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Task absorption and job demands: exploring task performance through neural and pupillary data

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Abstract: This study investigates the relationship between task characteristics, episodic absorption, and performance, based on the job demands-resources theory. Given that modern tasks often require processing substantial data and making real-time decisions, they demand significant attentional focus. Absorption, defined as a temporary state of deep attentional engagement, is thought to enhance task performance and efficiency. To explore this, we conducted an n-back task with participants, a task that requires focused, voluntary attentional control. Physiological and neural data were collected, with a particular focus on pupillary dynamics and the P300 wave, an event-related potential marker associated with attentional and cognitive processes. The study aimed to test three hypotheses: (a) absorption, as a temporary cognitive state, enhances performance and task efficiency; (b) absorption episodes are linked to activation in the P300 wave and pupillary responses; and (c) task demands and resources significantly impact the occurrence of absorption episodes. Specifically, we expected high job demands coupled with high resources to result in frequent absorption episodes, while high demands with low resources and low demands with high resources would lead to fewer episodes. Findings from this research may provide insights into how task design and resource allocation influence cognitive engagement, shedding light on optimal work conditions that foster absorption and improve performance. This research has potential applications in designing tasks and environments that promote sustained attentional engagement, ultimately contributing to more effective, resource-aligned organizational practices.

Keywords: Absorption; Task performance; Job demands; Resources; Episodes

1.0 BACKGROUND

With technology increasingly automating routine tasks, human operators must now tackle more cognitively demanding aspects of their work, necessitating extensive information processing (Demerouti, 2020). This shift highlights the importance of maintaining a sustained focus on time-sensitive tasks, particularly for employees in administrative roles. Task characteristics in these work environments can have either a positive or negative impact on an individual's absorption, productivity, and performance (Tadić et al., 2014; Bakker & Demerouti, 2017).

The Episodic Process Model (EPM) similarly suggests that engagement and attention are crucial for optimal performance during task episodes (Beal et al., 2005).

In today's dynamic work landscape, technological advances bring new opportunities but also substantial challenges, as employees must balance demands with constant digital distractions. With over 30 percent of the global population actively using social media, maintaining focus on work tasks has become a considerable challenge (Schwab, 2017). Although work experiences are increasingly episodic — structured around cohesive time segments aimed at achieving objectives (Weiss et al., 2004) — not all tasks require deep absorption. For example, tasks like writing evaluations may not need sustained focus, while others, such as critical decision-making in supply chain management, cannot afford lapses in attention.

From a neuroscience perspective, tasks that activate reward systems enhance task-focused behavior, often accompanied by strong absorption and intrinsic motivation (Berridge et al., 2009). Despite its significance, the relationship between task characteristics and episodic absorption remains underexplored. To address this gap, we will examine an n-back task under different conditions suggested by the Job Demands-Resources (JD-R) Theory (Bakker & Demerouti, 2017).

Using eye-tracking and EEG, this experimental design will analyze the effects of episodic absorption on task performance and explore the role of task characteristics. By integrating neurocognitive insights, this study aims to advance the understanding of absorption in work contexts, offering practical applications for improving focus and productivity in realistic work environments (Barker, 1968).

1.1 Literature review

1.1.1 Episodic absorption

We will begin by clarifying the concept of absorption, which is a shared dimension of both flow and engagement. In both cases, absorption is linked to cognitive aspects associated with sustained attention. As a dimension of engagement, absorption refers to a positive mental state in which individuals are so immersed in their work that time seems to pass quickly (Bakker et al., 2008). Research over the past two decades has confirmed Kahn's (1990) idea that absorption fluctuates with the natural ebbs and flows of work, varying not only from day to day but also within the same day or even during different work episodes (Bakker & Demerouti, 2017).

In the context of flow, absorption occurs when people are fully engaged in a task, reaching a level of focus so intense that they have minimal self-reflection and limited awareness of their surroundings. This state, characterized by strong concentration and immersion, is often described as "flow" (Csikszentmihalyi & Csikszentmihalyi, 1988). There are key similarities between flow and engagement absorption: both involve specific episodes in which individuals are fully immersed, with the ability to block out environmental distractions. In such states, employees enter a level of focused attention where self-reflection is minimized, and they are scarcely aware of their surroundings (Bridgeman, 1992; Van der Linden et al., 2020). This experience is commonly referred to as absorption (Hopstaken et al., 2014).

