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The influence of cognitive load on visuospatial processing and multisensory integration in older adults

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ABSTRACT

This study’s goal is to explore and identify the extent to which cognitive load impacts everyday activities that depend on our abilities to attend, integrate, and process visuospatial information (Làdavas & Berti, 2020; Stirling & Elliott, 2008). Through visuospatial attention and multisensory integration, we can pick up salient information, bind it together and construct a representation of what we’re perceiving (Keil, 2020; Stirling & Elliott, 2008). However, the influence of cognitive load impacts these processes. In fact, the attentive resources of our brains are limited, which leads us to inevitably allocate them according to task difficulty and to unintentionally ignore certain stimuli (Broadbent, 1958; Treisman, 1964; Wahn & König, 2017). In young, healthy individuals, for example, a general bias towards left-presented stimuli is usually present (Kinsbourne, 1970, 1987; Reuter-lorenz et al., 1990). However, when cognitive load is increased, the bias seems to shift towards the right rather than the left (Naert et al., 2018). This doesn’t seem to occur in older people, due to age-related compensatory processes aimed to contrast the physiological decline (Casagrande et al., 2021). Cognitive load has also been shown to influence multisensory integration, with a general performance exacerbation using SIFI experiments (Michail et al., 2021). To the best of our knowledge, no study so far has investigated how cognitive load influences the ability to attend to lateralized stimuli and to integrate multisensory information in older adults and younger adults to then compare them. For this reason, in this study two separate groups of individuals underwent a dual task experiment that involves both lateralized multisensory stimuli detection and working memory tasks that could generate either a high or low cognitive load to interfere with the primary task. From the analysis of the data obtained, both younger and older groups revealed to be susceptible to the SIFI effects, displaying less accuracy in audio-visual stimuli detection during the incongruent rather than congruent trials. However, the experiments have yielded mixed results regarding the effects of reduced attentional resources on such detection tasks. While the group of younger participates appeared to be affected by the impact of cognitive load, this wasn’t revealed for most of the trial type conditions in the group of older individuals. Moreover, neither group showed a preference for the side on which the lateralized visual stimuli were displayed, suggesting the absence of any bias towards the left or the right visual field.

1. INTRODUCTION

1.1 Visuospatial processing

Visuospatial perception and processing allow the individual to navigate, experience and make sense of the world surrounding us by forming an internal representation of the outside environment, to analyze it and, if necessary, to interact with it, if not even manipulate it (Làdavas & Berti, 2020; Stirling & Elliott, 2008). In this thesis, I will proceed by explaining what the attention mechanisms underlying visuospatial processing consist of, and towards the end of this introduction, I will go on with the presentation of the multisensory integration processes, how they modulate spatial processing, and how they can be tested to give a further understanding of the general visuospatial elaboration function and the aim of this study.

1.2 Visuospatial attention and spatial asymmetries

Visuospatial attention is the ability to attend to various elements presented in our visual field, allowing the individual to construct a model of what our senses are perceiving of the surrounding environment (Corballis, 2003; Posner and Petersen, 1990; Stirling & Elliott, 2008). The attention mechanisms underlying visuospatial processing set the foundation for the creation of a reliable mental map and act as mediators between what our senses are perceiving and what our brain registers (Stirling & Elliott, 2008). This happens by selecting and prioritizing the most salient stimuli and neglecting those who are not labeled as important (Broadbent, 1958). In fact, human information processing is limited by our attentional resources (Wahn & König, 2017). According to Kahneman's capacity model, for example, attention is a limited-capacity resource that can be allocated to different tasks but that can reach exhaustion when its demand tops its availability. These resources could be conceptualized as a pool of mental energy from which the individual takes what he needs and allocates the resources to meet the expectations presented by the task (Kahneman, 1973; Raab et al., 2016). However, the consumption of the resources leads to some side effects such as potentially ignoring determined, "insignificant" labeled stimuli (Broadbent, 1958; Treisman, 1964; Wahn & König, 2017).

Furthermore, our visuospatial processing ability seems to rely heavily, at least in the younger population, on lateralization. In fact, different hemispheres of the brain activate in a specific manner to maximize the effectiveness of this process. Our attentional resources are theorized to be shared by two systems, originating from the two different hemispheres, which both lead attention towards its contralateral visual field (Kinsbourne, 1970). However, both do so by competing with one another and mutually inhibiting the adversary, since attentional resources are, as previously highlighted, limited. Therefore, the processor system who gets the more activation during a specific task, inevitably creates a bias towards its contralateral visual field and elaborates information in that area with higher success. Regarding visual processing of space, this ability is mostly carried out by the right rather than in the left attentional dorsal network (Reuter-lorenz et al., 1990), leading to an attentional asymmetry in our way of processing space (Kinsbourne, 1970, 1987; Reuter-lorenz et al., 1990). This phenomenon is called pseudoneglect, or in other words the general tendency in younger, healthy individuals, to shift the visuospatial attention to the left, due to a dominance of the right hemisphere in visuospatial processing (Friedrich et al., 2018).

This phenomenon seems to fade throughout the lifespan of the individual, as there seems to be a reduction of lateralization in older adults as the years go by (Cabeza et al., 1997). In a meta-analysis conducted by Jewell and McCourt in 2000, the authors concluded that younger subjects (less than 40 years-of-age) typically erred to the left of center on a line bisection task, whereas older adults (greater than 50 years-of-age) had the tendency to do so to the right of center, results which were also found by Benwell and colleagues in 2014. Another study, using perceptual landmark tests, found once again evidence for an age-related shift, from a strong attentional leftward bias in young adults toward a suppressed or even a reversed bias in the elderly (Schmidtz & Peigneux, 2011). This decreased hemispheric asymmetry in the elderly could be due to a compensatory process aimed to contrast the normal physiological decline that comes with age (Casagrande et al., 2021; Dolcos et al., 2002). To explain this phenomenon, two different, but not necessarily separate models have been created. The first is the right hemi-aging model (RHAM), which hypotheses a faster, age-related deterioration in the right hemisphere functions rather than in the left one; and the second one being the HAROLD model, which states that with age comes a general, reduced lateralization of the cerebral activities during certain tasks, leading to a reduction of that more pronounced asymmetry that characterizes young brains (Cabeza et al., 1997; 2002; Dolcos et al., 2002).

