantification-correlation with other constructs. Furthermore, a bidirectional relationship between anxious mood and sleep quality was highlighted, suggesting a negative cycle were anxiety influences sleep and vice versa. However, no correlations were found between chronotype and depressed or anxious mood, likely due to the predominance of an intermediate chronotype in the study sample.

2.6 LIMITATIONS

Nevertheless, there are limitations to be noted: Both the studies were represented by samples consisting of young and healthy subjects who were predominantly women (62% in study 1 and 70% in study 2), and came from an Italian background, therefore the results may not be generalizable.

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APPENDIX

rSCRAM questionnaire

The following sentences deal with sleep, mood, and the timing of daily activities. Thinking back on your life over the last 2 weeks, try to give an answer that summarizes your habits.

	Strongly Disagree	**Disagree**	**Somewhat Disagree**	**Somewhat Agree**	**Agree**	**Strongly Agree**
1) I sleep soundly through the night						
2) People talk about "morning" and "evening" people, I'm a morning person						
3) I have lost interest in things that I used to enjoy						
4) I get very tired by 11 pm						
5) I can laugh and see the funny side of things						
6) I week up feeling refreshed, like I've had enough sleep						
7) All I want to do is cry						
8) I get the amount of sleept hat I need						
9) Everything is going from bad to worse						
10)I work most efficiently before midday						
11)If I slept better at night my life would be drastically different						
12)Waking up at 7am or earlier works really well for my natural body clock						
13)I felt nervous, anxious and/or tense						
14)I could not stop worrying or keep my worries under control						
15)I felt agitated and/or upset						
16)I felt I had difficulty relaxing						

Table A1 - Version of rSCRAM

The scores of items 5, 11 are reverse. The score for each subscale (Good Sleep, Morning, Depressed Mood and Anxious Mood) is calculated by summing up the scores of the relevant items after the score inversion and has a minimum of 4 and a maximum of 24.

STUDY 3: Circadian rhythms and effects of total sleep deprivation on attention assessed with the Attentional Demands Task.

3.1 INTRODUCTION

Circadian variations, chronotype, and sleep pressure influence cognitive functioning in healthy individuals (Schmidt et al., 2007).

Life on Earth has evolved under the influence of environmental cycles such as the light-dark cycle and the seasons, which have led to the development of internal oscillations in organisms, known as biological rhythms, including circadian rhythms lasting approximately 24 hours (Moore-Ede et. al, 1983; Foster & Kreitzman, 2014). The suprachiasmatic nucleus (SCN) acts as the brain's master clock and regulates these rhythms by keeping physiological functions synchronized and regulating variables such as body temperature, hormone secretion, and the sleep-wake cycle (Golombeck & Rosenstein, 2010; Czeisler & Buxton, 2017). Circadian rhythms are also crucial for regulating cognitive processes, including attention, working memory, and executive functions (Carrier & Monk, 200; Valdéz et al., 2012; Irie, 2021). Research has shown that cognitive performance varies throughout the day, with peaks generally observed during the day and significant declines during the night (Valdéz et al., 2012), suggesting the importance of such rhythms in optimizing daily activities (Refinetti, 2016; Schmidt et al., 2007; Valdez, 2019). Disruption of circadian rhythms can cause significant cognitive deficits, particularly in attention and alertness (Minkel & Dinges, 2009). For example, circadian misalignment, such as that occurring during jet lag or shift work, can lead to reduced attention and increased fatigue (Lahti et al., 2010; Lee, 2022). Human cognitive performance is regulated not only by circadian mechanisms, which follow an approximately 24-hour cycle, but also by homeostatic mechanisms. The circadian rhythm promotes alertness during the day and sleepiness during the night, physiologically influencing body temperature and brain activity. Homeostatic mechanisms, on the other hand, ensure the balance of physiological functions, with alertness occurring in the morning after a good night's sleep and gradually decreasing over the day as the need for sleep increases (Borbèly, 1982; Borbèly et al., 2016).

Borbély's (1982) two-process model explains the mechanisms that regulate the sleep-wake cycle through the interaction between the S-process and the C-process. The S-process represents the homeostatic pressure of sleep, which increases during wakefulness and dissipates during sleep, especially in the non-REM phases. While the C process is a 24-hour circadian rhythm that regulates sleep propensity independently of activity, synchronizing with the light-dark cycle. The propensity to sleep reaches its minimum in the early evening hours when homeostatic pressure (S) is high and

its maximum in the early morning hours when homeostatic pressure is low. Both processes interact, influencing the alternation between states of drowsiness and vigilance (Borbely, 2022; Schimdt et al., 2007; VonDongen & Dinges, 2005).

Another aspect to consider when studying circadian and homeostatic effects on cognitive performance is the chronotype, understood as an individual's natural preference for morning or evening activities. Research seems to indicate that cognitive performance, including attention, is influenced by the alignment of an individual's chronotype with their daily activities (Salehinejad et al., 2021). Indeed, the timing of cognitive activities about an individual's circadian rhythm can significantly influence performance results. In support of this hypothesis, Salehinejad et al. (2021) found that cortical excitability, associated with attention functioning, can vary by chronotype and time of day, suggesting that individuals perform better when their activities align with circadian rhythms (Salehinejad et al., 2021). The interaction between cognitive ability and chronotype and misalignment may lead to reduced performance in attention-related tasks (Ujma & Kirkegaard, 2021). A further phenomenon that may explain the relationship between cognitive performance and chronotype lies in the relationship with mood, whereby morning chronotypes generally report better mood correlated with better attention and cognitive function (Walsh et al., 2022), whereas evening chronotypes may experience greater mood fluctuations resulting in greater attention difficulties (Melo et al., 2020).

Research has shown that variations in circadian rhythm can also alter the ability to task-switch, thereby affecting performance and speed of execution. Steinborn et al. (2010) showed that task difficulty and circadian phase can interact significantly, having a greater impact on performance when individuals must switch between tasks rather than repeat the same task. One explanation for this phenomenon may be related to cognitive flexibility, crucial for task switching, which seems to be more associated with the circadian phase than with sleepiness (a component of a homeostatic nature) indicating that circadian rhythm plays a key role in the ability to adapt to new tasks (Cheng et al., 2017). Another executive function fundamental to task-switching is inhibitory control, which, in the same way as cognitive flexibility, is subject to impairments in gating the circadian rhythm (Bratzke et al., 2012).

Further considerations on homeostatic and circadian influences on cognitive performance come from sleep deprivation studies. Sleep deprivation, whether acute or chronic, significantly impairs cognitive processes such as attention and executive functions, Dodds et al. (2011), showed that already after 24 hours of sleep deprivation there is a marked reduction in performance in attention-demanding tasks. Similarly, chronic sleep restriction (e.g. 4-6 hours of sleep per night for about 14 days) can cause a

decline in attention comparable to the effects of one night of total deprivation (Deliens et al., 2015). In support of these considerations, Lo et al. (2012) introducing the 'neuropsychological hypothesis' believe that sleep deprivation may cause temporary functional lesions in areas crucial to cognitive tasks such as the frontal and prefrontal areas. Indeed, we know from other studies that vigilant attention is significantly impaired under sleep deprivation conditions (Stepan et al., 2022). Different components of attention are affected in different ways by sleep deprivation (Jugovac & Cavallero 2012). Cunningham et al. (2018) show how sustained focus is significantly impaired, while selective attention, may remain more resilient. The mechanisms underlying these deficits are caused by changes in brain function and connectivity, with altered cortical activation during attentional tasks leading to a decreased brain response to visual stimuli and reduced attentional processes (Chee et al., 2011). The detrimental effects of sleep deprivation exacerbate as attentional demands increase, indeed, when attention is divided, individuals often struggle to maintain focus on primary tasks, resulting in poorer performance in memory retention and task performance (Murphy & Castel, 2023; Gaspelin et al., 2013). Sleep deprivation has also been shown in some studies to alter the brain's ability to efficiently process information under divided attention conditions (Honn et al., 2018). This phenomenon is particularly evident under multitasking conditions, where cognitive load increases and further stresses attentional resources (Herff & Czernochowski, 2017). Task switching understood as flexible switching between different tasks relies heavily on the prefrontal cortex (PFC), a region particularly vulnerable to sleep deprivation (Lo et al., 2012). Recent studies show that a single night of sleep deprivation can increase performance decrements in task switching compared to task repetition, so-called 'switching costs', impairing the ability to adapt quickly to new demands (Couyoumdjian et al. 2010). These effects may be due to the negative impact of sleep deprivation on cognitive flexibility, which is crucial to performing task-switching effectively (Whitney et al., 2017). These effects are further amplified in situations where divided attention is required, where overloaded cognitive resources and the ability to handle multiple tasks simultaneously impaired (Murphy & Castel, 2023; Gaspelin et al., 2013) lead to impairments in memory retrieval processes and worsen the ability to adapt to fast-moving tasks (Glass & Kang, 2019; Herff & Czernochowski, 2019) while also altering the brain's ability to allocate cognitive resources efficiently (Honn et al., 2018).

Considering these results, this study aims to investigate the effects of circadian rhythms and sleep deprivation on attention, focusing on two fundamental components: selective attention and divided attention, and the switching between them. In contrast to the literature, in this work a single instrument, the Attentional Demands Task, will be used to study both attentional components while also assessing the switching costs of using them alternately. By observing how circadian variations

and sleep deprivation modulate attention and influence task-switching performance, this study will contribute to clarifying how circadian and sleep-related factors impact cognitive flexibility and executive functions.

3.2 PHASE 1: DIURNAL VARIABILITY IN ATTENTIONAL COMPONENTS AND INFLUENCE OF SWITCHING

3.2.1 AIM

Evaluation of the influence of circadian fluctuations and the effects of switching on attention using the AD-Task

3.2.2 MATERIALS AND METHODS

Participants

Thirty-two subjects (19F, mean age 24.9±3.14) participated in the study, as five participants were eliminated due to technical problems with the instrumentation. No participants had a history of neurological or psychological problems. All reported normal vision and hearing. Most of the participants were selected by the University of L'Aquila. The study, approved by the university's ethics committee, was conducted according to the principles of the Declaration of Helsinki. Each participant provided written informed consent at a time before the experiment, and it was explained to them that they could stop participating at any time without any consequences.

Materials

The instruments used in this study for data collection and evaluation include the Attentional Demands Task, the Karolinska Sleep Diary (KSD), the Pittsburgh Sleep Quality Index (PSQI), rSCRAM, the Karolinska Sleepiness Scale (KSS), the Epworth Sleepiness Scale (ESS) and the Global Vigor-Affect Scale, which have been described in detail in the previous sections and are not discussed further here.

3.2.3 PROCEDURE

The experiment was conducted at the Laboratory of Cognitive and Behavioral Sciences at the University of L'Aquila. It involved 37 participants selected based on Pittsburgh Sleep Quality Index

(PSQI) scores and monitored with the Karolinska Sleep Diary (KSD) during the week of the experiment; no participants were smokers. The entire experimental protocol was conducted over two days: on day 1, participants performed a brief familiarization phase with the AD-Task and completed the questionnaire to assess sleep quality, chronotype, and mood (rSCRAM); on day 2, they performed a full version of the AD-Task at different times of the day (09:00, 12:00, 15:00, 18:00). The experiment was conducted in a room free of distractions and external interference, with constant lighting conditions. The participants, seated at a workstation equipped with a computer with a screen measuring 35.4 x 19.9 cm, completed the Epworth Sleepiness Scale (ESS), Karolinska Sleepiness Scale (KSS), and Global-Vigor and Affect Scale (G-VAS) questionnaires to measure sleepiness, vigor, and affect before each session. Subsequently, subjects completed, in randomized order, the Attentional Demands Task (AD-Task), designed to assess selective attention, divided attention, and switching ability. For the duration of the protocol, subjects were asked not to take any excitatory substances such as caffeine, theine, or chocolate. Each experimental session lasted approximately 40 minutes. For performance assessment, accuracy was measured using the Signal Detection Theory (SDT; Stanislaw & Todorov, 1999), calculating the hit rate (H), false alarm rate (FA), and sensitivity (d'), with possible extreme value correction according to Macmillan & Kaplan (1985), while speed was assessed based on reaction times (RTs).

The investigation was approved by the Internal Review Board of the University of L'Aquila (#61/2021-2022) and was conducted according to the principles established in the Declaration of Helsinki.

3.2.4 DATA ANALYSIS

Descriptive statistics were performed on the characteristics of the sample (age, gender, schooling, occupation) on the chronotype (assessed through rSCRAM) on the indices of sleep quality (measured through the completion of the rSCRAM and PSQI questionnaires) and depressed and anxious mood (rSCRAM) of the participants. In addition, the averages of the scores obtained in the sleep diaries (KSDs) completed during the week of sleep monitoring (including experimental days) were calculated to consider sleep quality and restfulness.

To assess the variability of the indices of sleepiness, vigor, and affect, a repeated-measures ANOVA was performed in which TIME, understood as time of day, was included as a factor within the scores obtained on the KSS, ESS, and GVAS (vigor and affect) questionnaires.

To assess variability in performance (HIT RATE, d' and FA RATE) and speed (TRs) in the performance of the behavioral task AD-Task in selective and divided attention in the two different

conditions of single demand and switching, at different times during the experimental day, a repeated-measures ANOVA was performed in which TIME (time of day), TYPE OF ATTENTIONAL DEMAND (selective/divided) and CONDITION (single demand/switching) were entered as within-subject factors. Post-hoc comparisons were performed if statistical significance was reached ($p < .05$).

All analyses were conducted with the Jamovi program, and the level of statistical significance was set at $p<.05$.

3.2.5 RESULTS

Descriptives

The 32 participants (19F age m: 24.9±3.14) had mean schooling of 14.9±1.67, of which 3.1% were unemployed, 3.1% employed and 93,8% students, good sleep quality (PSQI: 4.44±1.98; rSCRAM: 15.2±2.58), an intermediate chronotype (rSCRAM: 14.5±3.28) and mean levels of depressed mood (rSCRAM: 9.94±3.66) and anxious mood (12.9±4.94). The indices of sleep quality and restorative remained stable during the monitoring days, as shown in Table 3.1 and Table 3.2.