According to Van der Linden et al. (2020), key aspects of the absorption state include: (1) Fusion of action and awareness, where tasks are executed automatically; (2) High focus/concentration, indicating deep engagement; and (3) Reduced self-reflection/absence of worry, as concentration lowers self-awareness and distractors are ignored. Absorption is associated with several positive outcomes: (1) Improved performance, as absorbed individuals tend to achieve higher productivity (Bakker & Demerouti, 2017); (2) Enhanced creativity, as immersion fosters creative problem-solving (Csikszentmihalyi & Csikszentmihalyi, 1988); (3) Increased well-being, linked to greater happiness, satisfaction, and reduced stress; and (4) Sustained engagement, as frequent absorption episodes encourage ongoing commitment to activities (Nakamura & Csikszentmihalyi, 2014).

Lupano Perugini and Waisman (2018) noted that individuals experiencing states of absorption at work dedicate substantial attentional resources to their tasks, often using large amounts of energy. This focus enables them to overcome workplace challenges, resulting in greater resilience and higher performance, which benefits both the individual and the organization. Salanova et al. (2006) highlighted that research on flow has primarily focused on identifying the elements and conditions that facilitate this state in workers. When employees experience absorption and focus on their tasks, they tend to have positive work experiences and may frequently enter states of flow.

However, there are still no established protocols for promoting flow in organizations (Sánchez et al., 2008). Sánchez et al. (2008) suggested that by understanding the components and antecedents of flow, organizations can develop tools and methods to foster it in the workplace.

Not everyone, however, can easily reach states of absorption. Factors like higher educational attainment and intrinsically rewarding jobs (e.g., managerial roles or teaching) are associated with higher scores in flow dimensions compared to roles with lower intrinsic rewards, such as office or production work (Sánchez et al., 2008). Employees who exhibit high energy and identify strongly with their work also tend to build personal resources over time, leading to better task performance (Hopstaken et al., 2014; Bakker & Demerouti, 2017). Neuroscientific research has shown that tasks capable of activating reward systems energize task-oriented behavior and are often accompanied by strong absorption and intrinsic motivation (Berridge et al., 2009).

The literature identifies several factors that promote task absorption: (1) Skill-task balance—when the task difficulty aligns well with an individual's skill level (Csikszentmihalyi & Csikszentmihalyi, 1988); (2) Clear goals—well-defined objectives provide purpose and facilitate focus (Locke & Latham, 1991); (3) Immediate feedback—timely feedback keeps individuals engaged (Csikszentmihalyi & Csikszentmihalyi, 1988); and (4) Autonomy—having control over one's tasks enhances absorption (Deci & Ryan, 1985).

However, absorption's largely subjective nature and reliance on self-reported methods limit the construct's validity, particularly in differentiating it from other states like motivation or focused performance (Kee & Wang, 2007; Sheldon et al., 2014). Though absorption is a cognitive component of both flow and engagement, engagement is more sustained over time, whereas flow is episodic. The distinction between absorption and related mental states, such as selective attention or concentration, remains unclear (Kee & Wang, 2007; Sheldon et al., 2021).

1.1.2 Job demands and resources theory

In a state of absorption, task characteristics have a significant influence on performance. Research indicates that when tasks are too easy, it is unlikely that individuals will reach a state of immersion; instead, they may experience boredom and mind wandering. Conversely, tasks that are overly demanding or difficult often lead to stress and a diminished sense of control (Keller, 2016). Both boredom and stress can disrupt flow experiences, while a moderate level of arousal is considered optimal for achieving a state of flow (Pfeiffer et al., 2014; Tozman et al., 2015).