As previously mentioned, these spatial asymmetries are strongly influenced by certain non-spatial attentional aspect factors all present and extremely relevant in our everyday life. The most common are restfulness, arousal, fatigue, but also, and this is particularly relevant for this project, the amount of cognitive load maintained by the individual while engaging in visuospatial processing. All these aspects have all the ability to affect our resources and modulate performances where the spatial allocation of visual attention is essential (Benwell et al., 2013; Manly et al., 2005; Fimm et al., 2006; Dufour et al., 2007). Usually, to test the effects that cognitive load has on visuospatial processing, dual tasks are employed, where a task is performed together with an interfering one. Dual tasks entail the implementation of our multi-tasking abilities, or the ability to share our attentional resources towards two parallel and nearly simultaneous activities. This method requires the brain to be fully engaged at an attentional level as it simultaneously allocates attentional resources to two concurrent tasks. This usually impacts performances, creating biases if the tasks are challenging enough (Howard et al., 2020). A pertinent example would be the study of Naert et al. (2018), in which participants were presented with letters and were instructed to attend to lateralized stimuli shortly after, only to be asked to correctly retrieve the letters initially presented. There were two conditions to this study: one with a high and one with a low cognitive load. The results showed that increasing cognitive working memory load had a more negative impact on detecting targets presented on the left side compared to those on the right side (Naert et al., 2018).

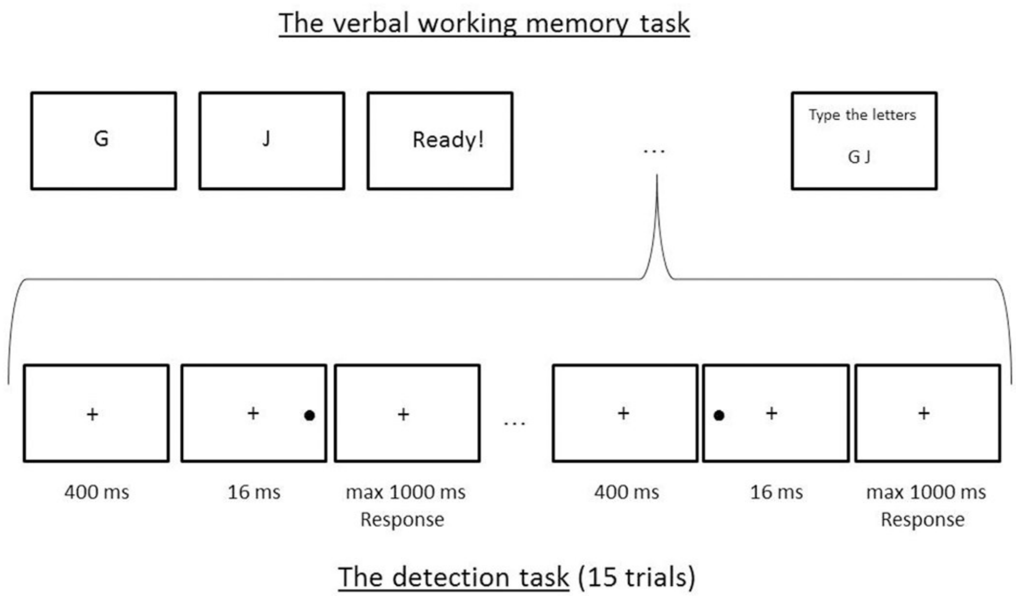

Figure 1*: An overview of a low WM load (two letters) trial in the WM task, which consists of 15 detection trials (Naert et al., 2018).*

Many studies have investigated this same phenomenon, and found that as attentional load increases, healthy, young individuals tend to show a rightward rather than leftward attentional bias, along with an increased activation of the left attentional dorsal network rather than the right (Bonato, 2015; O'Connell et al., 2011; Paladini et al., 2020). The effects of cognitive load on the brain have been investigated through bihemispheric transcranial direct current stimulation (tDCS) to simultaneously modulate the excitability of the left and the right posterior parietal cortices (PPCs), crucial nodes of the dorsal attention networks of the two hemispheres (Paladini et al., 2020). By placing an excitatory anode over the left PPC and inhibitory cathode over the right PPC, they found that this would exacerbate the rightward attentional shift, while by placing an inhibitory cathode over the left PPC and excitatory anode over the right PPC, this restored interhemispheric balance, thereby reducing the rightward attentional shift under high cognitive load.

Regarding older individuals, they tend to show further performance deterioration in tests that require sustained attention, like dual tasks. This because of the sharing and division of limited attentive resources during the execution of these tests, which inevitably leads to less adequate performances (Künstler et al., 2018). Studies that focused on reaction times and dual-task performance in the motor realm have found that cognitive load generally affects performance. In a study on the allocation of attention during a walking and counting dual task, it has been found that increasing cognitive load adversely affected both velocity and step-time variability in older people and led to a prioritization effect on gait over cognition, which often resulted in more cognitive errors (Maclean et al., 2017). A study analyzing the effects of cognitive load on reaction times to directional warning while driving revealed that older drivers' responses were slower for each type of warning compared with the young drivers' responses. When presented with a warning at the left, the center, and the right the correct response was to steer to the right, brake, and steer to the left, respectively. Older participants exhibited slower responses than the young for each type of warning and, overall, the responses were slower with an added cognitively loading task that involved backward counting (Lundqvist & Eriksson, 2019). However, the study has also found that when bimodal warnings were implemented (vibration-sound), older drivers can actually benefit from this in terms of both faster and more accurate response (Lundqvist & Eriksson, 2019), which is an aspect regarding multisensory integration that will be deepened later in this introduction. Nevertheless, drop in performances found in dual tasks are not limited to predictions within the realm of motor performance, but can also extend to cognitive aspects (Saccani et al., 2022), such as this study aims to do.

1.3 Multisensory Integration

As mentioned before, in our everyday life we are constantly bombarded with a wide range of stimuli that we must process and interpret to properly engage with the surrounding environment (Naert et al., 2018; Stirling & Elliott, 2008). However, these events are usually perceived through a process that allows us not only to pick up the most salient information, but also to create a more cohesive and complete perception of the many and simultaneous stimuli that we're presented with (Gaver, 1993). This process is called multisensory integration, a fundamental perceptual process that selects the different input present in our environment picked up by the different senses and binds them in a unified percept (Keil, 2020). This is extremely helpful to the individual and allows for faster reaction times (Diederich & Colonius, 2004; Pomper et al., 2014) and a more accurate representation of our perception, which in turn leads to an improved quality of responses (Stein & Stanford, 2008).