Descriptives – SLEEP QUALITY (KDS)				
	DAY 1	DAY 2	DAY 3	DAY 4
N	32	32	32	32
Mean	4.47	4.41	4.50	4.38
Median	4.75	4.75	4.50	4.38
SD	0.601	0.650	0.575	0.630

Table 3.1 - Sleep Quality assessment evaluated with KSD sleep diary

Descriptives - SLEEP RESTORATIVENESS (KSD)				
	DAY 1	DAY 2	DAY 3	DAY 4
N	32	32	32	32
Mean	3.82	3.71	3.56	3.35
Median	3.67	3.67	3.50	3.33
SD	0.750	0.820	0.773	0.708

Table 3.2 - Restorative Sleep assessment evaluated with KSD sleep diary

Variations in subjective ratings of sleepiness, vigor, and affect throughout the day

Analyses performed on the subjective sleepiness index measured by the Karolinska Sleepiness Scale (KSS) showed no significant changes throughout the day. No significant changes were observed in the Epworth Sleepiness Scale (ESS) either, so sleepiness at least from a perceptual point of view tends not to vary. The subject perceives himself to be at the same level of sleepiness. About the indices of vigor and affect measured by GVAS, a significant effect of TIME on vigor was found ($F_{(3, 66)} = 5.82$, $\eta^2p = 0.209$, $p = 0.001$). From the post-hoc findings, the subject perceived himself to be less physically efficient in the afternoon compared to midday when there was a peak in physical strength (15:00 - $t_{(22.0)} = 4.096$, Mdif= 12.02, p=.003; 18:00 - $t_{(22.0)} = 3.991$, Mdif= 10.53, p=.003). For details, see Figure 3.1.

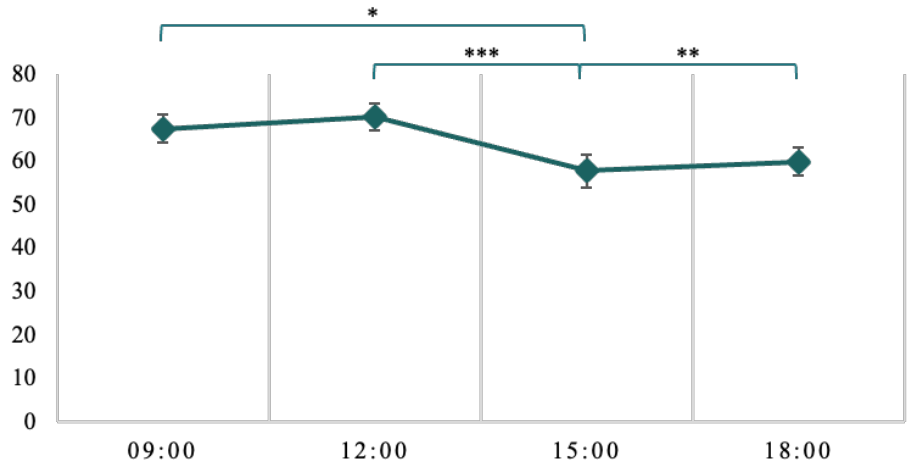


*Figure 3.2 - Diurnal fluctuations in perceived physical vigor measured by GVAS at different times of the day. *p<.05, ** p<01, ***p<.001*

Diurnal fluctuations in performance and speed indices

Regarding the success rate index in performance at the AD-Task (HIT RATE), an interaction effect emerged between TIME and TYPE OF ATTENTIONAL DEMAND ($F_{(3, 93)} = 3.403$, $\eta^2p = 0.099$, $p = 0.021$), suggesting that attentional demand type influences HIT RATE over time. Post hoc comparisons showed selective attention showed better performance than divided attention at all times investigated, at 09:00 ($t_{(31.0)} = 6.5305$, Mdif= 0.08061, p<. 001), at noon ($t_{(31.0)} = 6.4985$, Mdif= 0.06786, p<. 001), at 15:00 ($t_{(31.0)} = 6.3736$, Mdif= 0.07090, p<. 001)and at 18:00 ($t_{(31.0)} = 5.8109$,

Mdif= 0.04451, p<. 001). This suggests that participants were more accurate when focusing on a single stimulus than when dividing their attention over multiple stimuli (see Figure 3.2).
In general, selective attention shows better results than divided attention at any time of the day.

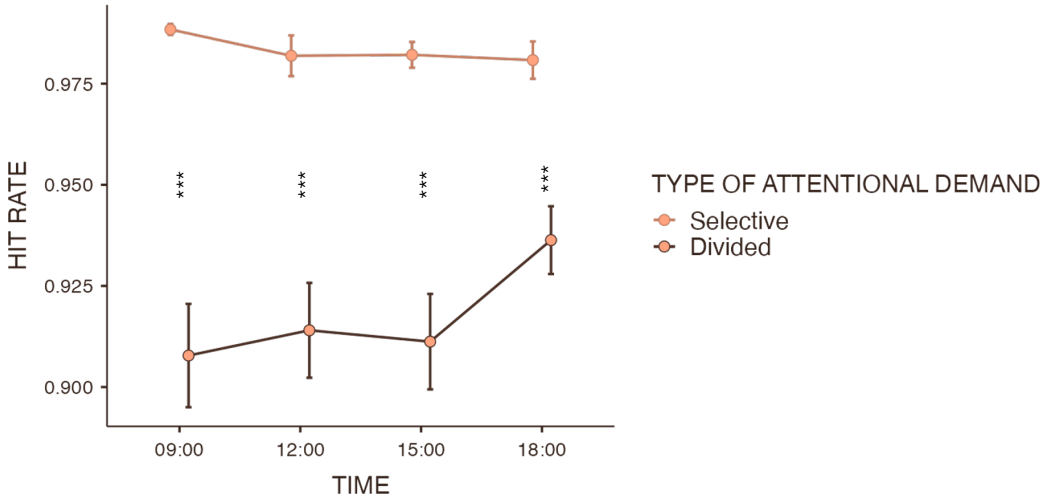


*Figure 3.3 - Interaction between Time and Type of Attentional Demand on HIT RATE performance in the AD-Task. *p<.05, ** p<01, ***p<.001*

Regarding the repeated-measures ANOVA applied on the index of discrimination of the target stimulus from the non-target (sensitivity or d'), an interaction effect emerged between TIME * CONDITION * TYPE OF ATTENTIONAL DEMAND ($F_{(3, 93)} = 3.188$; $p = 0.027$; $\eta^2p = 0.093$), which suggests that the effect of time on sensitivity (d') varies depending on whether participants are engaged in selective or divided attention tasks, in the single demand or switching condition. The post hoc findings show that selective and divided attention has taken on two different behaviors in the variability of the ability to recognize the target stimulus. In selective attention, compared to performance in the 09:00 'SINGLE DEMAND' condition, there appears to be an increase in the difference between single demand and switching starting at noon ($t_{(31.0)} = 5.8359$, Mdif= 0.48092, p<. 001) with a worsening of switching. Over the day, the target stimulus discrimination index worsens both in the single demand condition at 15:00 ($t_{(31.0)} = 4.2938$, Mdif= 0.35867, p=0.012) and 18:00 ($t_{(31.0)} = 4.0025$, Mdif= 0.39265, p=0.025) than in the switching condition at the same times (15:00 - $t_{(31.0)} = 5.1205$, Mdif= 0.41372, p=0.001; 18:00 - $t_{(31.0)} = 4.4619$, Mdif= 0.37820, p=0.008) than in the morning. In divided attention, however, the ability to recognize the target stimulus remains stable, showing only one statistically significant difference in afternoon performance in the single demand condition ($t_{(31.0)} = 3.7760$, Mdif= 0.32747, p=0.044), highlighting how better performance is achieved in the late afternoon than in the postprandial phase. Details shown in Figure 3.3.

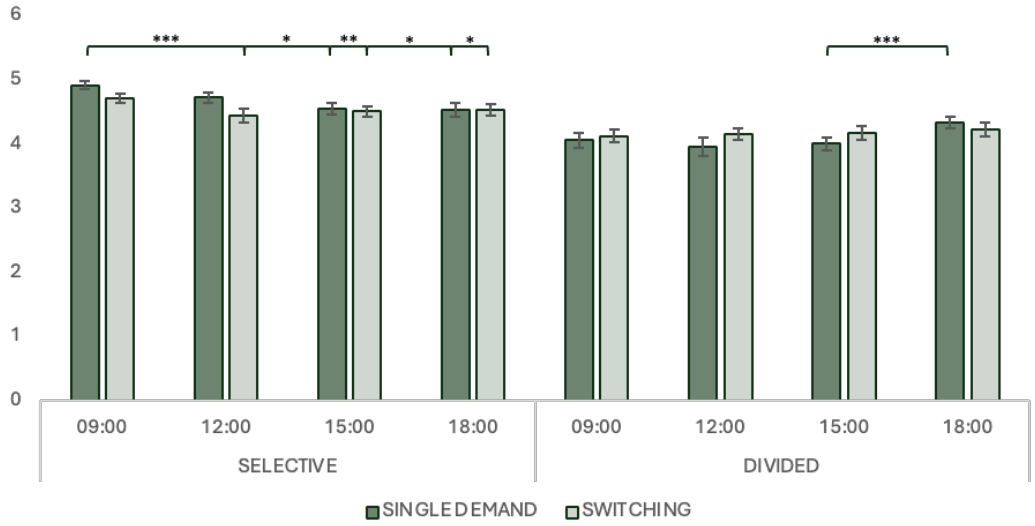


*Figure 3.4 - Interaction effect of time, attentional demand (selective vs. divided), and task condition (single demand vs. switching) on sensitivity (d'). *p<.05, ** p<01, ***p<.001*

The TIME*CONDITION*TYPE OF ATTENTIONAL DEMAND interaction effect also shows that the difference between the two attentional components (selective and divided) remains marked mainly in the single condition until the early afternoon. In fact, from the post hoc, it is evident that selective attention predicts a better ability to recognize the target stimulus among the irrelevant ones at 09:00 a.m. ($t_{(31.0)}$ = 8.3737, Mdif= 0.85939, p<.001), at noon ($t_{(31.0)}$ = 5.2615, Mdif= 0.76653, p<.001), and in the postprandial phase ($t_{(31.0)}$ = 5.3059, Mdif= 0.54929, p<.001); in the late afternoon, on the other hand, the two attentional demands tend to equalize. In the switching condition, however, the difference between the two types of attention is evident only at 09:00 am ($t_{(31.0)}$ = 5.9530, Mdif= 0.58419, p<.001). For more details, see Figure 3.4.

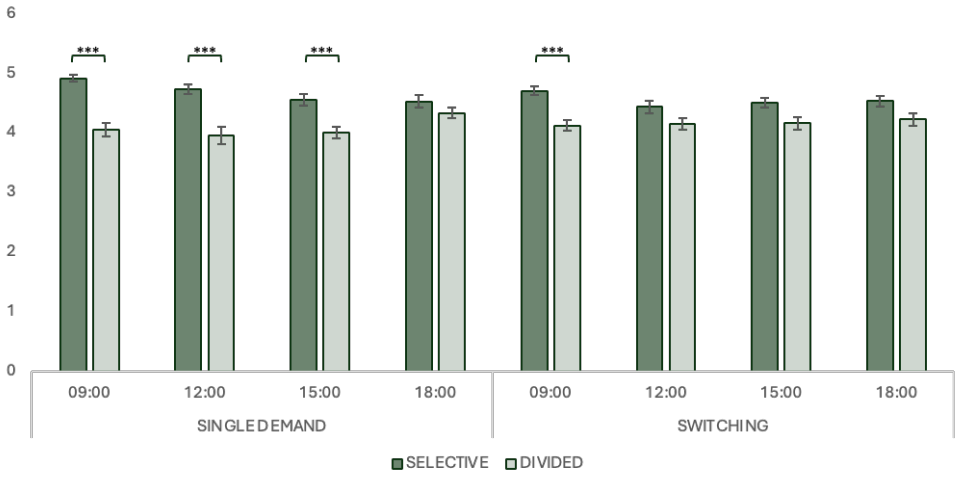


*Figure 3.5 - Changes in the ability to discriminate target stimuli (sensitivity, d') over the day under conditions of single and switched attention for selective and divided attention. *p<.05, ** p<01, ***p<.001.*

About the repeated-measures ANOVA applied to the number of commission errors (FA RATE), an interaction effect emerged between TIME * CONDITION * TYPE OF ATTENTIONAL DEMAND ($F_{(3, 93)} = 18.1$; $p < 0.001$; $\eta^2p = 0.368$), which suggests that the effect of time on the amount of committal errors varies depending on whether participants are engaged in selective or divided attention tasks, in the single or switching question conditions. Post-hoc comparisons show that the two attentional components begin to show statistically significant differences at midday and in the early afternoon, only in the switching condition in which divided attention predicts higher rates of distraction with consequent commission errors (12:00 - $t_{(31.0)} = -4.7616$, Mdif= -0.06402, p=.004; 15:00 - $t_{(31.0)} = -5.0613$, Mdif= -0.06332, p=.002). In the late afternoon, however, there is a worsening in selective attention compared to divided attention in both the single demand ($t_{(31.0)} = 4.1176$, Mdif= 0.00934, p=.019) and switching ($t_{(31.0)} = 4.4739$, Mdif= 0.00925, p=.008) conditions. All results are shown in Figure 3.5.

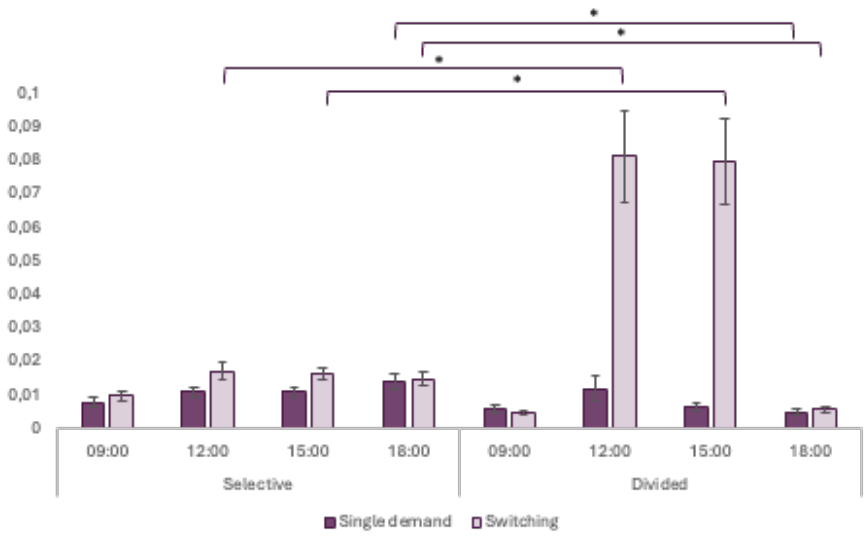


*Figure 3.5- Fluctuations in FA RATE during the day depending on the type of attentional demand (selective or divided) and task condition (single or switching). *p<.05, ** p<01, ***p<.001.*

In addition, post-hoc comparisons also show that divided attention exclusively in the switching condition is more sensitive to circadian effects, showing more commission errors at midday and early afternoon than both in the morning (12:00 - $t_{(31.0)} = -5.6170$, Mdif= -0.07668, p<.001; 15:00 - $t_{(31.0)} = -5.9015$, Mdif= -0.07526, p<.001) and late afternoon (12:00 - $t_{(31.0)} = -5.6060$, Mdif= -0.07560, p<.001; 15:00 - $t_{(31.0)} = -5.8877$, Mdif= -0.07418, p<.001), as shown in Figure 3.6.