The Job Demands-Resources (JD-R) theory, proposed by Demerouti et al. (2001), provides a framework for understanding various mental states in the workplace. According to JD-R theory, job demands and resources initiate two distinct processes: strain and motivation (Tadić et al., 2014; Bakker & Demerouti, 2017). Job resources—encompassing physical, psychological, social, and organizational aspects of work—help individuals achieve their goals and foster personal growth, learning, and development (Bakker & Demerouti, 2017). In contrast, job demands—such as high work pressure, role overload, emotional demands, and poor environmental conditions—require sustained effort and are associated with physiological and psychological costs (Bakker & Demerouti, 2017).

The literature on cognitive effort also sheds light on this process. Mental fatigue arises when cognitive resources are depleted through sustained mental tasks, signaling a higher risk of performance errors (Veldhuizen et al., 2003). Typically, daily work activities can tire individuals, but they usually have enough energy to meet task demands. However, under high mental workload and fatigue, such as at the end of a workday, additional mental effort is required to maintain performance, mobilizing extra energy to counterbalance the fatigue (Hockey et al., 1986; Hockey, 1997; Gaillard, 2001).

1.1.3 Pupillary dynamics and the P300 wave

During attention-demanding cognitive tasks, certain brain regions consistently increase in activity, while others decrease. Absorption is a cognitive process that adapts to environmental demands and fluctuates over time. Thiele et al.'s research (2002) highlights those changes in cognitive processing that influence pupil activity, potentially signaling neural dynamics related to attention states.

Pupil size fluctuations are linked to norepinephrine release, providing a time-sensitive indicator of attention shifts (Joshi et al., 2015). Additionally, gaze direction and blink rate offer insights into attention focus, revealing how individuals shift between internal thoughts and external stimuli (Wohltjen & Wheatley, 2024). Recent, though inconclusive, evidence suggests that attention span may also correlate with pupil size (Mathôt, 2020). Pupil responses may functionally adjust vision to meet different processing demands, whether focusing on narrow or wide spans of information (Mathôt, 2020).

Several studies in cognitive neuroscience demonstrate a relationship between pupil diameter and mental effort (Beatty & Lucero-Wagoner, 2000; Just et al., 2003). Other research links pupil diameter to task performance (Schneider & Fisk, 1982; Tsukahara et al., 2016), with pupil size serving as a proxy for cognitive effort during tasks (Ares et al., 2012; Wyble et al., 2012; Yang & Yang, 2016; Krucien et al., 2017; Astudillo et al., 2018). In tasks involving updating, shifting, and inhibition, pupil diameter aligns with changes in cognitive demand and, in some cases, predicts improved task performance. However, the literature has yet to clarify the practical relationship between pupil dynamics and the absorption of episodic or sustained tasks. **Figure 1** shows a constricted pupil and a dilated pupil.

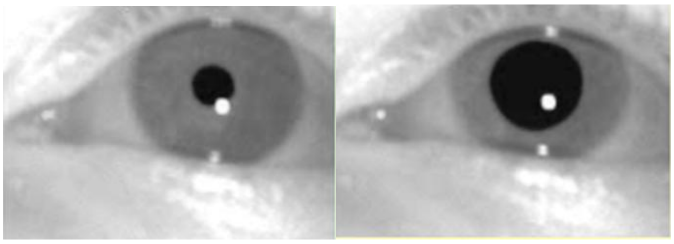


Figure 1. Constricted and dilated pupils (Juyumaya et al., 2024).

Studies indicate that a tendency to become fully absorbed in one's work, akin to flow states, is associated with individual differences in dopaminergic system sensitivity—the brain's behavioral reward system (Van der Linden et al., 2020). Additionally, the P300 event-related potential (ERP) is associated with task engagement and access to memory systems (Polich, 2007). The P300 component, primarily recorded in the frontocentral region, emerges in response to the attentional demands of a task (Posner & Petersen, 1990; Pardo et al., 1991; Posner & Driver, 1992; Polich, 2007) and is linked to the frontal dopaminergic network (Polich, 2007). Meanwhile, the P3b component, observed in parietal regions, is associated with attention and cognitive processes, such as working memory updates (Donchin & Coles, 1988). **Figure 2** shows the neural networks underlying attention.

The P300 serves as a strategic indicator for processing new information, prompting individuals to adjust their strategies in response to current task demands (Donchin, 1981). Task-focused attention and goal-directed behavior are typically associated with increased activity in the task-positive network and decreased activity in the task-negative network (Cabeza & Nyberg, 2000; Corbetta et al., 2008; Raichle, 2009).