Multisensory integration, however, is not infallible and can have some side-effects: it can lead to a wide array of perceptual illusions. The perception of one sensory modality sometimes creates a conflict with another, generating a subjective illusion of the perceived information gathered (Keil, 2020). The study of these perceptual illusions is useful to investigate load-induced visuospatial attention asymmetries during multisensory integration, as the complexity of the tasks included in such studies can clarify some of the inconclusive or clashing results obtained while testing the effects of high cognitive load on spatial attentional asymmetries in younger individuals, probably due to ceiling effects. The goal is to create tests with complex lateralized multisensory stimuli that induce an effortful engagement in multisensory integration and memory tasks to avoid such ceiling effects.

1.4 SIFI

One example, relevant to this study, of perceptual illusions that could be used to investigate load induced visuospatial attention asymmetries during multisensory integration in healthy adults is the SIFI, namely sound-induced flash illusion. Sound-induced flash illusion was firstly investigated by presenting young, healthy participants with different visual flashes simultaneously with an either congruent or incongruent number of auditory sounds and asking them to report the number of flashes while ignoring the sounds (Shams et al., 2000). The results suggested that the reported number of perceived flashes were more accurate when the number flashes and sounds were congruent, but it dropped when incongruent (Shams et al., 2000, 2002), with two different illusory effects appearing. The first would be fission illusion, meaning the wrongful tendency to perceive one flash as more than one when presented with a simultaneous multiple sounds; and the second one being fusion illusion, or the tendency to perceive multiple flashes as just one when paired with a single sound (Andersen et al., 2004; Shams et al., 2000, 2002, 2005).

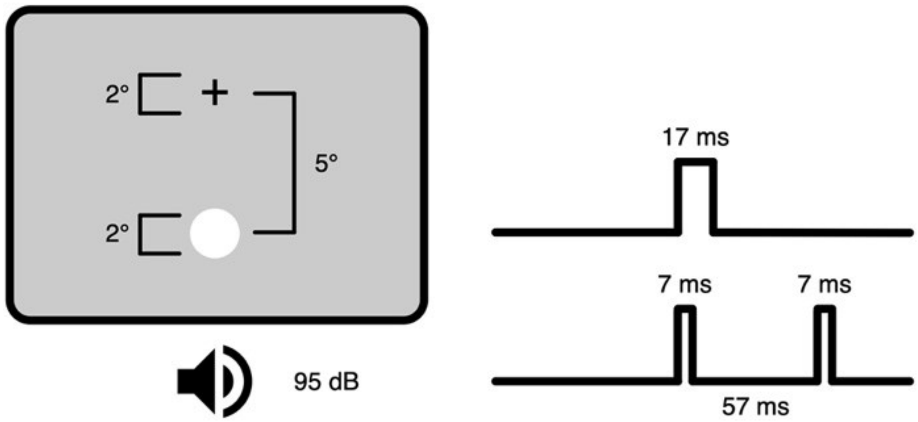

Figure 2*: Experimental setup in the sound-induced flash illusion (Keil, 2020).*

This illusion has also been tested with regards of the modulation of high cognitive load on multisensory integration and visuospatial attention in general. The effects have been tested with dual tasks involving verbal working memory, and results showed that the high cognitive load and the attentional resources available did indeed increase the number of perceived illusions (Keil, 2020; Michail & Keil, 2018, 2021). To the best of our knowledge, no study so far has investigated the effects of high cognitive load on the different probabilities of perceiving a higher number of illusions in the left or right visual field.

A lifespan perspective would also give more insight on the matter and is also pertinent to this study. Studies have found that older individuals exhibit increased multisensory integration abilities compared to younger individuals (DeLoss et al., 2013). It's been hypothesized that this could also be explained through the compensatory ability of older adults of overcoming those losses that characterize normal aging that has been mentioned above (Casagrande et al., 2021). A study from 2006 that examined discrimination responses to the display of visual, auditory or visual-auditory stimuli in younger and older participants showed that older people's performance gained the most, speed-wise, when presented with multisensory-stimuli. These results suggested, that despite the decline in sensory processing that accompanies aging, older people make up for these losses by using multiple sensory channels and engage in compensatory strategies (Laurienti et al., 2006). McGovern and colleagues (2014) have found that older adults tend to have an enlarged temporal window of integration, meaning the window of temporal offsets within which an individual perceives two sensory inputs as synchronous (Wallace et al., 2020). In the study, in fact, older adults showed to be significantly more susceptible to the fission illusions at longer stimulus onset asynchrony (SOAs), compared to younger participants. The higher number of fission illusions could be explained by the extended capacity of multisensory integration even in longer temporal intervals, which allows older individuals to bind auditory and visual stimuli even when presented further apart and even at the expense of accuracy (Laurienti et al., 2006; McGovern et al., 2014). In summary, older adults are generally more susceptible to the SIFI than younger adults and remain susceptible to the illusion at longer SOAs (McGovern et al., 2014; Setti et al., 2011, 2014).

1.5 Hypotheses

Based on this theoretical background, this study's goal is to analyze how visuospatial attentional resources are employed in high versus low cognitive load conditions, during multisensory integration, on a population of older adults compared to younger ones. By testing both with dual tasks that comprehend memory work and lateralized stimuli detection like the ones above-described (Naert et al., 2018), we wish to provide more insight on the matter. For younger adults, according to previously mentioned studies on the asymmetries of spatial attention induced by the cognitive load, we expect a reduction of accuracy in the multisensory integration task during incongruous conditions, therefore an increase in the number perceptual illusions of fission and fusion to emerge (Shams et al., 2000, 2002). Along with this, we expect that in conditions of high cognitive load, the reduction of cognitive resources by working memory tasks leads to an increase in illusions (Keil, 2020; Michail & Keil, 2018, 2021), especially when flashes are presented on the left side of the screen (Naert et al., 2018). In the population of older adults, we also expect the audiovisual integration performance to worsen during the high load and during incongruent conditions, thus, to witness a higher number of illusions, but especially fission illusions since older adults tend to be better at multisensory perception and have an enlarged temporal window of integration (McGovern et al., 2014). Lastly, according to previous studies on the effects of normal aging on lateralization, we don't expect to see any preference or asymmetry for the elaboration of the lateralized stimuli, this because of the reductions of interhemispheric activation in older adults (Cabeza et al., 1997; Williamson et al., 2019).