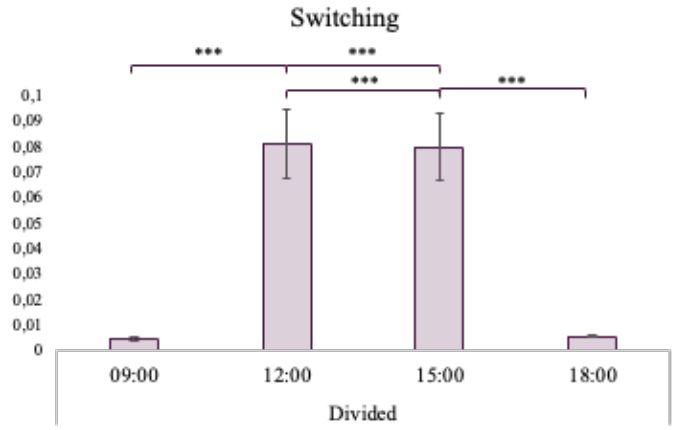


*Figure 3.6 – The impact of circadian rhythms on commission error rates during divided attention tasks in switching conditions. *p<.05, ** p<01, ***p<.001.*

Repeated-measures ANOVA applied on the speed of responding to task stimuli (RTs) showed an interaction effect between TIME and TYPE OF ATTENTIONAL DEMAND ($F_{(3, 93)} = 7.3134$; $p < 0.001$; $\eta^2p = 0.191$), which suggests that the effect of time on stimulus responsiveness varies depending on whether participants are engaged in selective or divided attention tasks. Indeed, post-hoc comparisons show that in general selective attention predicts better reaction times than divided attention at all times investigated (09:00 - $t_{(31.0)} = -18.878$, Mdif= -148.27, p<.001; 12:00 - $t_{(31.0)} = -16.652$, Mdif= -129.35, p<.00; 15:00 - $t_{(31.0)} = -19.088$, Mdif= -123.28, p<.001; 18:00 - $t_{(31.0)} = -20.097$, Mdif= -118.87, p<.001). In addition, it is also possible to highlight the effect of time of day on reactivity to respond to task stimuli in divided attention in which 09:00 performance turns out to be the worst compared to the other times (12:00 - $t_{(31.0)} = 7.223$, Mdif= 33.79, p<.001; 15:00 - $t_{(31.0)} = 5.022$, Mdif= 36.69, p<.001; 18:00 - $t_{(31.0)} = 6.471$, Mdif= 45.32, p<.001) being characterized by the most reaction times throughout the day, see figure 3.7.

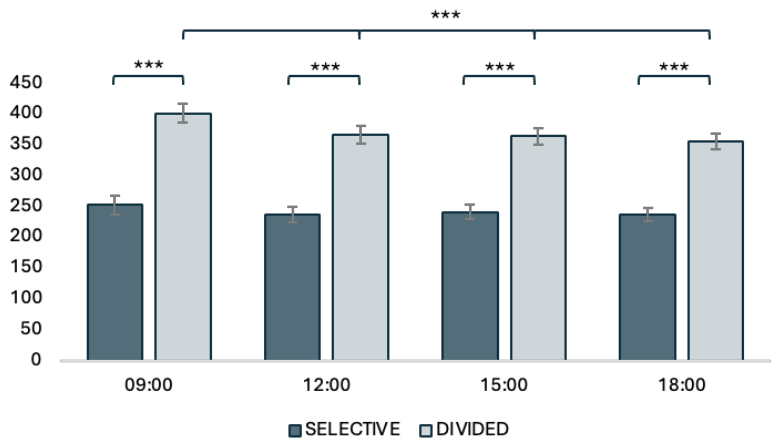


*Figure 3.7 - Effects of time of day on reaction time in selective and divided attention tasks. *p<.05, ** p<01, ***p<.001.*

3.3 PHASE 2: ASSESSING THE EFFECTS OF SLEEP DEPRIVATION ON SELECTIVE ATTENTION, DIVIDED ATTENTION, AND TASK-SWITCHING ABILITIES

3.3.1 AIM

To evaluate the effects of a night of sleep deprivation on selective and divided attention and switching between them

3.3.2 MATERIALS AND METHODS

Participants

The final sample consisted of 8 participants (age: 18-30 years; 4 females and 4 males) as 2 participants were eliminated due to technical problems with the instrumentation. None of the participants reported a history of neurological or psychological issues. In addition, all reported normal vision and hearing. Most of the participants were selected from the University of L'Aquila. The study was approved by the university's Ethics Committee and was conducted by the principles of the Declaration of Helsinki. Before proceeding with the experiment, each participant provided informed consent in written form. It was explained to them that they could decide to discontinue their participation without any consequences.

Materials

The tools used in this study for data collection and evaluation include:

Actigraphs

All participants wore Actiwatch Spectrum Plus (Philips) actigraphs to obtain objective activity, sleep, and movement measurements. The actigraphs were initialized to record activity from 6 pm on day 1 and were worn by participants until they awoke after the night following the deprivation night.

The other instruments used, Attentional Demands Task (AD-Task), Karolinska Sleep Diary (KSD), Pittsburgh Sleep Quality Index (PSQI), Karolinska Sleepiness Scale (KSS), Epworth Sleepiness Scale (ESS) and Global Vigor-Affect Scale, have been described in detail in previous sections and are not further elaborated here.

3.3.3 PROCEDURE

The experiment was conducted at the Laboratory of Cognitive and Behavioral Sciences at the University of L'Aquila. It involved 10 participants selected based on Pittsburgh Sleep Quality Index (PSQI) scores and monitored with the Karolinska Sleep Diary (KSD) during the entire week of the experiment, all nonsmokers.

Participants were tested every 3 hours over two days, including one night of total sleep deprivation, for 36 hours of wakefulness. The experiment occurred in a specially selected room to minimize distractions and outside interference. Participants were seated at a workstation equipped with a computer with a screen size of 35.4 x 19.9 cm. Before each session, the Epworth Sleepiness Scale (ESS), Karolinska Sleepiness Scale (KSS), and Global-Vigor and Affect Scale (G-VAS) were administered to measure sleepiness, vigor and affectivity. Next, subjects completed, in randomized order, the Attentional Demands Task (AD-Task), designed to assess selective attention, divided, and switching ability. For the entire protocol duration, subjects were asked not to take excitatory substances such as caffeine, theine, or chocolate. Each experimental session lasted about 40 minutes. The investigation was approved by the Internal Review Board of the University of L'Aquila (#61/2021-2022) and was conducted according to the principles established in the Declaration of Helsinki.

3.3.4 DATA ANALYSIS

Descriptive statistics were made on the sample characteristics (age, gender, schooling, occupation) on the indices of sleep quality (measured by filling out the rSCRAM, PSQI and ISI questionnaires) and depressed and anxious mood (rSCRAM) of the participants. In addition, the averages of the scores obtained in the sleep diaries (KSDs) completed in the week of monitoring sleep habits (including experimental days) were calculated to consider their quality and restorativeness. On the data from the aggregated analyzed actigraphs, averages of the variables of Sleep Onset, Final Awakening, Total Time in Bed (TIB), Total Sleep Time (TST), Sleep Onset Latency (SOL), Sleep Efficiency (SE), and Wake After Sleep Onset (WASO) were estimated to have a physiological index of the sleep characteristics of the participants in the week of experimentation.

To assess the variability of the indices of sleepiness, vigor, and affect, a repeated-measures ANOVA was performed in which TIME, understood as time of day, was included as a factor within the scores obtained on the KSS, ESS, and GVAS (vigor and affect) questionnaires.

To assess the variability across the two experimental days of performance (HIT RATE, d' and FA RATE) and speed (TRs) in the performance of the AD-Task behavioral task in selective and divided attention in the two different conditions of single demand and switching, a repeated-measures ANOVA was performed in which TIME (time of day), TYPE OF ATTENTIONAL DEMAND (selective/divided) and CONDITION (single demand/switching) were entered as within-subject factors. Post-hoc comparisons were performed if statistical significance was reached ($p < .05$).

All analyses were conducted using the Jamovi program, and the level of statistical significance was set at $p < .05$.

3.3.5 RESULTS

Descriptives

Of the 10 subjects selected to participate in the study, two were excluded due to technical problems with the instrumentation. The final sample consisted of 8 subjects (4F age m:24.42.20) with average schooling of 14.6±2.33 composed of 12.5% unemployed, 12.5% employed, and 75% students. The participants reported good sleep quality (PSQI: 3.38±1.69; rSCRAM: 16.6±1.60), low levels of insomnia (ISI: 0.5±0.4), an intermediate chronotype (rSCRAM: 14.6±3.02) and average levels of both depressed mood (rSCRAM: 9.88±0.9) and anxious mood (10.50±5.9). Sleep quality and restorativeness remained stable over the monitoring days, as shown in Tables 3.3 and 3.4. The data from the extracted and analyzed actigraphs are shown in Table 3.5. and Figure 3.8. is an example of the actogram obtained for each participant.

Descriptives - SLEEP QUALITY (KDS)							
	DAY 1	DAY 2	DAY 3	DAY 4	DAY 5	DAY 6	DAY 7
N	8	8	8	8	8	8	8
Mean	4.25	4.69	4.75	4.56	4.63	4.47	4.38
Median	4.50	4.75	5.00	4.75	5.00	4.75	4.75
SD	0.876	0.320	0.401	0.678	0.655	0.700	0.732

Table 3.3 - Sleep Quality assessment evaluated with KSD sleep diary

Descriptives - SLEEP RESTORATIVENESS (KSD)								
	DAY 1	DAY 2	DAY 3	DAY 4	DAY 5	DAY 6	DAY 7	DAY 8
N	8	8	8	8	8	8	8	5
Mean	3.83	4.04	3.87	4.04	4.42	3.58	3.71	4.13
Median	4.00	4.00	3.83	4.50	4.33	3.50	3.67	4.00
SD	0.667	0.603	0.665	1.16	0.527	0.792	0.744	0.506

Table 3.4 -Restorative Sleep assessment evaluated with KSD sleep diary

	SLEEP ONSET	FINAL AWAKENING	TIB	TST	SOL	SE	WASO
DAY 1	1:47±03:31	06:59±05:26	08:12±00:50	06:38±01:16	25,75±18,04	81,24±11,41	55,25±39,85
DAY 2	01:21±01:48	09:25±01:06	08:04±01:24	06:50±01:13	11,62±9,07	84,68±4,29	48,87±34,41
DAY 3	01:11±00:46	06:50±07:13	08:39±01:05	07:12±00:56	8,5±7,78	83,73±9,49	51,62±30,39
DAY 4	23:59±00:57	09:00±01:13	09:00±01:19	07:47±01:14	9,37±13,45	87,95±3,36	47,37±20,65
DAY 5	00:26±00:56	09:46±01:38	09:20±01:51	07:45±01:58	8,87±12,81	82,72±7,99	59,37±28,81
DAY 6	23:42±00:38	07:16±00:49	07:34±01:17	06:32±01:10	11,5±20,17	87,68±6,67	31,5±8,45
DAY 7	NaN	NaN	NaN	NaN	NaN	NaN	NaN
DAY 8	22:08±01:13	06:01±00:58	07:52±05:59	07:01±06:15	2,71±5,61	92,62±2,99	43,14±32,55

Table 3.5 - Mean ± SD of the actigraphic sleep variables during the entire monitoring week

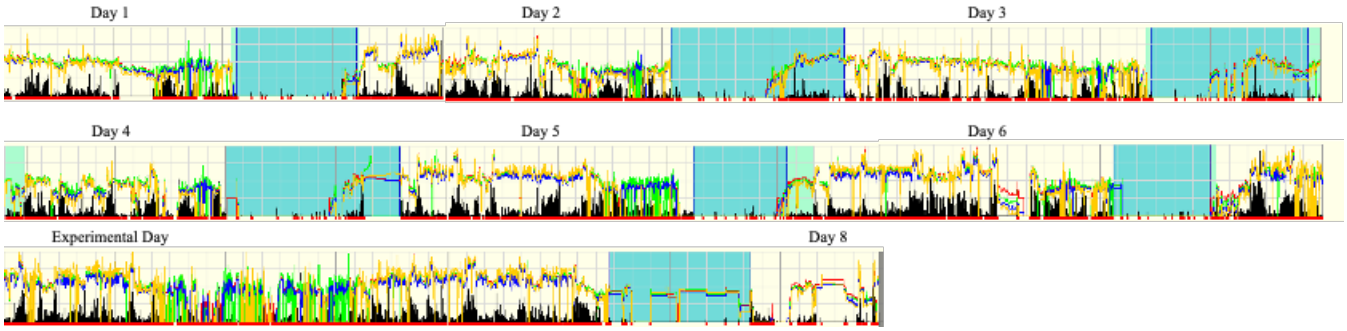


Figure 3.8 - Example of a participant's actogram

Variations in subjective ratings of sleepiness, vigor, and affect over the two experimental days

A repeated-measures ANOVA showed a main effect of TIME on perceived current sleepiness level ($F_{(11,77)} = 10.6$, $p < .001$, $\eta^2 p = 0.602$). Post-hoc comparisons (Table 3.6.) show that subjects tended to experience greater sleepiness in the night from midnight onwards compared to the day before sleep deprivation and then maintained constant sleepiness the following day, as shown in Figure 3.9.