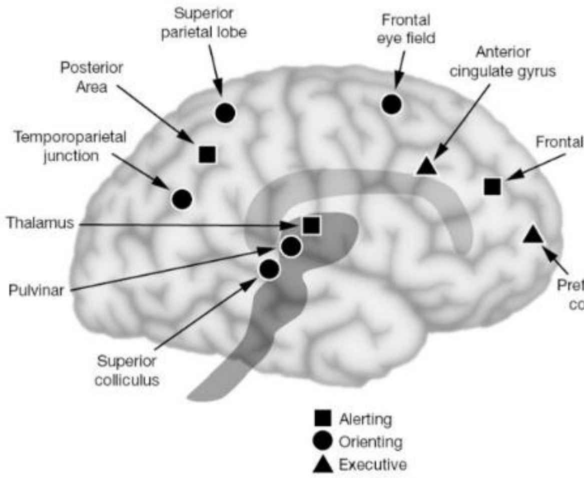


Figure 2. Neural networks underlying attention (Munakata et al., 2004).

In this context, an employee's absorption level can be analyzed by observing the behavior of the P300 wave, which reflects cortical responsiveness to task-relevant stimuli driven by norepinephrine release from the locus coeruleus (Nieuwnhuis et al., 2005). Norepinephrine acts as a signal to focus attention on the environment (Bouret & Sara, 2004). Thus, the P300 wave serves as a neural correlate of absorption, revealing cognitive effort in response to varying job demands and resources during task performance. **Figure 3** shows the P300 wave (positive activity at 300 milliseconds) caused by the presence of a novel stimulus.

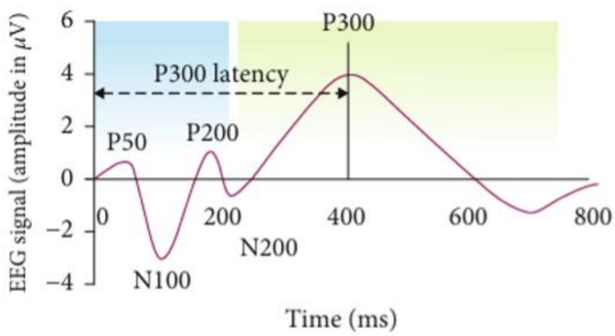


Figure 3. P300 wave caused by the presence of a novel stimulus (Olichney et al., 2022).

1.2 Methods

A between-subjects experimental design will be employed, with participants randomly assigned to one of four conditions to explore different combinations of labor demand and resources: (1) Low labor demand/Low labor resource; (2) Low labor demand/High labor resource; (3) High labor demand/Low labor resource; and (4) High labor demand/High labor resource.

The task will be programmed in Python and will be based on the n-back task, a continuous interactive activity used to measure and train working memory, fluid intelligence, and attention (Hirst & Kalmar, 1987). This task can be diversified, allowing for adjustments to the stimuli to maintain novelty for participants.

In this study, we will modify the traditional n-back task into a calendar scheduling task. Participants will be asked to schedule meetings based on a pre-presented weekly calendar. The labor demand is defined by the amount of information participants must retain to schedule meetings (i.e., how far back in time they need to recall information), while the labor resource is determined by the viewing time allotted for the schedule (either two or five seconds). Participants will then fill in the blanks to schedule meetings, ensuring no overlap with existing appointments (Bluedorn et al., 1992; Vail & Bluedorm, 2003; Kühnel et al., 2011; Krucien et al., 2017).

Task performance will be evaluated based on two criteria: (1) whether participants successfully scheduled meetings without overlaps, and (2) whether they completed the task within the provided time frame. **Figure 4** shows the four conditions that will be programmed and randomly distributed among four groups of individuals.

Participants

Based on the average sample size of 57 investigations using Electroencephalography (EEG) during tasks (Hinojosa et al., 2015), 23 workers will be recruited to participate in a meeting session scheduling task. An additional 5 subjects will be recruited as part of the experiment's piloting. Adding a total of 28 participants. I will follow a repeated measures design. All participants will be exposed to the entire experimental condition.