1.6 Preliminary study: feasibility of self-administered online testing

While for the younger participants the test only comprehends a dual task on SIFI, it feels necessary to ensure its feasibility also on older participants before proceeding to the same testing. For this reason, the pool of older participants will undergo a first phase of online experiments composed by a GEMS test, a Trial Making Task and finally a Landmark Task, that will enable us to record their memory, attention and perception abilities. This first phase works as a remote cognitive testing, test screening and, in the case of the GEMS test, also exclusion process. Remote, online testing is a rather modern and promising modality of testing administration that differs from the usual in-presence, laboratory-based one. Because of our current historical situation and need for strategies to counteract the imposed physical distancing, its potentials have allowed it to become a fundamental resource both in the clinical and in the research setting of psychology. In fact, online testing offers wide accessibility to the test and therefore the recruitment of a wide range of participants in a short period of time and at very low expenses and resources (Sauter et al., 2020). Technology-based testing allows for standardized administration, a higher precision in measurements and scoring and an instant interpretation. It reduces costs both in terms of money for materials, supplies, and time, meaning minimizing the need to train staff and supervise the participants while testing (Tsoy et al., 2021). Lastly, self-administered assessments allow for fast and accessible detection for potential impairments that could lead to degenerative disorders. Compared to to the canonical paper-and-pen tests, which usually are not sensitive enough to detect subtle deficits, research using well-developed, online testing paired with dual-task conditions mimicking the cognitive demands experienced by the individual in a more ecological way, can be a viable option for sensitive, early detection of deficits with good diagnostic and prognostic ability (Saccani et al., 2022).

2. MATERIAL AND METHODS

2.1 Participants

At first, 39 participants between the age of 19 and 25 from a previous experiment were also included in the study (5 males, 34 females; mean age = 21,02; age range = 19-25). The pool of younger participants had been obtained entirely through online recruitment. After having shown their interest, the participants were sent an email with the instructions and the link to the experiment. The test was taken online. Then, 11 participants between the age of 70 and 90 years old were recruited for this experiment (5 males, 6 females; mean age = 76,36; age range = 70-88). They were recruited through acquaintances and, after agreeing on participating, were presented with the instructions on how to approach the test and the links to the experiment. All testing and data collection was performed and obtained online. Older participants were accompanied by the presence of a caregiver who could supervise the participant and guide them in the comprehension of the instructions and utilization of the technological devices in case of need. To participate to the experiment, both older and younger individuals had to accept an informed consent form, had to declare of not be suffering from neurological conditions nor visual nor other impairment that could hinder them from using a computer, had to not be engaging in frequent use of alcohol and/or other narcotic substances. Furthermore, all participants (and potential caregivers) were presented with specific instructions on the preferred environment and conditions on how to perform the tasks.

2.2 Tasks and procedures

The dual task used in this experiment is divided in a primary audiovisual integration task and a working memory task. The former is performed during the retention interval of the latter.

In the audiovisual integration task, participants were presented with the prompt “Ready!” and then they started the audiovisual integration trials. In each of them, they were presented with a black fixation cross followed by lateralized flashes and binaural sounds. The lateralized flashes consisted of white discs with a diameter of 4°. They were shown for 16.7 ms on the left or on the right of the screen, once or twice, with and interval of 50.1 ms in the case of double presentation. The binaural sounds consisted of 7 ms long hamming windowed sine waveform. The participants were asked to attend to the flashes while ignoring the sounds, and then report the number of perceived visual stimuli. They were asked to tap one time on the space bar to indicate the perception of one flash, and to tap twice to indicate two flashes. All participants were right handers, with half of them responding with the dominant hand and the other half with the non-dominant hand, to avoid confounding effects.

The secondary working memory task is integrated in the experiment to induce an either low or high cognitive load and influence the levels of attention. It is divided in an encoding and a retrieving phase. In the former, participants had to memorize short or long sequences (low/high load) of consonants or spatial positions (verbal/spatial load). In the verbal variant, participants were presented with a sequence of 50px-large consonants appearing in the center of the screen. In each spatial variant, participants were presented with a sequence of black dots appearing one after the other, located in random positions on the screen. Each consonant and dot were preceded by a grey screen of 2004 ms and lasted for 2004 ms. No consonants or dot positions were repeated within a sequence. After the encoding phase, where participants were instructed to memorize consonants and dot positions, the audiovisual integration task took place, and after that the recall phase started. In this phase, the participants were asked to report stimuli sequences in the same order. Consonants were typed using the keyboard, dot positions were clicked on the screen using the mouse. The accuracy of the answers was collected, and the clicks were considered accurate when falling within 100 px from the original dot center.

The first part of the experiment consisted of two micro-trials. The actual experiment comprehended 8 blocks formed by 5 macro-trials each, with each macro-trial composed of one working memory task and 16 audiovisual integration trials, to be performed between the encoding phase and the recall phase of the working memory task. Each block is characterized by the same working memory condition and block order will be randomized across participants. In total, there are 40 working memory trials, 10 for each working memory condition, and 640 audiovisual integration trials, 80 for each audiovisual integration condition.

To avoid low motivation and tiredness, older participants were asked to take the first session of tests on a day and the second session, the SIFI dual task, on another. All participants encouraged to take short breaks in between blocks.

2.3 Data collection and analysis

The data collection took place entirely via web through the receipt of a link. The dual-task was programmed in HTML, CSS and JavaScript using jsPsych (version 1.4), which is a library that provide a flexible framework for building laboratory-like experiments that can be run online (de Leeuw, 2015). It was then uploaded on JATOS, which is a server used to manage participants and collect data (Lange et al., 2015). At the end of the experiment, all the data was automatically saved and downloadable from the Jatos platform, ready to be ordered and analyzed. For the analysis, the manipulations of load type and load level were combined in 4 different working memory conditions: verbal-low, verbal-high, spatial-low and spatial-high. Meanwhile, the variables of the audiovisual integration task were lateralization (left or right) and congruency (congruent or incongruent). This meant that the manipulations of flashes lateralization and of the congruency between the number of flashes and sounds combined 8 different audiovisual integration conditions: left-1F1S, left-2F2S, left-1F2S, left-2F1S, right-1F1S, right-2F2S, right-1F2S, right-2F1S. In addition to that, two control variables were manipulated: block order, and modality of answer, which could be either with dominant hand or non-dominant hand. A generalized linear model was initially adapted. Together with the model, a deviance analysis (Type II, Wald chisquare tests) was applied to highlight the presence of factors that influenced the accuracy of participants in the perceptual task. Subsequently, post-hoc comparisons were made for the significant factors identified by ANOVA, correcting the p-value with "False Discovery Rate" (FDR) control procedure.