Post Hoc - TIME							
TIME		TIME	Mean Difference	SE	df	t	p_{tukey}
09:00	-	00:00	-1.875	0.350	7.00	-5.351	0.022
	-	03:00	-3.250	0.675	7.00	-4.816	0.038
	-	06:00	-3.750	0.701	7.00	-5.351	0.022
12:00	-	00:00	-2.000	0.423	7.00	-4.733	0.041
	-	03:00	-3.375	0.730	7.00	-4.621	0.046
	-	06:00	-3.875	0.693	7.00	-5.594	0.017
15:00	-	03:00	-3.125	0.549	7.00	-5.693	0.016
	-	06:00	-3.625	0.498	7.00	-7.283	0.004
18:00	-	06:00	-3.500	0.655	7.00	-5.346	0.022
21:00	-	03:00	-2.875	0.611	7.00	-4.709	0.042
	-	06:00	-3.375	0.460	7.00	-7.329	0.004

Figure 3.6. - Post-hoc comparisons to assess changes in the perception of sleepiness during the two experimental days at different times of day

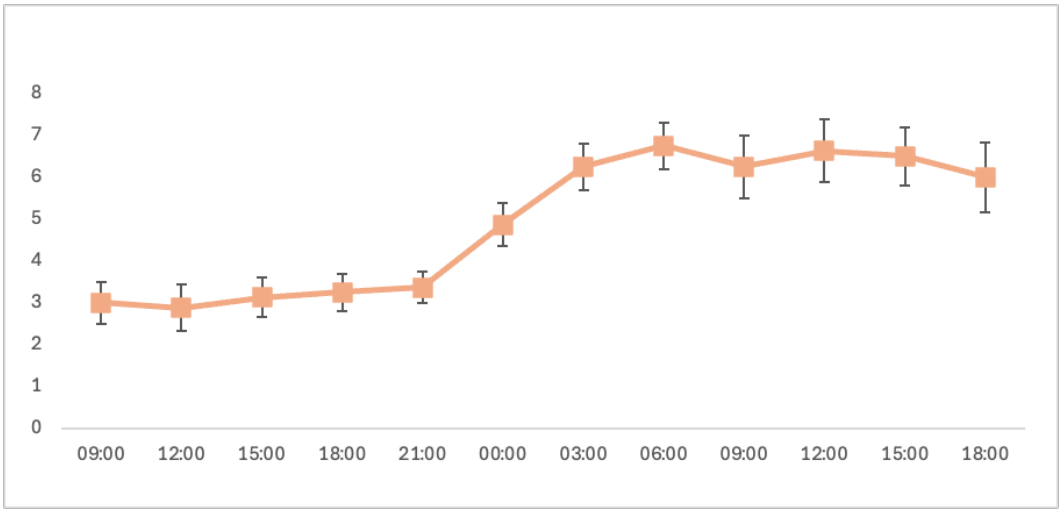


Figure 3.9 - Graphical representation of changes in the perception of sleepiness during the two experimental days, at different times of the day. For significance, see the post-hoc in Table 3.6.

A repeated measures ANOVA showed a main effect of TIME on perceived vigor as measured by GVAS ($F_{(11,77)}$ =17.8, p<.001, η^2p =0.718). Post-hoc comparisons show that subjects tended to experience less physical effectiveness starting the night of deprivation and throughout the following day than they experienced on the day before sleep deprivation (see Table 3.7. and Figure 3.10.).

Post Hoc - TIME							
TIME		TIME	Mean Difference	SE	df	t	p_{tukey}
09:00	-	00:00	17.156	3.25	7.00	5.286	0.023
	-	03:00	22.375	3.87	7.00	5.781	0.014
	-	06:00	30.750	4.49	7.00	6.856	0.005
	-	09:00 (2)	34.531	7.21	7.00	4.788	0.039
	-	12:00 (2)	33.406	6.02	7.00	5.547	0.018
	-	15:00 (2)	35.156	5.55	7.00	6.337	0.009
	-	18:00 (2)	32.250	5.86	7.00	5.506	0.019
12:00	-	03:00	23.469	4.16	7.00	5.635	0.016
	-	06:00	31.844	3.98	7.00	7.998	0.002
	-	09:00 (2)	35.625	6.42	7.00	5.550	0.018
	-	12:00 (2)	34.500	6.05	7.00	5.706	0.015
	-	15:00 (2)	36.250	5.36	7.00	6.759	0.006
	-	18:00 (2)	33.344	5.73	7.00	5.814	0.014
18:00	-	00:00	13.281	2.57	7.00	5.160	0.026
	-	06:00	26.875	4.76	7.00	5.651	0.016
	-	12:00 (2)	29.531	5.29	7.00	5.586	0.017
	-	15:00 (2)	31.281	5.01	7.00	6.244	0.009
	-	18:00 (2)	28.375	5.15	7.00	5.509	0.019
21:00	-	00:00	14.594	3.05	7.00	4.778	0.039
	-	06:00	28.187	4.16	7.00	6.781	0.006
	-	12:00 (2)	30.844	5.68	7.00	5.428	0.020
	-	15:00 (2)	32.594	5.33	7.00	6.112	0.010
	-	18:00 (2)	29.687	5.73	7.00	5.185	0.026

Figure 3.7 - Post-hoc comparisons to assess changes in the perception of physical efficiency during the two experimental days at different times of the day

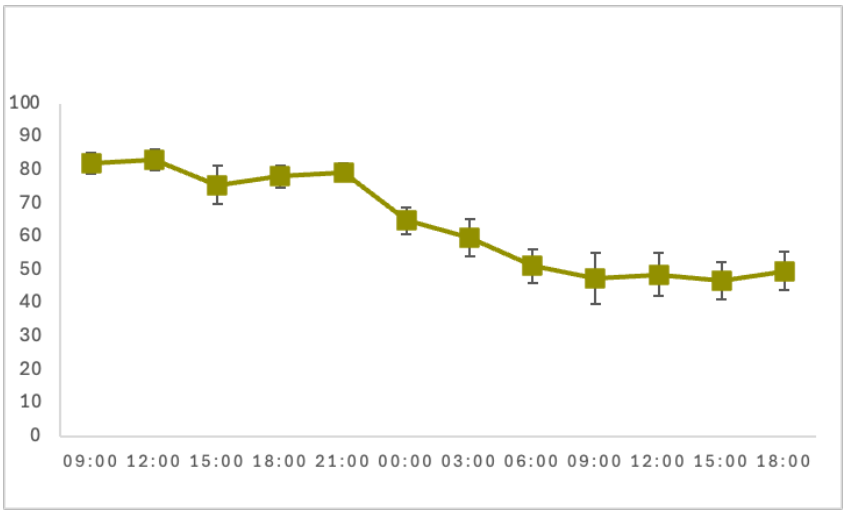


Figure 3.10 - Graphical representation of changes in the perception of physical efficiency during the two-day experiment, at different times of the day. For significance, see the post-hoc in Table 3.7.

No significant changes were observed in the Epworth Sleepiness Scale (ESS) and affect as measured by GVAS.

Changes in performance and speed indices assessed by behavioral measures as a function of sleep deprivation

The repeated-measures ANOVA performed on the target stimulus discrimination index (d') showed an interaction effect between CONDITION and TYPE OF ATTENTIONAL DEMAND ($F_{(1,7)}$= 15.177, η^2p=0.684, p=.006) in which from the post-hoc comparisons a better ability to identify the target stimulus among the no-targets in selective attention is found compared to the divided attention in both the single demand ($t_{(7.0)}$=5.78, M_{dif}=0.6129, p=.003) and switching ($t_{(7.0)}$=3.82, M_{dif}=0.3029, p=.026) conditions. Furthermore, the post-hoc comparisons also reveal a statistically significant difference in selective attention between the single demand and switching ($t_{(7.0)}$ =3.65, M_{dif}=0.2306, p=.032) condition in which there is a worsening of the target stimulus discrimination index when investigated in switching.

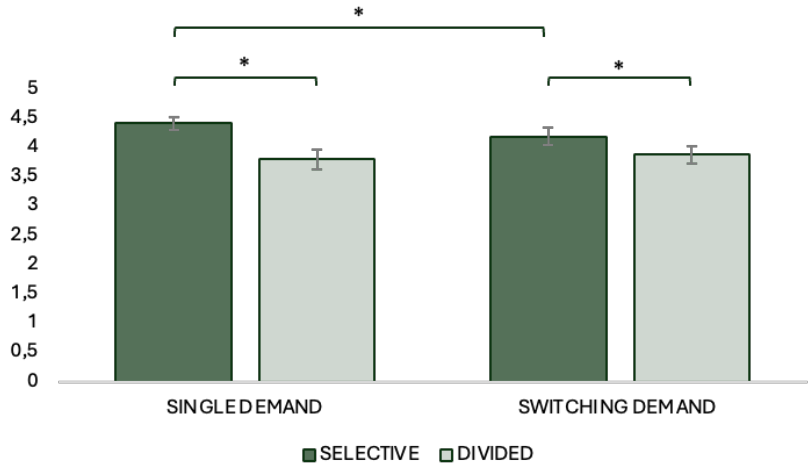


*Figure 3.11 - Variations in the ability to discriminate target stimuli (sensitivity, d') on the two experimental days under conditions of single and switched attention for selective and divided attention. *p<.05, ** p<01, ***p<.001.*

In addition, a main effect of TIME ($F_{(11,77)}$ = 13.438, η^2p=0.657, p<.001) was found to show that the passage of hours and increased wakefulness due to the sleep deprivation manipulation affect the ability to detect the target stimulus while ignoring the no-target stimulus. Post-hoc findings show that the target stimulus discrimination index tends to decrease at 09:00 on the post-sleep deprivation day and then slowly rises again during the day, becoming non-statistically different at 18:00 compared to the day before the manipulation. See Table 3.8 and Figure 3.12.

TIME		TIME	M_{dif}	SE	df	t	p_{tukey}
09:00	-	09:00 (2)	131.285	0.2770	7.00	47.395	0.041
12:00	-	09:00 (2)	136.521	0.2372	7.00	57.550	0.015
	-	12:00 (2)	105.606	0.2006	7.00	52.648	0.024
	-	15:00 (2)	101.130	0.1985	7.00	50.952	0.028
15:00	-	09:00 (2)	139.279	0.2947	7.00	47.254	0.041
	-	12:00 (2)	108.365	0.2034	7.00	53.269	0.022
	-	15:00 (2)	103.888	0.2234	7.00	46.513	0.045
18:00	-	09:00 (2)	145.486	0.2859	7.00	50.886	0.028
	-	12:00 (2)	114.571	0.2409	7.00	47.563	0.040
	-	15:00 (2)	110.094	0.2354	7.00	46.762	0.044
21:00	-	09:00 (2)	145.731	0.3183	7.00	45.782	0.048
	-	12:00 (2)	114.817	0.2416	7.00	47.516	0.040
	-	15:00 (2)	110.340	0.2338	7.00	47.187	0.042
00:00	-	09:00 (2)	129.479	0.2565	7.00	50.482	0.030
	-	12:00 (2)	0.98564	0.1788	7.00	55.115	0.019
	-	15:00 (2)	0.94087	0.1414	7.00	66.517	0.006
03:00	-	09:00 (2)	0.88762	0.1948	7.00	45.562	0.050
	-	12:00 (2)	0.57847	0.1019	7.00	56.749	0.016
	-	15:00 (2)	0.53371	0.0831	7.00	64.193	0.008
15:00 (2)	-	18:00 (2)	-0.38062	0.0714	7.00	-53.278	0.022

Table 3.8 - Post-hoc comparisons to assess changes in target stimulus discrimination ability (d') as a function of time over the two experimental days

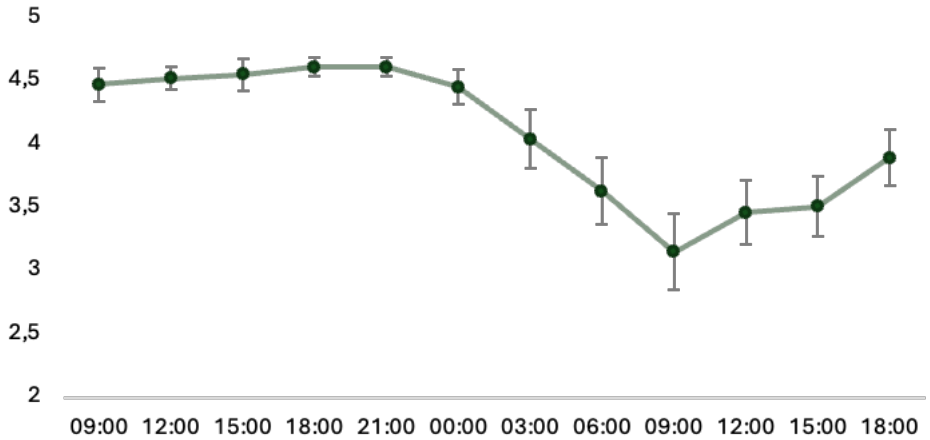


Figure 3.12 - Changes in target stimulus discrimination ability (d') as a function of time over the two experimental days. For significance, see the post-hoc in Table 3.8.

The repeated-measures ANOVA performed on the reaction times showed an interaction effect between TIME and CONDITION ($F_{(11,77)} = 1.948$, $\eta^2p=0.218$, $p=0.046$) and post-hoc comparisons show that the two conditions (single demand and switching) evolve differently as a function of sleep deprivation. In the switching condition, there is a significant increase in reaction times in the post-sleep deprivation day in the early morning and in the early afternoon compared to almost all assessment times of the previous day (see Table 3.9 and Figure 3.13). On the other hand, the single demand condition seems to show greater resistance to sleep deprivation, and worsening reaction times in the post-sleep deprivation day at 6 am and 3 pm only when compared to the peak times of the previous day (see 3.10 and Figure 3.14).

Post Hoc - TIME ✻ CONDITION									
Comparison									
TIME	CONDITION		TIME	CONDITION	Mean Difference	SE	df	t	p_{tukey}
12:00	Switching demand	-	09:00 (2)	Switching demand	-76.816	14.05	7.00	-54.669	0.041
		-	15:00 (2)	Switching demand	-74.146	11.20	7.00	-66.178	0.014
15:00	Switching demand	-	15:00 (2)	Switching demand	-61.523	11.55	7.00	-53.255	0.046
18:00	Switching demand	-	06:00	Switching demand	-56.606	8.47	7.00	-66.815	0.014
		-	09:00 (2)	Switching demand	-73.751	9.63	7.00	-76.582	0.006
		-	12:00 (2)	Switching demand	-83.931	15.97	7.00	-52.570	0.050
		-	15:00 (2)	Switching demand	-71.081	7.60	7.00	-93.534	0.002
		-	18:00 (2)	Switching demand	-62.638	11.60	7.00	-53.982	0.043
21:00	Switching demand	-	06:00	Switching demand	-53.324	9.98	7.00	-53.422	0.046
		-	09:00 (2)	Switching demand	-70.469	12.87	7.00	-54.775	0.040
		-	15:00 (2)	Switching demand	-67.799	8.85	7.00	-76.581	0.006

Table 3.9 - Post-hoc changes in reaction time (RT) over the two days in switching conditions.