The Inclusion criteria is people over 18 years of age, with more than 2 years of work experience and with a current activity related to administrative and managerial functions.

Exclusion criteria

We consider the following exclusion criteria:

a) Pupillary diameter: People with vision problems or who need to wear glasses during the task. The use of glasses can interfere with measurement devices due to the glare reflected in the corrective lenses, which is visible on a monitor. In addition, because some neuropsychological diagnoses and substance abuse (e.g., caffeine, alcohol, cannabis) interfere with the measurement of brain waves and pupillary dilation, subjects with neuropsychological diagnoses and a history of substance abuse will be excluded.

b) Brain waves: Individuals with clinical diagnoses of neurodevelopmental type, such as Attention Deficit Disorder (ADHD), Autism Spectrum Disorder (ASD), and others, in addition to the substances mentioned in the previous section. Along with informed consent, participants must complete a form declaring these aspects.

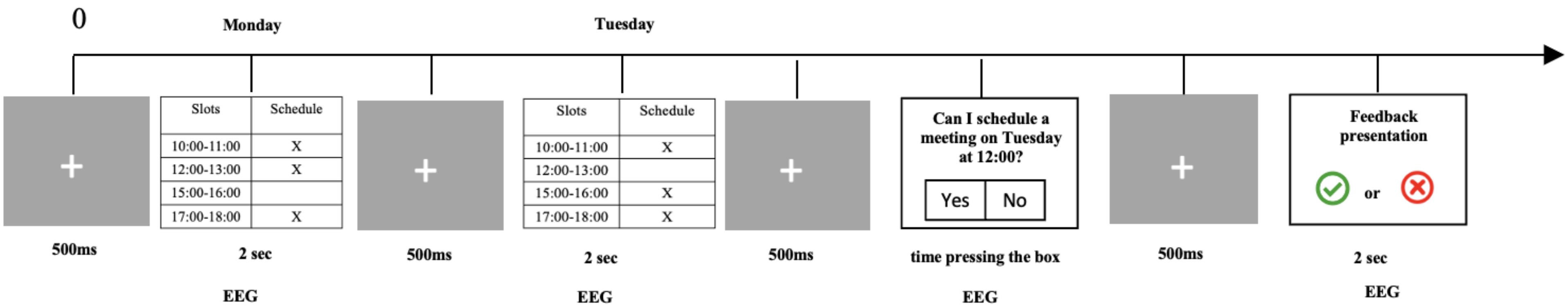
Procedures

During a single experimental session lasting no more than 90 minutes, we will record continuous EEG signals using a 32-channel EMOTIV Flex gel-based mobile EEG system, sampling data at a rate of 256 Hz. Markers will be generated using custom Python scripts. Additionally, eye-tracking data will be captured using a Pupil-Core binocular eye-tracking headset, which provides 200 Hz infrared tracking and online gaze estimates at 120 fps.

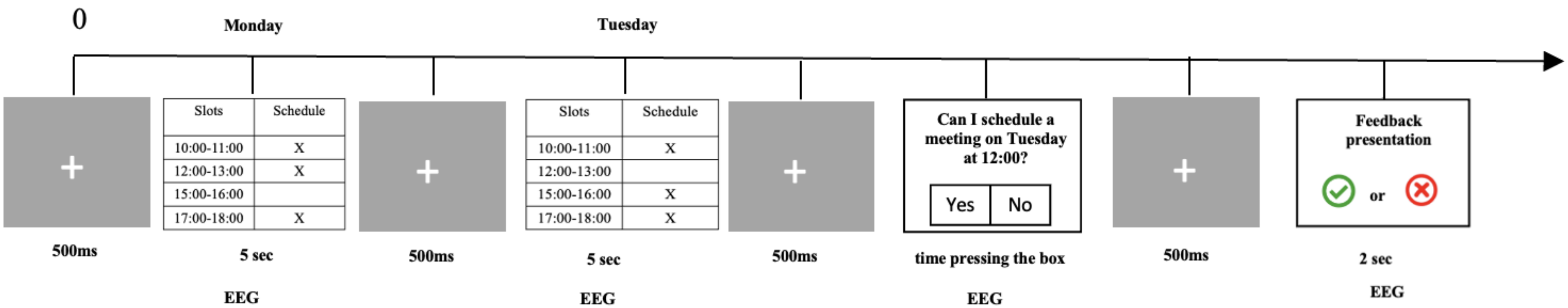
This data will facilitate the calculation of fixation-related cortical potentials during stimulus presentation and feedback. We will also measure the initial distance between participants' eyes and the screen to enable post-hoc calculations of saccadic velocities. This will allow for regression-based separation of overlapping event-related brain activity using the Unfolding toolbox (Ehinger & Dimigen, 2019).