In the younger participants pool, from the study was excluded anyone younger than 18 years old and older than 40 years old, left-handed participants, participants whose accuracy in congruent trials was too low (<0.6), those responses where reaction times (RT) were too fast (<100 ms) or too slow (>4000 ms) and participants whose total duration of the experiment took less than 20 minutes or more than 3 hours. After the exclusion processes, 38 participants were left (mean age = 20.97; age range = 19-25). From the pool of older participants, anyone younger than 70 years old or older than 90 years old or left-handed was also excluded. Plus, anyone with an accuracy in congruent trials lower than 60% and those responses where RTs were too fast (<100 ms) or too slow (>4000 ms). Furthermore, the participants who presented a score lower than 60 in the GEMS test, was also excluded from the study. After data cleaning, 9 participants were left (mean age: 76,33; age range: 70-88).

3. RESULTS

3.1 Younger participants

In the pool of younger individuals, the analysis revealed a significant effect of the type of trials (congruent and incongruent) on the accuracy of performance [$\chi 2$ (3) = 246.2138, *p* (with FDR) < 0.0001]. In particular, there was a drop in accuracy in incongruent conditions rather than congruent conditions. The 1F2S appeared to have the lowest accuracy [m = -0.332, SE = 0.266, *p* < 0.0001], followed by the 2F1S condition [m = -0.102, SE = 0.294, *p* (with FDR) < 0.0001]. Regarding the congruent conditions, 1F1S [m = 3.026, SE = 0.217, *p* (with FDR) < 0.0001] showed the highest accuracy, followed by 2F2S [m = 2.712, SE = 0.255, *p* (with FDR) < 0.0001] (see Fig. 3).

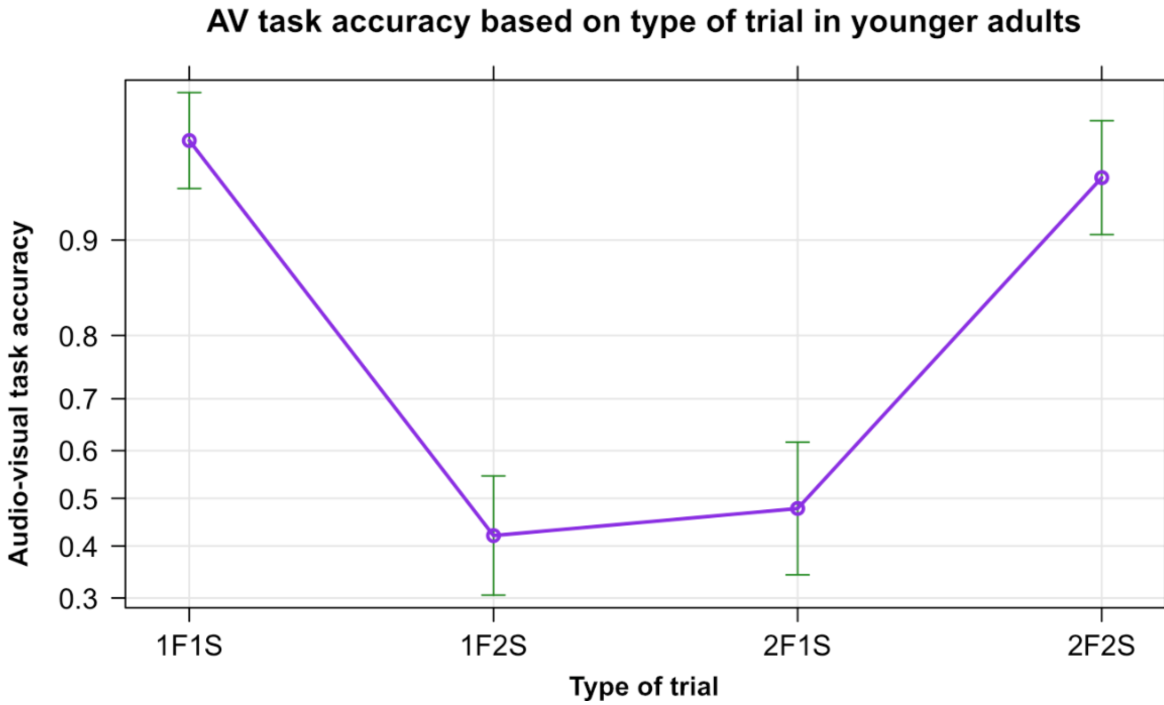

Figure 3: *Accuracy during congruent (1F1S/2F2S) and incongruent (1F2S/2F1S) types of trials in the population of younger adults.*

A significant effect of the interaction between the level of cognitive load and the type of trial conditions on the accuracy in the audio-visual integration tasks performance was also found [$\chi2$ (3) = 35.4499, *p* (with FDR) < 0.0001]. Post-hoc analysis revealed that in both congruent conditions performance dropped in the high cognitive load condition with respect to the low cognitive condition, for both 1F1S [z = -4.086, SE = 0.1060, *p* (with FDR) < 0.0001] and 2F2S [z = -3.022, SE = 0.0927, *p* (with FDR) = 0.0042]. However, the high cognitive load condition induced an increase in accuracy in the incongruent conditions, for both 1F2S [z = 2.100, SE = 0.0637, *p* (with FDR) = 0.0446] and 2F1S [z = 2.426, SE = 0.357, *p* (with FDR) = 0.0219]. Lastly, the analysis didn't reveal any significant effect on the accuracy of performance when comparing the two incongruent trials, 1F2S and 2F1S [z = -0.645, SE = 0.0637, *p* (with FDR) = 0.5187] (see Fig. 4).