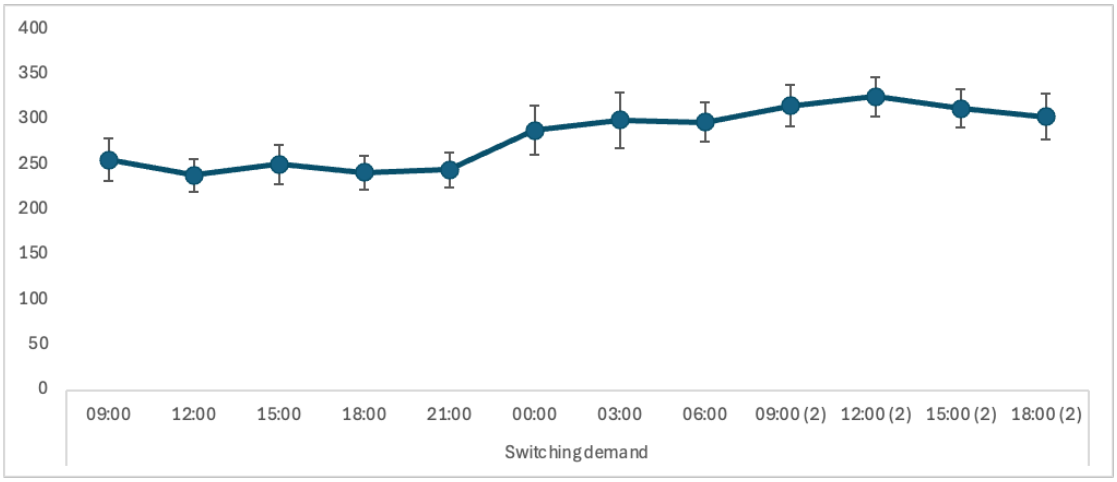


Figure 3.13 - Variations in reaction times (RTs) over the two days in switching conditions

Post Hoc - TIME ✻ CONDITION Comparison									
TIME	CONDITION		TIME	CONDITION	Mean Difference	SE	df	t	p_{tukey}
15:00	Single demand	-	06:00	Single demand	-57.364	8.28	7.00	-69.277	0.011
18:00	Single demand	-	06:00	Single demand	-57.791	5.54	7.00	-104.393	< .001
		-	15:00 (2)	Single demand	-68.205	10.53	7.00	-64.797	0.016

Table 3.10 - Post-hoc changes in reaction time (RT)as a function of time over the two days in a single demand condition

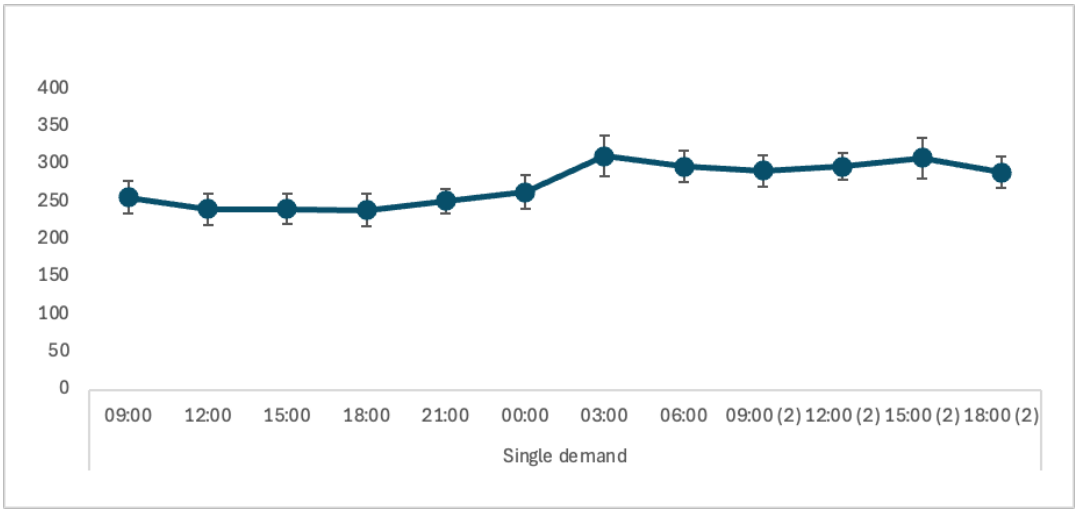


Figure 3.14 - Changes in reaction time (RT) as a function of time over the two days in a single demand condition.

In addition, a main effect of TYPE OF ATTENTIONAL DEMAND ($F_{(1,7)} = 275.186$, $\eta^2p=0.975$, $p<.001$) has been shown, and post hoc comparisons ($t_{(7.0)} =-16.6$, $M_{dif}=-132$, $p<.001$) show that selective attention generally predicts shorter reaction times than divided attention, as shown in Figure 3.15.

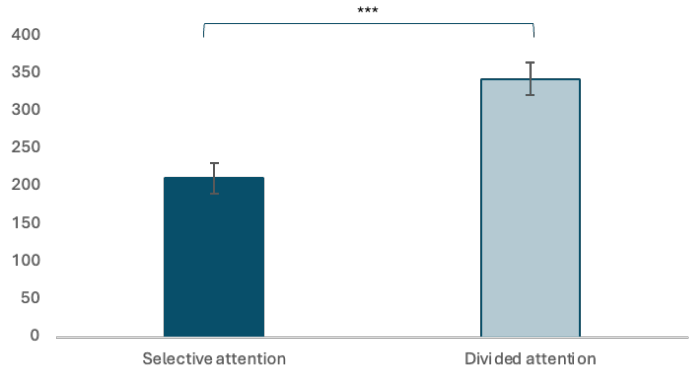


Figure 3.15 - Comparison of Reaction Times Between Selective and Divided Attention Tasks

3.4 DISCUSSION

This study investigated circadian fluctuations and the effects of total sleep deprivation on two components of attention and the ability to switch between selective and divided attention. The first phase evaluated how daytime fluctuations influence selective and divided attention and the cognitive cost of switching between them. In the second phase, the impact of a night of total sleep deprivation on the same attentional dimensions was examined. A sample of 32 participants (19 women, average age: 18-30 years) with good sleep quality, no neurological or psychological problems, and an intermediate chronotype was considered to assess the influence of circadian rhythms on cognitive performance under investigation. During the experimental phase, the participants, selected based on their scores in the Pittsburgh Sleep Quality Index (PSQI) and monitored with the Karolinska Sleep Diary (KSD), completed the subjective questionnaires of sleepiness, vigor, and affection and subsequently performed the Attentional Demands Task (AD-Task) at four different times of the day (09:00, 12:00, 15:00 and 18:00), under controlled conditions and without distractions. The sample of the second phase consisted of 8 participants (4 women and 4 men, age: 18-30 years), selected based on their scores in the Pittsburgh Sleep Quality Index (PSQI) and monitored throughout the week with the Karolinska Sleep Diary (KSD) and using actigraphs. In this phase, participants were tested for a total of 36 hours of continuous waking. After subjectively assessing their sleepiness, vigor, and affectivity by specific questionnaires, they completed the AD-Task every three hours under controlled conditions and without distractions.

The results support the hypothesis that circadian and homeostatic rhythms significantly modulate attentional performance during the day. This is in line with the findings of Valdez (2019), who showed that selective and divided attention is subject to circadian and homeostatic variations.

Regarding subjective variables, contrary to expectations, subjects did not show significant changes in subjective sleepiness levels, as measured by the KSS and ESS scales, during the day without sleep deprivation. This result suggests that, from a perceptual point of view, the participants tended to maintain a constant perception of their state of alertness. We know from the literature that daytime sleepiness is usually associated with poor sleep quality, irregular hours, and insufficient sleep duration (Gandhi et al., 2021; Hershner & Chervin, 2014; Anacleto et al., 2022). Sleep quality is considered a good predictor of daytime sleepiness often associated with sleep disorders (Meyer et al., 2017). Age may also contribute to the onset of daytime sleepiness, with the elderly reporting higher levels of sleepiness (Roeder et al., 2020; Vashum et al., 2013). Furthermore, psychological factors such as

anxiety and depression can significantly influence daytime sleepiness and general well-being (Espuga, 2016; Gustafsson et al., 2019). In our study, the lack of statistically significant differences in current and daytime sleepiness indices is probably associated with the characteristics of the sample analyzed. The young age, good health, good sleep quality, and unremarkable levels of anxiety and depression of the participants in this work appear to be characteristics far removed from those usually associated with increased daytime sleepiness, such as sleep disorders, advanced age, or high levels of psychological distress. These data are corroborated by the evident accumulation of sleepiness that occurs during the night of sleep deprivation, demonstrating that sleep deprivation leads to an increased perception of sleepiness that is maintained during the following day. As extensively demonstrated in the literature, sleep deprivation causes a cumulative increase in sleepiness, which is caused by the activation of homeostatic sleep pressure, understood as the body's natural need to sleep that accumulates the longer one stays awake (James et al., 2011; Wang et al., 2018). One plausible explanation for this progressive accumulation of sleepiness following a night of sleep deprivation may be related to changes in brain activity. Sleep deprivation may alter connectivity between neural networks, impairing vigilance and cognitive abilities (Liu et al., 2024; Mai et al., 2022). Changes in hormones and brain neurochemistry associated with sleep deprivation may also exacerbate sleepiness and subsequent cognitive deficits (Wu et al., 2023). It is known that malfunctioning of the thalamic and prefrontal regions correlates with increased perceived sleepiness, as it is crucial for maintaining vigilance (Chen et al., 2024). Increased subjective sleepiness leads to reduced cognitive performance, with proven effects in slowing down reactions and increased distraction (Goel et al., 2009). Several studies have focused on assessing the relationship between sleepiness and cognitive performance, finding that higher levels of daytime sleepiness may be associated with lower test accuracy and lower scores in cognitive performance (Alhola & Kantola, 2007; Liu et al., 2014; Hayden et al., 2023).

A clear circadian and homeostatic effect emerged on perceived physical efficiency as measured by the GVAS scale. In the circadian domain, a peak was shown at midday and then a decrease in the afternoon, this decrease was maximized as a function of increased waking hours, and an important decrease in physical efficiency under conditions of sleep deprivation was evidenced. This phenomenon is in line with what has been documented in the literature on homeostatic and circadian processes underlying the postprandial decline in body temperature and alertness (Morris et al., 2015). In addition, sleep deprivation causes reduced physical efficiency through decreased muscle strength, impaired metabolic responses, and loss of cognitive function (Skein et al., 2011; Lopes et al., 2023; Mamiya et al., 2021).

In the behavioral field, the AD-Task proved to be a useful tool for assessing the two attentional processes for which it was created and measuring the cognitive cost of switching from one to the other, providing significant results in the scenarios investigated. Despite the absence of circadian fluctuations in sleepiness that could be predictive of performance declines (Demirci et al., 2023; Ramm et al., 2017), the performance and speed results of the AD-Task showed significant differences between selective and divided attention, as well as an interaction with time of day. This is in line with studies by Liu et al. (2014) who demonstrated how subjective assessments of daytime sleepiness can sometimes obscure the level of perceived sleepiness that then reveals itself in performance declines in cognitive functions.

Regardless of circadian and homeostatic aspects, selective attention is more accurate than divided attention, both in terms of speed and overall performance, confirming the fact that focusing on a single stimulus requires fewer cognitive resources than dividing attention among several stimuli. One explanation may stem from the consideration that repeated exposure to a target may reinforce cognitive responses, making information processing more efficient (Gozli et al., 2014), whereas dividing attention by increasing cognitive load may lead to conflicts between competing stimuli (Lavie, 2010). These considerations are in line with the idea that focusing attention on a single stimulus allows for facilitation in the allocation of cognitive resources, as indicated by the results of Smart et al. (2014), confirmed by an increased involvement of the P3 component during focused attention (Smart et al., 2014).

In support of these considerations, in the speed, it was found that reaction times are slower in the morning when performing divided attention tasks, whereas they remain more stable when selective attention is involved. A phenomenon that could explain this result is sleep inertia, understood as a transient state of reduced cognitive performance after waking up that usually results in decreased alertness and cognitive slowdown, ranging from 15 to 120 minutes after waking up (Vincent et al., 2019; Kovac et al., 2022). What emerges in our study is confirmed by the literature in which it is highlighted that selective attention tasks are less susceptible to the negative effects of sleep inertia. Burke et al. (2015) consider that performance in a visual search task known to assess selective attention is less affected by sleep inertia than tasks requiring divided attention, which are more significantly impacted by changes in cognitive state (Burke et al., 2015). These data are accentuated under sleep deprivation conditions, in which the slowing of reaction time extends to both attentional demands with a drastic decrease in the morning and postprandial phase of the day following sleep deprivation. Moreover, in support of what has been discussed so far, this effect is even more

pronounced when the two types of attention are investigated under switching conditions, confirming that greater cognitive load impairs performance more (Kotch et al., 2018). Numerous studies have shown that the effects of sleep deprivation on attention concentration vary significantly depending on the time of day, with a particular decline in the morning (Bougard et al.,2015, Jarraya et al., 2012; Dikker et al., 2020) and a tendency for improvement throughout the day, with faster response times in the late morning than in the early morning hours (Munnilari et al., 2023). The worsening of reaction times in the postprandial phase may be explained by the fact that food intake and rapid fluctuations in blood glucose levels may interact negatively with sleep deprivation, inducing a decline in the ability to respond readily to presented stimuli (Monk, 2005; Tucker et al., 2010; Nilsson et al., 2007).

Regarding a more specific aspect of performance, it should be specified that sensitivity in responding to target stimuli (d') is affected by circadian effects differently depending on the attentional component involved.
Selective attention is most affected by the time of day, showing obvious difficulties in recognizing the stimulus to respond to and inhibiting others in the afternoon, especially under switching conditions. As discussed in previous chapters, the idea that selective attention, while benefiting from the lower cognitive load, is more exposed to task-switching costs suggests that its efficiency is related to cognitive flexibility and inhibitory control of workload. In this regard, Monsell (2003) argues that the efficiency of inhibitory control is compromised when returning to a more focused attentional mode after performing a divided attention task. This is because divided attention requires a constant balance between multiple streams of information, which can leave a residual proactive interference that hinders the shift to a more selective focus (Monsell, 2003). Moreover, according to Allport et al. (1994), simpler tasks tend to be more affected by task-switching after a more complex activity, as cognitive resources adapt to a higher level of processing, and returning to a more selective control requires a less immediate disengagement process. These considerations explain why selective attention, throughout the day, performs better in its ability to accurately respond to presented targets only when assessed in isolation, away from switching costs. The only time of the day when sensitivity is more efficient in selective attention than in divided attention, even in switching conditions, is early in the morning when the effects of sleep inertia influence the more complex attentional component without impairing the simpler one (Burke et al., 2015).

In general, circadian factors modulate the discrimination of the target stimulus differently in the two attentional components analyzed. Selective attention is more affected by circadian factors, with a noticeable decline in the afternoon, especially during task switching. This is because it requires a high

level of executive control to filter out irrelevant stimuli, a process that involves fronto-parietal networks and is strongly influenced by cognitive fatigue accumulated throughout the day (Tóth et al., 2019; Agmon et al., 2021).