Given the overlapping nature of eye movement events in the visualization task (Dimigen et al., 2011), unmixing these signals will help control for event-related potential (ERP) overlap and individual differences, employing a novel analytical approach rarely used in traditional EEG experiments. The session will include participant questionnaires and sociodemographic surveys, followed by the setup and testing of the equipment. Finally, participants will be debriefed and have the opportunity to ask any remaining questions.

Trial Condition 1 (Low Demand/Low Resource)



Trial Condition 2 (Low Demand/High Resource)



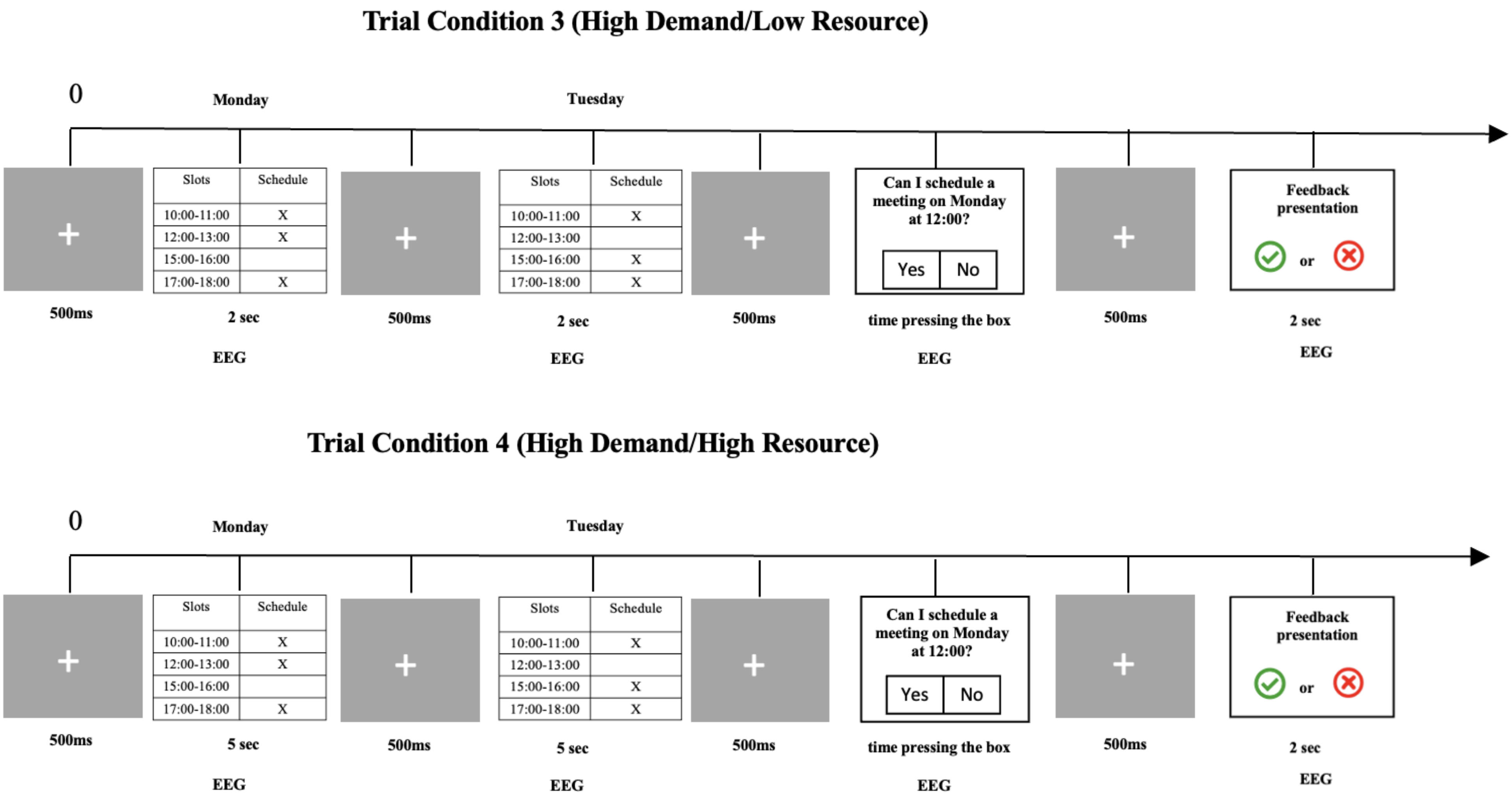


Figure 4: The proposed task performance trial conditions.

Instruments

We will utilize a combined EEG, mobile brain and body imaging (MoBI), and eye-tracking approach to examine brain information processing during free visual exploration of the programming task. A simplified MoBI (Gramann et al., 2011) will integrate eye tracking with brain activity sensors.

The PupilLabs mobile eye tracker will record data at 200 Hz and 120 fps. Using pre-prepared scripts, we will synchronize EEG and eye-tracking signals at the start of the experimental task to analyze evoked brain activity across four experimental conditions. All physiological measurements are non-invasive, posing no risk to participants or researchers.

Self-reported absorption

We will employ the Utrecht Engagement Scale (UWES-9), specifically the adapted short version focusing on the six items of the absorption dimension (cognitive dimension) developed by Schaufeli et al. (2006) and validated in the Chilean context by Juyumaya (2019). This scale employs a 5-point Likert-type response format, ranging from "Strongly disagree" (1) to "Strongly agree" (5), and demonstrates strong psychometric properties (Cronbach's alpha = 0.95).

Analysis strategy

EEG and eye-tracking data will be analyzed using Python (version 3.10). SPSS (version 23) will complement the analysis, facilitating regression and psychometric evaluations of the utilized scale.

Ethical aspects

Ethical approval will be secured from the relevant institutional ethics committee. All measurements are non-invasive and pose no risk to participants. Informed consent will be obtained from each participant prior to their involvement in the study. Participation contributes to national scientific knowledge and development, with no associated risks.