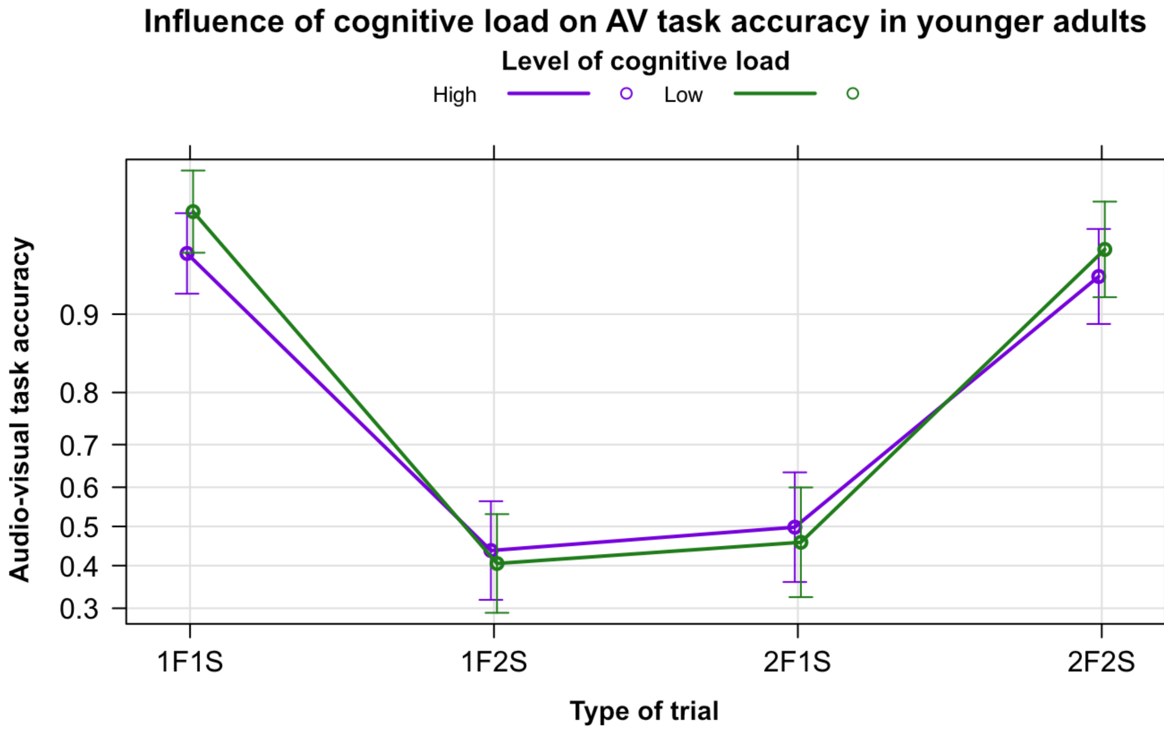

Figure 4: *Accuracy during congruent and incongruent types of trials under high and low cognitive load in the younger population.*

From the analysis, furthermore, no effect was revealed from the interaction between the level of cognitive load, type of trials and the position of the visual stimulus on the performance accuracy [$\chi 2$ (3) = 6.8137, $p = 0.0764$], nor of the position of the presentation of the visual stimulus on the accuracy of audio-visual task performance alone [$\chi 2$ (1) = 1.0350, p = 0.3089]. Lastly, the analysis didn't reveal an effect of type of hand used to perform the experiment and the side where the stimulus was presented in the accuracy [$\chi 2$ (1) = 0.0708, $p = 0.790184$], indicating that the hand used did not influence the accuracy of the responses.

The ANOVA further revealed an effect of the type of load on the accuracy in the performance of the working memory tasks [$\chi 2$ (1) = 484.8023, p (with FDR) < 0.0001], and an effect of the level of load on the accuracy in the performance of the working memory tasks [$\chi 2$ (1) = 144.7857, p (with FDR) < 0.0001]. The spatial task seemed to produce the less accuracy [m = 1.05, SE = 0.181, $p < 0.0001$] when compared to the verbal one [m = 2.75, SE = 0.19, $p <$ 0.0001]. The same happened for the effect of the level of load, with the high-level condition [m = 1.31, SE = 0.176, $p < 0.0001$] appearing harder than the low-level condition [m = 2.49, SE = 0.200, $p < 0.0001$].

3.2 Older participants

In the pool of older individuals, the analysis revealed a significant effect of the type of trials (congruent and incongruent) on the accuracy of audio-visual performance [$\chi2$ (3) = 47.6009, $p < 0.0001$]. More specifically, there was a drop in accuracy in incongruent conditions rather than congruent conditions. The 2F1S appeared to have the lowest accuracy [m = -2.524, SE = 0.760, p (with FDR) < 0.0001], followed by the 1F2S condition [m = 0.256, SE = 0.725, p (with FDR) < 0.0001]. Regarding the congruent conditions, 1F1S [m = 4.659, SE = 0.465, p (with FDR) < 0.0001] showed the highest accuracy, followed by 2F2S [m = 1.381, SE = 0.484, p (with FDR) < 0.0001] (see Fig. 5).

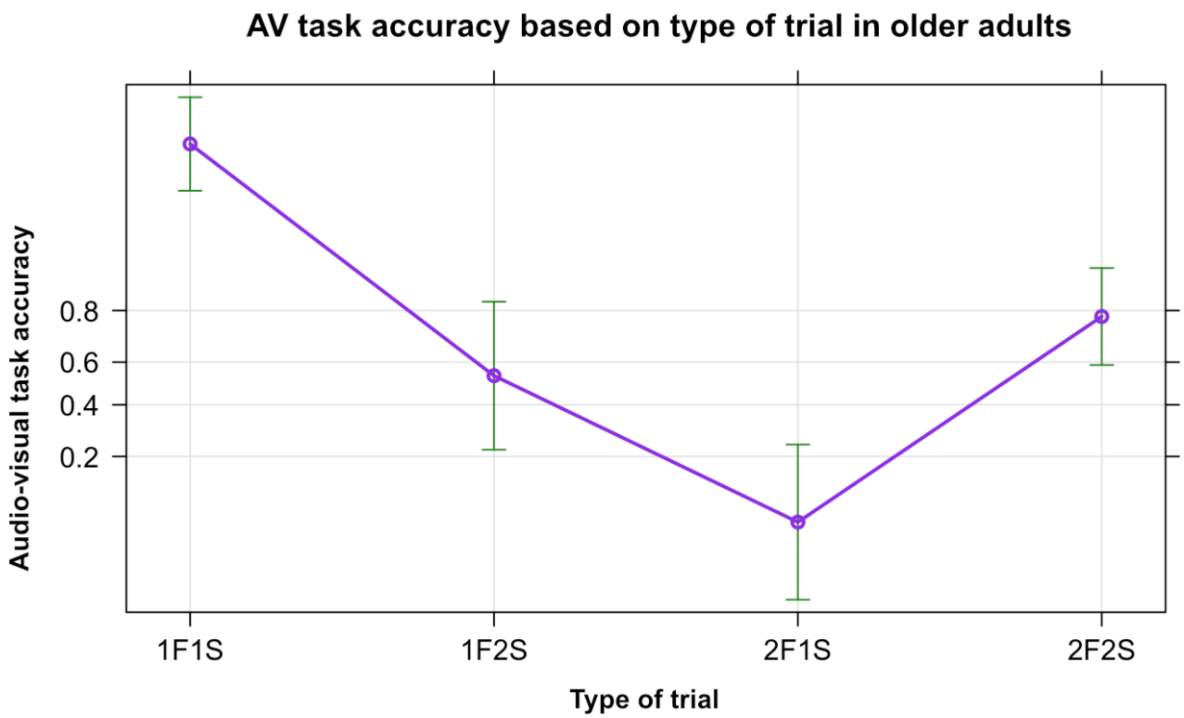

Figure 5: *Accuracy during congruent (1F1S/2F2S) and incongruent (1F2S/2F1S) types of trials in the population of older adults.*