Divided attention tends to be less susceptible to circadian fluctuations, showing only a slight postprandial decline due to the temporary reduction in cognitive resources (Moisala et al., 2015). The lower propensity to deterioration over the day compared to selective attention may be related to greater task automation or the involvement of separate cognitive resources that reduce the need for active control. (Agmon et al., 2021; McAvinue et al., 2012). In general, the afternoon decline is more pronounced in tasks that depend on executive control, whereas divided attention, supported by more automatic processes, is less vulnerable to fatigue, showing only a slight temporary decline after meals, as also shown by the increase in commission errors (McCloy et al., 2017).

Homeostatic factors seem to intervene in the analyzed variables with a more consistent course in which deterioration occurs in both attentional capacities, especially when involved in switching.

These phenomena develop at the level of performance, impairing the ability to discriminate the target stimulus (d'), which worsens with increasing waking hours, and at the level of execution speed, which predicts increasingly longer reaction times correlated with sleep deprivation. From the literature, we know that sleep deprivation can impair the prefrontal cortex, a key region for cognitive flexibility and switching (Lo et al., 2012; Killgor, 2010; Honn et al., 2019), leading to a worsening of both attentional demands (selective and divided), with a more pronounced impact on the latter due to the greater cognitive load required (Murphy & Castel, 2023; Honn et al., 2018). The cognitive cost associated with task switching undergoes a nonnegligible increase with prolonged wakefulness, with a massive increase in reaction time and a decrease in accuracy in switching conditions, confirming that sleep loss amplifies the vulnerability of executive processes (Couyoumdjian et al., 2010; Murphy & Castel, 2023). Reduced functional connectivity and cortical activation under sleep deprivation conditions may explain the slowed reaction time (RT) and reduced accuracy (Lo et al., 2012). In addition, top-down control impairment could result from these functional impairments, which may hinder the handling of irrelevant stimuli and cognitive conflict resolution (Chee et al., 2011). It follows that switching costs are more pronounced in cognitively complex tasks due to the greater vulnerability of challenging tasks to sleep loss (Allport, 1994).

3.5 CONCLUSIONS

The results of this study confirm circadian and homeostatic processes significantly modulate attentional performance. The task used demonstrates that selective and divided attention show different patterns of fluctuation throughout the day. Selective attention is more vulnerable to circadian effects, with a marked decline in the afternoon, while divided attention remains relatively stable, with a slight postprandial decline. The results also show a discrepancy between subjective sleepiness and objective performance. Although participants did not report significant changes in perceived daytime sleepiness, their cognitive performance revealed a clear circadian and homeostatic modulation. This suggests that people may not accurately perceive declines in alertness, underlining the importance of objective cognitive measures in assessing attentional efficiency.

Under conditions of sleep deprivation, both selective and divided attention are severely decreased, with a significant slowing of reaction time and an increase in errors, especially in switching tasks. Prefrontal cortex impairment and reduced functional connectivity following sleep deprivation could explain these deficits given their important implication in executive control and cognitive flexibility.

From a practical point of view, these results highlight the importance of considering the effects of time of day and sleep deprivation in contexts where attentional efficiency is a key issue.

3.6 LIMITATIONS

Despite the significant results, the study has some limitations. Both sample sizes under study, although adequate for an initial approach, may not best represent a larger population. Furthermore, the biggest limitation concerns the absence of physiological measurements (e.g. EEG or body temperature), which compromises the possibility of correlating cognitive changes with underlying physiological changes**.**

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STUDY 4: EVALUATION OF ATTENTIONAL COMPONENTS UNDER SINGLE DEMAND AND SWITCHING CONDITIONS AS A FUNCTION OF LIFESPAN

4.1 INTRODUCTION

Attention is a fundamental executive function that has major changes throughout life. Aging is a condition characterized by a general decline with different effects on physical psychological performance and cognitive performance. As the literature demonstrates, several abilities differ in their stability or decline with aging (Commodari & Guarnera, 2013). Among these, it has been shown that attentional skills deteriorate with advancing age, Simon and colleagues (2023) evaluate the evolution of attentional processes using a Continuous Performance Test (CPT) on a sample of 262 participants aged between 7 and 85 years. The results show that attentional abilities are reduced in children, peak in young adults, and then tend to decrease in the elderly, manifesting an 'inverted U' trajectory of attention across the lifespan and suggesting that cognitive decline affects the stability and duration of attention, with relevant clinical implications (Mani et al., 2005; Lufi & Haimov, 2019; Simon et al., 2023). Moreover, the age-related decline in attention may not be uniform, with some aspects more affected than others (Hsieh & Chen, 2023). Aging affects selective attention (Dahl et al.,2020). Previous findings indicate that older adults' task performance seems to be particularly affected by the presence of irrelevant stimuli compared to younger adults (Geerlings et al., 2014; de Fockert et al., 2009, Haring et al., 2013, Mager et al., 2007, Schmitz et al., 2010). Throughout life, selective attention increases capacity during childhood and adolescence due to brain maturation and increased practice and decreases (Reuter et al., 2019; Fortenbaugh et al., 2015; Robinson et al., 2018). Divided attention, understood as the ability to distribute cognitive resources to react to multiple tasks simultaneously, also does not remain unchanged across the lifespan (Malegiannaki & Metallidou, 2016). This attentional component seems to decline with age (Edwards et al., 2013; Craik et al., 2010). This impairment may relate to a decreased frontal lobe functioning or to a reduced ability and efficiency in coordinating processes, tasks, or skills that simultaneously impairs multiple tasks' performance (Craik et al., 2010). The same inverted U-shaped mechanism that is found in attention as a function of age has also been shown in performance in task-switching tasks (Wasylyshyn et al., 2011). Adults with advancing age tend to generally show slower response times and higher switching costs than younger adults (Terry & Sliwinski, 2012; Butler & Weywadt, 2013). Research indicates that with aging comes significant changes in cognitive flexibility, which is essential to perform task-switching effectively. Several papers pointed out that the elderly often show a substantial decline in cognitive flexibility, which can hinder their ability to switch tasks efficiently (Lacreuse et al., 2020; Wilson et al., 2018). This decline is explained by considering the changes that occur in the prefrontal

cortex and other brain regions associated with executive functioning as a function of age (Lacreuse et al., 2020; Phillips et al., 2019). Research indicates that with aging comes significant changes in cognitive flexibility, which is essential to perform task-switching effectively. In several articles, it is pointed out that the elderly often show a significant decline in cognitive flexibility, which can hinder their ability to switch tasks efficiently (Lacreuse et al., 2020; Wilson et al., 2018). This decline is explained by considering the changes that occur with advancing age in the prefrontal cortex and other brain regions associated with executive functioning (Lacreuse et al., 2020; Phillips et al., 2019). Although elderly adopt compensatory mechanisms to achieve acceptable performance, the decline in processing speed amplifies difficulties in task switching, leading to increased cognitive load that alters the handling of multiple tasks simultaneously and causes lower performance than in younger people (Fellows et al., 2014; Nóbrega-Sousa et al., 2020; Wilson et al., 2018).

From the data so far in the literature, attention certainly appears to undergo complex changes that may follow different trajectories throughout life. The evolution of attentional processes is driven by structural and functional neural changes that modulate the interactions between attention and cognitive processes, which are also subject to important changes with age. Therefore, it is important to better understand how different components of attention behave to get a more complete picture of what happens during aging.

For these considerations, the Attentional Demands Task is used in this paper to assess the evolution of selective attention and divided attention, also incorporating information on how the ability to switch between attentional processes may change as a function of age. Given the previous results, we generally expect a better performance in terms of both performance and speed in the young compared to the old. Furthermore, another aspect that may vary between young and old is a greater sensitivity to switching effects concerning single demand conditions with advancing age.

4.2 AIM

Evaluation of changes in selective and divided attention with possible effects of switching conditions in subjects of different ages.

4.3 MATERIALS AND METHODS

Participants

Possible age-related effects were evaluated on 100 subjects, of whom 7 were excluded due to instrumentation problems. The remaining 93 subjects (age 18-70, 64 F) were divided into three groups

according to age. The first group consisted of subjects 18 to 30 years of age (young adults), the second group consisted of subjects 50 to 60 years of age (adults), and the third group consisted of subjects 61 to 70 years of age (young seniors). None of the participants reported having a history of neurological or psychological problems. In addition, all reported normal vision and hearing. All participants provided their written informed consent and were informed that they could discontinue participation at any time.

Materials

The tools used in this study for data collection and evaluation include:

Montreal Cognitive Assessment (MoCA)

Montreal Cognitive Assessment (MoCA; Nasreddine et al., 2005; Pirotta et al., 2015) is a brief cognitive screening tool used to detect mild cognitive impairment by assessing six domains: executive function, visuospatial abilities, short-term memory, language, attention, concentration and working memory, and temporal and spatial orientation. Unlike the Mini-Mental State Examination (MMSE), the MoCA includes tasks to assess visuospatial abilities, executive functions, and long-term memory, allowing for a more precise and comprehensive assessment of cognitive function. The test can be completed in about 10 minutes and has a maximum score of 30 points, with a score of 26 or higher considered normal. High sensitivity and specificity make it a valuable tool for detecting early cognitive decline associated with conditions such as mild cognitive impairment (MCI) and neurodegenerative diseases and for monitoring cognitive changes in clinical and research settings.

The other instruments used, Attentional Demands Task (AD-Task), Karolinska Sleep Diary (KSD), Pittsburgh Sleep Quality Index (PSQI), Karolinska Sleepiness Scale (KSS), Epworth Sleepiness Scale (ESS) and Global Vigor-Affect Scale, have been described in detail in previous sections and are not further elaborated here.

4.4 PROCEDURE

The experiment was conducted in the Laboratory of Cognitive and Behavioral Sciences at the University of L'Aquila. Study participants were selected based on a preliminary assessment with the Montreal Cognitive Assessment (MoCA) and the Pittsburgh Sleep Quality Index (PSQI). The MoCA, which is used to assess global cognitive functions (memory, attention, language, executive functions, and orientation), provided for the exclusion of participants with scores below 26, while the PSQI,

which measures subjective sleep quality, allowed the identification of any sleep problems that could affect cognitive performance. Only subjects who met the inclusion criteria were admitted to the experimental phase. In the experimental phase, participants would report to the laboratory at the predetermined time (in a time interval between 09:00 and 18:00). On arrival, once completed the Sleep Diary (KSD) for the assessment of sleep quality and duration of the previous night. Then, before performing the behavioral task, subjects were asked to complete questionnaires for the evaluation of momentary sleepiness (KSS) and daytime sleepiness (ESS) and those for the measurement of vigor and affect (G-VAS). After completing the questionnaires, the participants were taken to an adequately lit isolated room free of visual or auditory stimuli that could interfere with concentration. In the room, the participants sat in a chair in front of a desk, on which a laptop computer was placed to perform the AD-Task. The experimenter verbally explained the detailed instructions of the task, including the structure of the test, how to respond, and the expected pauses. After checking to see if the participants understood the instructions, the participant was left alone in the room to complete the test. When the experiment was completed, the participant was dismissed and the experiment ended. For performance assessment, accuracy was measured using the Signal Detection Theory (SDT; Stanislaw & Todorov, 1999), calculating the hit rate (H), false alarm rate (FA), and sensitivity (d'), with possible extreme value correction according to Macmillan & Kaplan (1991), while speed was assessed based on reaction times (RTs).

The investigation was approved by the Internal Review Board of the University of L'Aquila (#61/2021-2022) and was conducted according to the principles established in the Declaration of Helsinki.

4.5 DATA ANALYSIS

Descriptive statistics were conducted on the characteristics of the sample (age, gender, education, occupation). The two groups of older adults were evaluated and included in the sample based on the scores obtained on the MoCA questionnaire, to avoid the inclusion of subjects with mild cognitive impairment. Descriptive statistics were also calculated to assess the sleep quality of the participants, using the PSQI and the sleep diary KSD referring to the night before the experimental day, as well as the indices of sleepiness (KSS, ESS), affect, and vigor (G-VAS) evaluated immediately before performing the computerized task (AD-Task).

The performance achieved by the three groups in the AD-Task was compared using a repeated-measures ANOVA, with CONDITION (single demand/switching) and TYPE OF ATTENTIONAL DEMAND (selective/divided) entered as within-subject factors, and GROUP (1/2/3) entered as a

between-subjects factor, for all the variables investigated in terms of both execution speed (RTs) and performance (HIT RATE, d', and FA RATE).
Switching costs, calculated for each type of attentional demand, were compared using a repeated-measures ANOVA, with TYPE OF ATTENTIONAL DEMAND (selective/divided) entered as a within-subject factor, and GROUP (1,2,3) entered as a between-subjects factor. Post hoc comparisons were performed if statistical significance was reached ($p < .05$).

All analyses were conducted using the Jamovi program, and the level of statistical significance was set at $p < .05$.

4.6 RESULTS

Descriptives

The first group consisted of young adults (25 F, ages 21.1±2.47, min 19 max 29) with average schooling of 13.0±0 and composed of 100% students, the second group of adults (20 F, ages 55.7±3.05, min 50 max 60) with average schooling of 12.7±2.82 and consisting of 3. 2% students, 71% workers and 25.8% unemployed, and finally the third group of older young adults (19 F, mean age 65.6±2.85, min 61 max 70) with average schooling of 10.5±3.77 and equal employment of 26.7% workers, 30% unemployed and 43.3% retired. All participants reported good sleep quality in the past month, as assessed by the PSQI questionnaire (Group 1: 4.91±2.29; Group 2: 4.81±2.56; Group 3: 4.63±1. 73) and at night before the experimental day, as monitored by the KSD sleep diary, both in terms of quality (Group 1: 4.36±0.6; Group 2: 4.34±06; Group 3:4.25±05) and restorativeness (Group 1: 3.35±0.8; Group 2: 3.86±0.6; Group 3: 3.98±06). Regarding the indices evaluated at the time before completion of the AD-Task behavioral task, all participants reported low current sleepiness as measured by KSS (Group 1: 4.06±1.44; Group 2: 3.16±1.57; Group 3: 2.87±1.43) and normal daytime sleepiness as evaluated by ESS (Group 1: 6.24±3.36; Group 2: 5.00±3.33; Group 3: 4.33±3.33). For the indices of vigor and affect calculated based on scores at the G-VAS, the younger group showed a low level of physical efficiency (Group 1: 39.5±34.8) and affect (Group 1: 37.3±31.3) while the two groups of more adults showed a higher perception of vigor (Group 2: 67.9±19.7; Group 3: 72.8±14.2) and more affect (Group 2: 72.4±16.8; Group 3: 72.1±14.3). Subjects aged 50 to 70 years eligible to participate were selected from their MoCA score; All subjects with MoCA below 26 were excluded. The scores obtained by the participants included in the study (Group 2: 27.5±1.26; Group 2:

26.7±1.17) allowed us to exclude possible influences on performance at the AD-Task due to mild cognitive impairment.