2.0 HYPOTHESIS

Based on the preceding discussion, the following hypotheses are proposed:

1. Absorption is a transient cognitive state that positively influences task performance and output.
2. Episodes of absorption are associated with increased activation of the P300 wave and distinct pupillary dynamics.
3. Task characteristics, specifically job demands and resources, significantly affect the frequency and intensity of temporary absorption episodes.
   a. High work demands combined with high resources will lead to a greater frequency of absorption episodes
   b. High demands paired with low resources will result in a lower frequency of absorption episodes.
   c. High resources but low demands will also lead to a reduced presence of absorption episodes

These hypotheses aim to investigate how cognitive absorption states are influenced by task design and to identify potential neural and physiological markers of such states

This hypothetical study aims to empirically establish the connection between task characteristics, episodic absorption, and performance outcomes. The anticipated findings are expected to demonstrate that specific job demands and resources embedded within task design have a significant impact on both P300 wave activity and pupillary dynamics.

We propose that tasks perceived as novel and engaging foster episodic absorption, highlighting the influence of personal interest and task appeal in triggering absorption states. Additionally, the positive association between episodic absorption and task performance reinforces the value of designing work environments that support deep cognitive engagement, ultimately enhancing productivity and effectiveness.

The results of this study highlight the importance of considering cognitive factors, such as absorption, when optimizing performance in dynamic work settings. Moreover, neurofeedback-based training emerges as a potential tool for enhancing task performance, providing employees with techniques to improve focus and engagement in the workplace.

Author Contributions:

JJ and AL conceived and designed the experiments and protocols. All authors contributed to the writing and critically revised the paper.

Conflicts of Interest:

The authors declared no conflict of interest.

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