No effect of the interaction between the level of cognitive load and the type of trial conditions on the accuracy in the audio-visual integration tasks performance was found [$\chi2$ (3) = 3.4031,

p = 0.33355]. However, post-hoc analysis revealed that the 2F1S condition, low cognitive load condition induced an increase in accuracy in the performance [z = -2.413, SE= 0.178, p (with FDR) = 0.0263]. Moreover, the analysis revealed a significant effect on the accuracy of performance when comparing the two incongruent trials, 1F2S and 2F1S [z = 4.549, SE = 0.611, p (with FDR) <0.0001]. Plus, under high cognitive load, the 2F1S condition showed the biggest change in accuracy [z = -2.413, SE = 0.178, p (with FDR) = 0.0263], hinting to an overall higher number of fusion illusions rather than fission illusions in the incongruent conditions (see Fig. 6).

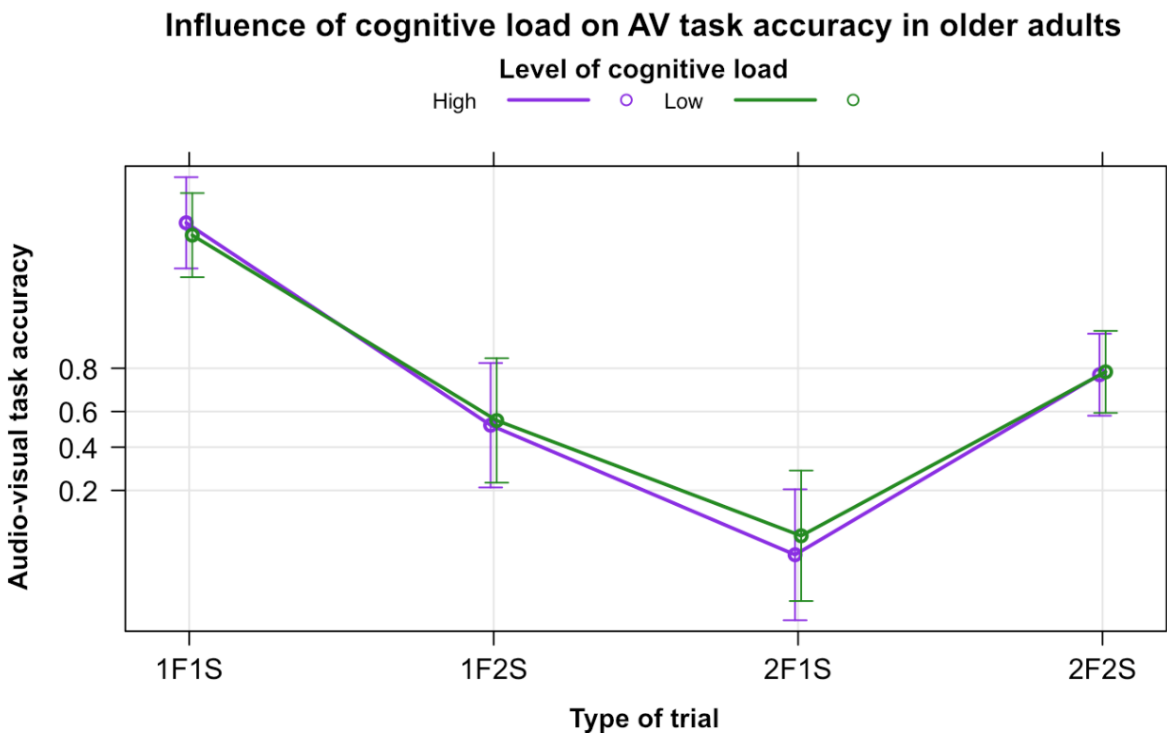

Figure 6: *Accuracy during congruent and incongruent types of trials under high and low cognitive load in the older population.*

From the analysis, once again no effect was revealed from the interaction between the level of cognitive load, type of trial and the position of the visual stimulus on the accuracy on identifying the four types of trials [χ2 (3) = 2.3686, p = 0.49950], nor an effect of the position of the visual stimulus on the accuracy on identifying the four types of trials alone [χ2 (1) = 1.0926, p = 0.29589]. Lastly, the analysis didn't reveal an effect of type of hand used to perform the experiment and the side where the stimulus was presented in the accuracy [χ2

(1) = 0.0001, p (with FDR) = 0.99424], indicating that the hand used did not influence the accuracy of the responses.

Finally, the ANOVA further revealed an effect of the type of load on the accuracy in the performance of the working memory tasks [$\chi 2$ (1) = 29.5819, p (with FDR) < 0.0001], and an effect of the level of load on the accuracy in the performance of the working memory tasks [$\chi 2$ (1) = 137.3933, p (with FDR) < 0.0001]. Once again, the spatial task seemed to produce the less accuracy [m = -0.443, SE = 0.571, p (con FDR) < 0.0001] when compared to the verbal one [m = 0.757, SE = 0.580, p (con FDR) < 0.0001]. The same happened for the effect of the level of load, with the high-level condition [m= -1.03 SE = 0.566, p (with FDR) < 0.0001] appearing harder than the low-level condition [m = 1.34, SE = 0.585, p (with FDR) < 0.0001].

4. DISCUSSION

This study's aim was to discover how everyday important processes such as memory tasks consume the limited attentional resources and affect visuospatial processing and multisensory integration abilities in younger and older adults. This was investigated through the employment of complex dual tasks that would demand a high amount of cognitive load maintained by the individual while engaging in visuospatial processing. This can be very helpful when considering that every day activities can be very demanding attention-wise and require visuospatial orienting to occur in parallel with other tasks.