Evaluation of differences in performance in different attentional components and switching between them as a function of age

The repeated-measures ANOVA conducted to assess potential differences in the ability to discriminate the target stimulus from the non-target stimulus (d') revealed a significant effect of GROUP ($F_{(2,90)}$ =40.9, η^2p =0.476, p<.001), indicating that advancing age is associated with a gradual decline in the ability to recognize the target stimulus while ignoring irrelevant stimuli. Post hoc comparisons showed a statistically significant difference for the young adult group, characterized by greater sensitivity in recognizing the target stimulus, both when compared to adults ($t_{(90.0)}$ =5.67, Mdif=0.966, p<.001) and to young older adults ($t_{(90.0)}$ =8.92, Mdif=1.533, p<.001). Additionally, adults and young older adults also differed significantly ($t_{(90.0)}$ =3.27, Mdif=0.567, p=.004), with the latter group exhibiting a lower ability to discriminate the target stimulus, see figure 4.1.

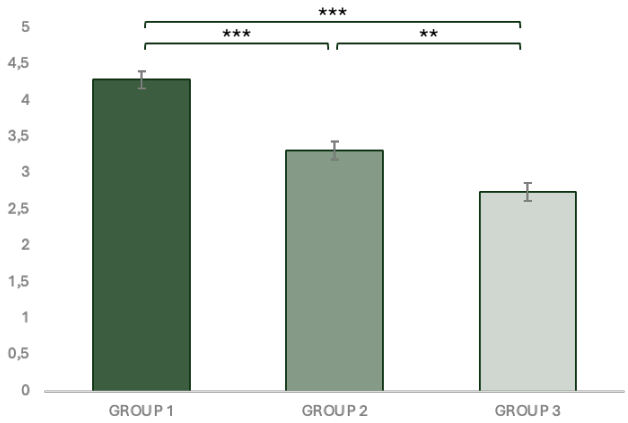


*Figure 4.1 Age-related decline in target discrimination sensitivity in different groups, *p<.05, ** p<01, ***p<.001*

Additionally, an interaction effect between CONDITION and TYPE OF ATTENTIONAL DEMAND was found ($F_{(1,90)}$=14.174, η^2p=0.136, p<.001), and post hoc comparisons show that selective attention predicts a better ability to discriminate the target stimulus than divided attention in both the single demand ($t_{(90.0)}$=10.56, Mdif=-0.950, p<.001) and switching ($t_{(90.0)}$=8.17, Mdif=-0.587, p<.001) conditions. Unlike divided attention, however, selective attention is affected by the switching condition, resulting in its impairment compared to the single demand ($t_{(90.0)}$ =-2.74, Mdif=-0.204, p=0.036) condition, as shown in Figure 4.2.

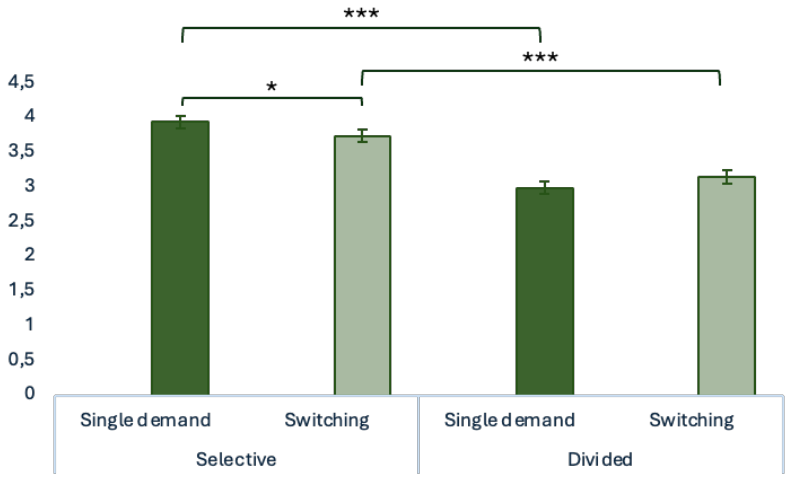


*Figure 4.2 - Comparison of Selective and Divided Attention on Target Discrimination in Single and Switching Demand Conditions, *p<.05, ** p<01, ***p<.001*

The repeated-measures ANOVA conducted to assess differences in performance (hit rate) on the AD-Task showed an interaction effect between TYPE OF ATTENTIONAL DEMAND and GROUP ($F_{(2,90)}$ =7.1790, η^2p =0.138, p=0.001). From the post hoc comparisons, it is possible to find that selective attention is markedly worse in the older youth group when compared with young adults ($t_{(90.0)}$ =5.751, Mdif=0.2522, p<.001) and adults aged 50 to 60 ($t_{(90.0)}$ =3.005, Mdif=0.1328, p=0.039). In contrast, divided attention tends to behave differently, deteriorating earlier than selective attention, as shown by the statistically significant difference between the first group and the second ($t_{(90.0)}$ =4.053, Mdif=0.2163, p=0.001) and third ($t_{(90.0)}$ =6.577, Mdif=0.3539, p<.001). Moreover, regarding the two attentional components investigated, the post-hoc results indicate that all three groups tend to achieve better performance, regardless of whether the task involves single demand or switching conditions when selective attention is involved compared to divided attention (Group 1: $t_{(90.0)}$ =4.587, Mdif=0.0973, p<.001 ; Group 2: $t_{(90.0)}$ =9.009, Mdif=0.1942, p<.001; Group 3: $t_{(90.0)}$ =9.083, Mdif=0.1990, p<.001), as shown in Figure 4.3.

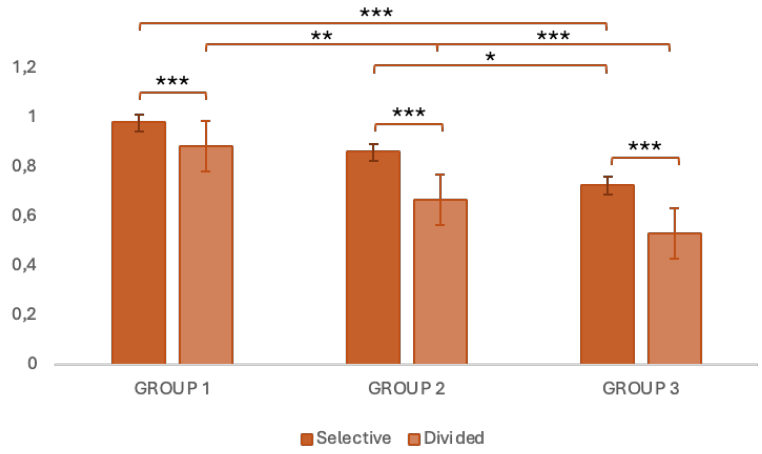


*Figure 4.3 – Group differences in selective vs. divided attention across task conditions, *p<.05, ** p<01, ***p<.001*

Repeated-measures ANOVA on commissioning errors (FA RATE) showed a between-subjects effect due to GROUP ($F_{(2,90)}$=7.09, η^2p = 0.136, p =0.001), and post hoc comparisons show that the youth group tends to inhibit responses to irrelevant stimuli better, making fewer errors than both the adult ($t_{(90)}$ = -2.925, Mdif = -0.01, p =0.012) and older youth ($t_{(90)}$ = -3.498, Mdif = -0.01, p =0.002) groups, see Figure 4.4.

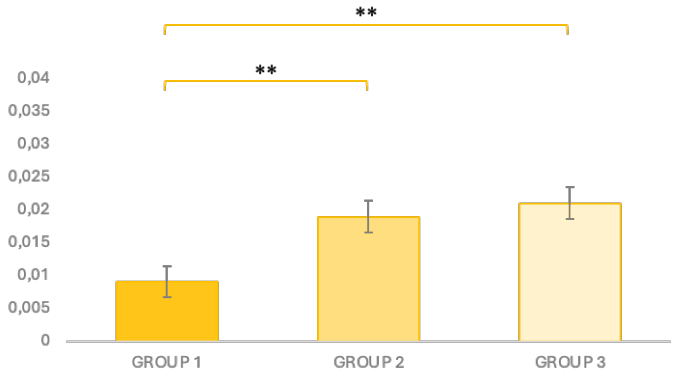


*Figure 4.4 - Group effect on commissioning errors (FA Rate), *p<.05, ** p<01, ***p<.001*

Moreover, a significant interaction effect was observed between CONDITION and TYPE OF ATTENTIONAL DEMAND ($F_{(1,90)}$ =5.4409, η^2p = 0.057, p =0.022), where post-hoc analyses revealed a statistically significant difference exclusively in commission errors. Specifically, commission errors were higher during tasks requiring selective attention compared to those involving divided attention, but only under switching conditions ($t_{(90)}$ = 3.023, Mdif = 0.006, p =0.017). See Figure 4.5 for more details.

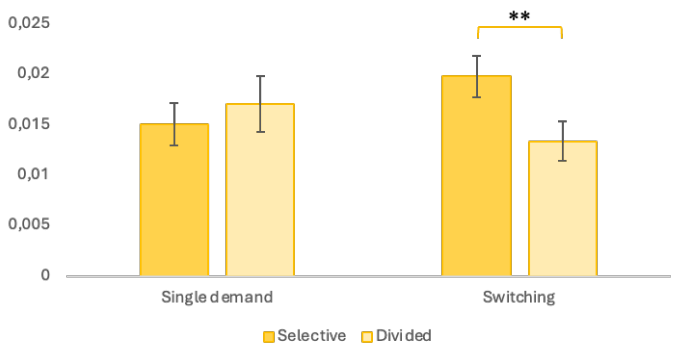


*Figure 4.5 - Interaction Between Condition and Attentional Demand on Commission Errors, *p<.05, ** p<01, ***p<.001*

Repeated-measures ANOVA conducted on reaction times in performing the different components of the AD-Task, for between-subjects effects showed a GROUP effect ($F_{(2,90)}$=5.36, η^2p = 0.106, p < .001), and post hoc comparisons show that younger subjects tended to have lower reaction times only than the older group ($t_{(90)}$ = -3.182, Mdif = -97.2, p = 0.006), as shown in Figure 4.6.

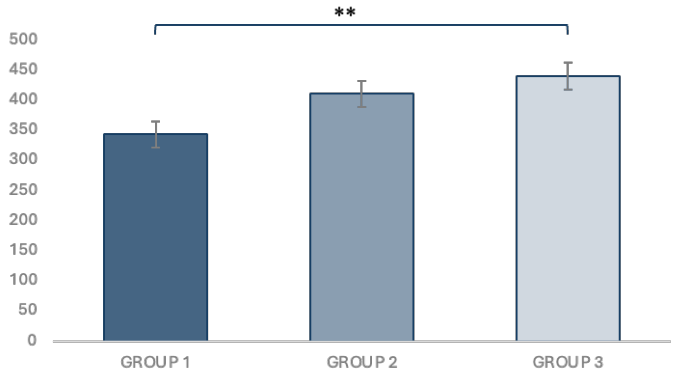


*Figure 4.6 - Effect of the group on reaction times in the AD-Task, *p<.05, ** p<01, ***p<.001*

In addition, a main effect of TYPE OF ATTENTIONAL DEMAND ($F_{(1,90)}$=783.208, η^2p = 0.897, p < .001) has been shown, and post hoc findings indicate that, in general, regardless of age and single or switching demand status, subjects tend to show faster reaction times in selective attention than in divided attention ($t_{(90)}$ = -28.0, Mdif = -173, p <.001), as shown in Figure 4.7.

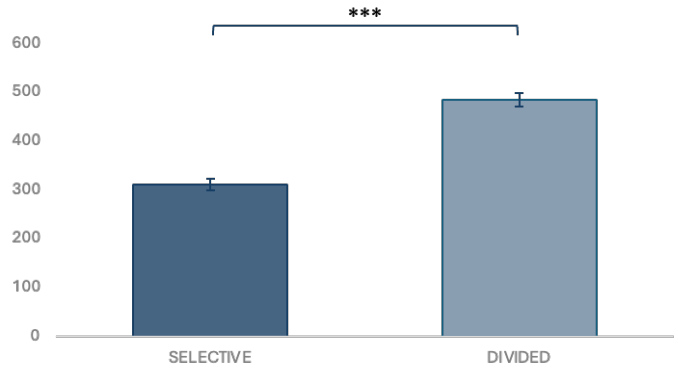


*Figure 4.7 - Effect of attentional demand on speed (RTs), *p<.05, ** p<01, ***p<.001*

Repeated-measures ANOVA on switching costs, calculated as the difference between reaction times in the two different attentional components in the switching condition subtracted from those obtained in the same attentional demands in a single demand, showed a main effect of TYPE OF ATTENTION ($F_{(1,90)} = 6.453$, $\eta^2p = 0.067$, $p = 0.013$), independent of group. Post hoc comparisons show that switching tends to burden selective attention more than divided attention ($t_{(90)} = 2.54$, Mdif = 24.9, $p = 0.013$). See Figure 4.8 for more details.

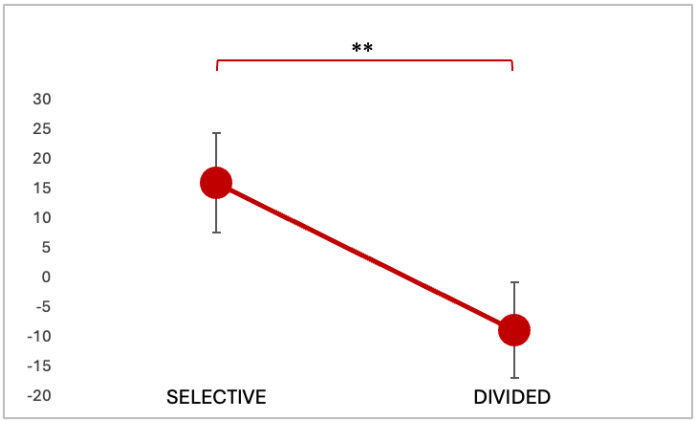


*Figure 4.8 - Selective vs. divided attention: Impact on switching costs, *p<.05, ** p<01, ***p<.001*

4.7 DISCUSSION

This study aimed to gain further insight into the evolution of attention and its subcomponents over the life span, adding information on the switching between selective and divided attention using the new Attentional Demands Task (AD-Task). For this purpose, a sample of 93 subjects aged between 18 and 70 years was examined, divided into three groups the first group consisted of subjects aged between 18 and 30 years (young adults), the second group of subjects aged between 50 and 60 years

(adults) and the third group of subjects aged between 61 and 70 years (young elderly). Cognitively healthy subjects were considered based on their scores on the Montreal Cognitive Assessment (MoCA; Nasreddine et al., 2005; Pirotta et al., 2015), to avoid the possible effects on performance on the attentional task being mediated by cognitive impairment. Muir and colleagues found that elderly people with mild cognitive impairment (MCI) may show difficulties, especially in dual tasks (Muir et al., 2012).