The results showed us that in the population of younger adults, the performance in the audio-visual task did change according to the type of trial presented, revealing that there is a general drop in accuracy in the incongruent type of condition. These results confirmed the presence of Sound Induced Flash Illusions effects (Shams et al., 2000, 2002). Moreover, effects of the impact of the level of cognitive load in the working memory tasks on the accuracy of audiovisual stimuli detection were also revealed. Interestingly, high cognitive load worsened performance in the congruent trials (1F1S, 2F2S), while it didn't in the incongruent trials (1F2S, 2F1S). This partially confirmed the theories of the negative effects of high cognitive load on multisensory integration and visuospatial processing, however only during congruent conditions. In fact, results showed that, when the condition of the stimuli was incongruent, participants were actually better at audio-visual detection performance under high cognitive load when compared to their performance under low cognitive load. In this group it seemed that reduced attentional resources led to an improvement of the performance. Lastly, concerning the interaction between the lateralization of the stimuli, the level of cognitive load of the WM tasks and the accuracy in detection of the audio-visual stimuli, there was no correlation, showing that there was no preference for the left or the right presented stimuli over the other, failing to confirm our third hypothesis on the impact of high cognitive load on the detection of stimuli presented on the left side of the screen (Naert et al., 2018).

In the population of older adults, sound-induced flash illusions also emerged more frequently during the incongruent rather than congruent conditions, confirming the first hypothesis of the study on expecting a reduction of accuracy in the multisensory integration task in incongruous conditions (Shams et al., 2000, 2002). The second hypothesis focused on the effects on high cognitive load and its impact on cognitive resources leading to an increase of illusions (Keil, 2020; Michail & Keil, 2018, 2021). The analysis didn't find an effect on high cognitive load on the accuracy of the multisensory integration task, with the only exception of the incongruent 2F1S condition, which showed an improvement in audio-visual detection performance under low cognitive load when compared to their performance under high cognitive load, confirming the second hypothesis only for one condition. Moreover, while we expected older individuals to display a higher number of fission rather than fusion illusion during the high load and incongruent conditions, the analysis didn't reveal such phenomenon. In fact, as previously explained, studies have found that older adults tend to be better at multisensory perception and have a tendency to be more more susceptible to the fission illusion because of a usual enlarged temporal window of integration (McGovern et al., 2014). However, during the 2F1S conditions, there was a general tendency towards an exacerbation of the performance under high cognitive load when comparting it to the performance under low cognitive load, hinting to a majority of fusion illusions. Lastly, according to previous studies on the effects of normal aging on lateralization, we didn't expect to see any preference or asymmetry for the elaboration of the lateralized stimuli, this because of the reductions of interhemispheric activation in older adults (Cabeza et al., 1997; Williamson et al., 2019). The analysis confirmed this hypothesis, showing no correlation between from the interaction between the level of cognitive load, type of trial and the position of the visual stimulus on the accuracy on identifying the four types of trials, nor an effect of the position of the visual stimulus on the accuracy on identifying the four types of trials alone. This suggested that there was no preference for the left or the right presented stimuli over the other. Lastly, one interesting finding from this group was the strikingly low accuracy in the 2F2S trials [m = 1.381, SE = 0.484, p (with FDR) < 0.0001] with respect with the other congruent trial 1F1S [m = 4.659, SE = 0.465, p (with FDR) < 0.0001], under both high and low cognitive load. This suggests for a general difficulty in the older adults' group in being able to distinguish the two flashes, even during the simplest conditions. This is in line with the theories on the extended capacity of multisensory integration at even longer temporal intervals in older adults, which leads them to bind stimuli even when presented further apart and even at the expense of accuracy (Laurienti et al., 2006; McGovern et al., 2014).

In conclusion, both younger and older groups were susceptible to the sound-induced flash illusion effect, displaying less accuracy in audio-visual stimuli detection during the incongruent rather than congruent trials. However, the experiments have yielded mixed results regarding the effects of reduced attentional resources on such detection tasks. In fact, while the group of younger participates appeared to be affected by the impact of cognitive load, this effect wasn't revealed for most of the trial type conditions in the group of older individuals. Interestingly, while the first group didn't show a higher number of one type of illusion over the other as expected, the older adults did, with a higher susceptibility to fusion rather than fission illusions, differently from what we'd predicted based on the literature. Moreover, neither group showed a preference for the side on which the lateralized visual stimuli were displayed, suggesting the absence of any bias towards the left or the right visual field.

4.1 Study limitations

Being a preliminary study, a first limitation was the rather small sample size, which reduces the statistical power of the study and increases the margin of error. Moreover, from what emerged from the data analysis on the reduced capacity of older individuals in distinguishing separate stimuli when presented close to one another, a useful edit to the study design would be presenting the double visual stimuli at slightly longer intervals or SOAs, in order to accommodate their needs and allow them to distinguish the two separate flashes. The length and complexity of the experiment also led to a general drop in motivation throughout the experiment in the older population. The absence of a face-to-face interaction between experimenter and participant can in fact result in a lack of monitoring to ensure compliance, effort, or motivation, but these issues were promptly dissipated by the presence and encouragement of the supervisors or caregivers. Furthermore, it has been hypothesized that the presence of a completion bar showing the progress of the participants in terms of percentage and the insertion of a performance feedback at the end of each task could help motivate the participant; a suggestion that could be implemented in the next design of this study. Moreover, while this experiment allowed for an opportunity to create and test the feasibility of remote administration, especially to an older population, some participants did encounter some difficulties when being presented with the online-testing modality. Some typical disadvantages of self-administered online testing are in fact linked to the absence of a controlled setting. Namely, the environment in which the individual is asked to engage in cognitive tasks is not completely controlled, which may lead to differences across individuals and the potential rise of external distractors that the experimenter cannot control. There is also a loss of qualitative data about the participants that can give valuable insights that cannot be obtained with remote unsupervised testing and the absence of an interaction where the experimenter can unsure that the participant has clearly understood the instructions can also lead to complications, along with the lack of support should the patient run into technological issues. Another big limitation of remote self-administered testing is the necessary use of technology and the participants' familiarity with the assessment tool, which is not as widespread in a population of older individuals at it is between younger individuals. The complexity of this type of testing may not guarantee the best performance, as participants could approach the tests in a hasty and superficial manner. These issues can be partially resolved with the presence of a well-informed caregiver, however some minor difficulties may still arise, as it did for this study. Lastly, it is not guaranteed that every possible participant owns a suitable device for the execution of the experiment and, since each individual is supposed to use what's available to them, this may present additional challenges related to potential technological differences between devices and it makes it hard to ensure consistent stimuli presentation and reaction time measurement (Tsoy et al., 2021). With this being said, this type of administration still demonstrated its potential and proved itself to be a valid and reliable form of testing. It has shown its validity in detecting sound-induced flash illusions and its variations according to the cognitive load, while still being extremely accessible and fast. With further work on its structure and further proof of its validity and reliability, self-administered online testing could become a more common modality of research in the future. This could be possible even in the clinical area, as it would offer a useful tool in both detecting and therefore potentially preventing conditions.

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