From the results obtained, it was possible to corroborate the hypothesis of an age-dependent change in processes, with clear differences between young people, adults, and the young elderly.

The results of this work show clear differences in overall performance in attention tasks between selective and divided attention, particularly with advancing age. Indeed, while selective attention tends to be better preserved as we age, divided attention begins to show earlier deterioration, often evident as early as around 50 years of age, which steadily worsens given the difference even between the two groups of more adults. This distinction is crucial for understanding cognitive aging and its implications for daily functioning. Selective attention, in which one is required to focus on specific stimuli while ignoring others, appears to decline later in life than divided attention. An explanation for this longer retention could be that selective attention is driven by distinct subsystems capable of functioning independently and may maintain some abilities despite age-related cognitive changes (McAvinue et al., 2012). Furthermore, another finding supporting this result comes from the consideration that divided attention is more complex, requires a greater number of processing operations, and thus appears to be more prone to age-related declines (Madden and Pluden, 1993).

Advancing age, in contrast to overall performance, causes a gradual decline in the ability to discriminate the target stimulus in both attentional demands investigated (Simon et al., 2023; Reuter et al., 2019). This decline may be explained by the deterioration of the ability to suppress irrelevant information which, although documented in the literature at older ages (Lee et al., 2014), in this work appears to begin as early as age 50 and then decline further in older subjects. Indeed, age-related declines in performance in attentional tasks are predominantly related to deficiencies in inhibitory control (Walker et al., 2022). Typically, experiments investigating inhibitory control as a function of age (Banich et al., 2000; Bugg et al., 2007; Laguë-Beauvais et al., 2013; Mayas et al., 2012; Milham et al., 2002; Spieler et al., 1996) employ paradigms that require participants to respond to the relevant feature while simultaneously inhibiting the irrelevant feature, and this has proven increasingly difficult as age increases. In these protocols, the ability to inhibit the processing of the irrelevant

feature is assessed by examining the accuracy or reaction time (RT) to the target stimulus, resulting in lower accuracy and/or slower RTs that could indicate higher distraction rates and reduced inhibitory control. However, limiting oneself to these two indices could make it difficult to understand whether the decline in performance is due to a difficulty of the attentional system in facilitating target processing, distraction inhibition or a decline in performance in older adults is related to a deficit in both processes (Walker et al., 2022). In this case, the target stimulus discrimination index provides a more precise measure of what impairs performance in the elderly, allowing the decline to be attributed to an inefficiency of inhibitory control rather than a decline in processing. This is also confirmed by the increase in errors of commission with increasing age, which documents a significant difficulty in interrupting the response to nontarget stimuli (Bloemendaal, 2016). Moreover, commission errors appear to increase when investigated in switching, showing that performance can be impaired as soon as the required attentional load increases (Liebherr et al., 2019; Owsley, 2011). Differences in inhibitory control so important between young and old, according to Amer et al. (2016), can be explained by the interaction between two networks proposed to control externally directed attention (dorsal attention network; DAN) and internally focused attention (default mode network; DMN). Distraction control and attention are mainly regulated by a competitive relationship between the Dorsal Attention Network (DAN) and the Default Mode Network (DMN; Corbetta and Shulman, 2002; Fox et al., 2005). The Dorsal Attention Network, involved in the top-down selection of relevant goal-based stimuli, comprises the dorsolateral prefrontal cortex (dlPFC) and the intraparietal sulcus (IPS; Corbetta et al., 2008). The default mode network, deactivated during outwardly oriented tasks, supports processes such as autobiographical memory, including the medial prefrontal cortex (mPFC) and posterior cingulate cortex (pCC; Raichle et al., 2001; Andrews-Hanna et al., 2014). For both the young and the old, the extent of DAN-DMN anticorrelation is associated with reduced distractions (Kelly et al., 2008; Cole et al., 2012). In Amer and colleagues' (2016) study, however, activation of a common set of frontal and insular control regions during task performance was associated with opposite patterns of network interaction and distractibility across age groups. For older adults, recruitment of these regions was associated with higher DAN-DMN anticorrelation and lower distraction (better performance). For younger adults, it was associated with decreased DAN-DMN anticorrelation and higher distraction and thus worse performance (Amer et al., 2016).

With advancing age, consistent with findings in the literature, processing speed also begins to deteriorate with subjects over the age of 60 showing a progressive slowdown in processing complex tasks (De Fockert et al., 2009). From the age of 60, a slowdown in stimulus-response speed is observed that can be attributed to deficits in attention allocation that impair the ability to produce

rapid responses, especially when participants are subjected to dual-task conditions (Godefroy et al., 2010). This suggests that the cognitive load imposed by additional tasks slows reaction times and worsens performance in the elderly. In addition to cognitive factors, physiological changes associated with ageing may explain the deterioration in the speed of response to stimuli. The natural ageing process leads to a decline in neuromotor function, which is reflected in slower reaction times and reduced motor reactivity (Morrison & Newell, 2019). This decline is further exacerbated by factors such as visual processing speed, which is particularly affected by age, especially in the presence of attention demands (Owsley, 2011).

These phenomena can be explained at the neurophysiological level, Cona and colleagues (2013) point out that longer reaction times and lower accuracy in the elderly compared to the young may be related to a slowdown in cognitive processing (Salthouse,1996), evidenced by the delay in latencies of ERP components N2 and P3a, reflecting a slower response to target stimuli and a difficulty in shifting attention to the next stimulus (Cona et al.,2013). In their study, the greater amplitudes of the N2 and P3a components for targets in the elderly suggested a greater use of attentional resources, but their absence for the next stimulus explained the difficulty in redirecting attention. Furthermore, as already discussed, reduced inhibitory capacity (Hasher et al., 1991; Kok et al., 2000) increases the interference of irrelevant stimuli, contributing to errors and delays further exacerbated by motor decline (Cona et al., 2013).

Some results of this study confirm what has already emerged in the previous chapters. First, selective attention always predicts better performance and shorter reaction times than divided attention, regardless of age. Also, in general, selective attention, while involving a lower cognitive load than divided attention (Madden and Plude, 1993), is more sensitive to switching costs, with a slowdown in response time to the target stimulus when affected by switching with divided attention. The latter, on the other hand, shows a tendency, albeit not significant, to improve under switching conditions with a simpler attentional component. These findings are consistent with previous studies suggesting that tackling simpler tasks before complex ones can reduce cognitive overload, improving planning and overall attentional capacity (Richter & Yeung, 2015; Wearden et al., 2010). These effects were already discussed in depth in Study 1 and are now confirmed in this study, which includes a larger and more generalized population, strengthening the evidence supporting the observed dynamics.

The lack of findings on deterioration in switching performance could be explained by the consideration that older individuals, despite cognitive decline, tend to use compensatory mechanisms,

including increased reliance on executive control to support memory and maintain good performance (Bouazzaoui et al., 2014; Bouazzaoui et al., 2013).

In support of what has been discussed here, aging leads to a marked reduction in inhibitory control, cognitive flexibility, and processing speed due to alterations in the prefrontal cortex, white matter, and brain activity (Lacreuse et al., 2020; Phillips et al., 2019). Changes in the prefrontal cortex (PFC), both functional and structural, negatively affect attention, working memory, and executive control (Morrison & Baxter, 2012). These changes include synaptic alterations, difficulties in suppressing distractions (Chadick et al., 2014), and inefficiencies in cognitive resource management as workload increases (Agbangla et al., 2019). The elderly often enact compensatory mechanisms with increased PFC recruitment, documented by alterations in the hemodynamic response (Zhu et al., 2013; Hamasaki et al., 2018), improving performance in some contexts (Ryan et al., 2012; Rieck et al., 2017), but such strategies do not always prove sufficient. Furthermore, reduced white matter integrity worsens brain efficiency and contributes to cognitive decline (Zhu et al., 2013).

In general, the aging process is associated with a significant deterioration in attentional capacity and performance, particularly in tasks that require selective and divided attention (Murman,2015).

4.8 CONCLUSIONS

This study provides important evidence on the evolution of attention in aging. The use of the Attentional Demands Task (AD-Task) also shows promise in this analysis as it allows the integration of the study of selective, divided attention, and switching ability, avoiding using long batteries to investigate the different cognitive aspects individually. Furthermore, the presence of the same stimuli for the two different attention components significantly reduces the possibility that the differences observed between selective and divided attention are attributable to different stimulus configurations, thus ensuring a more accurate and reliable measurement of attentional abilities. Among the main findings highlighted in this work, it is important to emphasize the early decline in divided attention present from the age of 50 and the selective attention being more resistant but sensitive to switching costs, which remains constant throughout life. The study supports the finding that attentional deterioration in aging is due to a reduction in inhibitory control efficiency rather than a decrease in processing capacity. The absence of deterioration in switching between the two attentional components is probably related to compensatory mechanisms adopted to maintain acceptable performance. The use of this innovative approach allows for an integrated and detailed view of

attentional decline trajectories, with implications for early and personalized interventions aimed at preserving cognitive abilities.

4.9 LIMITATIONS

Despite the attention paid to detail, the study is not without its limitations such as the sample size, which, although well stratified, is not sufficient to guarantee full generalizability. There is no coverage of certain age groups (31-49 years), creating a gap in the data. Furthermore, potential confounding effects related to socio-economic or general health factors were not explored in detail.

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GENERAL CONCLUSIONS

In this work, we set out to explore two different attentional processes and their evolution under switching conditions in different contexts. There is no data in the literature on the switching between two components of the same cognitive domain and the resulting cognitive cost. We attempted to fill these gaps by creating the Attentional Demands Task (AD-Task), a tool capable of studying selective and divided attention while also allowing us to assess the costs of switching between the two. Before it could be used in the contexts of interest, the new tool was created and validated. The AD-Task proved effective in distinctly measuring selective and divided attention, as demonstrated by high correlations with commonly used measures, in particular, the Oddball paradigm for selective attention and the Dual-Task for divided attention. The results showed that divided attention results in slower reaction times and lower accuracy than selective attention. A plausible explanation was related to the saturation of available cognitive resources when simultaneous processes are required on stimuli of the same sensory modality. Since divided attention involves a higher cognitive cost, this causes competition for perceptual resources, resulting in reduced processing efficiency. A novel result derived from the possibility of studying the switching costs of alternating between two attentional components and, thus, the cognitive impact of alternating between selective and divided attention tasks. Higher switching costs emerged in selective attention tasks, indicating that switching to a simpler attentional mode after a more complex one still requires significant reorganization of cognitive resources.

The central focus of this work lay in the desire to study attentional processes and the switching between them in the context of circadian fluctuations, sleep deprivation, and life span.

To proceed towards this goal, given the volume of variables that had to be assessed in the different samples of interest, and to avoid excessively long questionnaire batteries, a single questionnaire was validated to assess sleep quality, chronotype, and mood. For this purpose, the Revised Sleep, Circadian Rhythms, and Mood Questionnaire (rSCRAM) was validated, which compared to the original Sleep, Circadian Rhythms, and Mood Questionnaire (SCRAM) proposed by Byrne et al. in 2017, also includes four questions on anxiety. The questionnaire is thus able to measure sleep quality, chronotype, depressed mood, and anxiety. The questionnaire reported good results in reliability and internal consistency and high correlations with standard instruments for measuring sleep, chronotype, and mood, confirming its accuracy.

Drawing general conclusions from this series of studies, circadian fluctuations, and total sleep deprivation can be considered to significantly influence attention. The results of this study document that selective attention is most influenced by circadian rhythms. It is affected by fatigue accumulated during the day by manifesting a significant decline in performance in the afternoon. Divided attention, on the other hand, is less flexible to such aspects and is more stable, with a slight postprandial decline. Attentional performance thus follows a clear circadian pattern, with selective being more affected by temporal fluctuations than divided. Furthermore, about switching between attentional components, the most novel and surprising finding of this work, emerged that sleep deprivation tends to amplify the cognitive cost of switching between the two types of attention, with a significant slowdown in reaction time and a clear decrease in accuracy, attributable to an impairment of the prefrontal cortex and executive processes.

Finally, it is possible to highlight that a further modulation of attention and of the ability to switch between selective and divided attention is linked to advancing age. A progressive decline in attentional capacity is observed, with a more precocious and marked worsening of divided attention concerning selective attention, attributable to the greater cognitive load required by the former. Difficulties increase further in tasks requiring inhibition of irrelevant stimuli and in cognitive costs associated with switching, partly explained by a deterioration of the prefrontal cortex and brain connectivity.

These results, in general, emphasize the importance of considering both age-related neurophysiological processes and circadian and homeostatic rhythms in the management of attentional abilities.

Limitations of the study and prospects

Despite the remarkable results obtained, some limitations should be considered in this study that could be addressed in future research. First, the sample size could be expanded to represent a larger population, including participants with different characteristics (people with extreme chronotypes, such as morning and evening chronotypes, or individuals with sleep disturbances), with the goal of better understanding individual variations in attentional performance. Further sample improvement could involve the inclusion of a child population in order to assess the evolution of attention from children to the elderly. Limitations certainly include the absence of neurophysiological measures, such as electroencephalogram (EEG) or functional magnetic resonance imaging (fMRI), which are

useful for understanding neural processes and prefrontal cortex activation in selective, divided, and switching attention processes in the different contexts studied. EEG could be useful for examining changes in P3 and N2 components associated with attentional resource allocation and inhibitory control, respectively, offering a more objective measure of the impact of aging, sleep deprivation, and circadian rhythms. Another issue to consider is the lack of follow-up to verify any long-term effects of sleep deprivation on attentional capacity. Although the study showed the immediate effects of total deprivation, it would be interesting to assess whether and how these effects accumulate over time with repeated partial deprivation, which is more common in daily life. Another issue to consider is the lack of follow-up to check for any long-term effects of sleep deprivation on attentional capacity. Although the study clearly showed the immediate effects of total deprivation, it would be interesting to assess whether and how these effects accumulate over time with repeated partial deprivation, which is more common in daily life. Another future perspective again related to the context of sleep deprivation could be the evaluation of recovery strategies such as short naps (power naps) or cognitive stimulation techniques that could mitigate the negative effects on attentional performance. In addition, noninvasive brain stimulation, such as transcranial direct current stimulation (tDCS), could also be integrated with the use of AD-Task to assess whether increased prefrontal activation could compensate for attentional deficits resulting from sleep deprivation.

In conclusion, despite the large size, the integration of larger samples, neurophysiological measures, and cognitive retrieval methodologies could provide a more comprehensive view of the mechanisms underlying changes across the lifespan, fluctuations in the impact of sleep deprivation on attentional processes.