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**The influence of the visual surrounding environment in older adults
and young adults' cognitive performance: An alternative paradigm**

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Abstract

This study investigated how the characteristics of the visual surrounding environment influence older and young adults' cognitive performance. Sixty-four older adults and 64 young adults performed four visual cognitive tasks (attention and memory tasks) in two independent sessions while being exposed to a high-load and a low-load visual surrounding environment. Considering the difficulties that older adults often have in ignoring irrelevant stimuli, we expected their performance to be poorer when exposed to the high-load as compared to the low-load environment. On the other hand, young-adults' performance, whose cognitive abilities are at their best, should be less susceptible to be influenced by this manipulation. Overall, our results were consistent with our prediction in three of the tasks (go/no-go, choice reaction time, and Corsi block-tapping). Additionally, the older adults performed worse than the young adults in all tasks, thus confirming expected age-related differences. Our results suggest that the difficulties displayed by the older adults in ignoring distractors when targets and distractors are in the same display (as revealed by the typical procedure) expand to paradigms in which the distractors are present in the surrounding environment.

Keywords: visual surrounding environment, older adults, young adults, attention, memory

Introduction

In our surrounding environment some visual stimuli are relevant to the task-at-hand (i.e., target information), whereas others are irrelevant information (i.e., distractors) (Forster & Lavie, 2011; Gilbert & Li, 2013). Some authors define *distractors* as the stimuli present at a given moment that are not directly related to the task-at-hand (non-target information). Distractors usually compete with target information and individuals should ignore them to successfully perform the task of interest (Gilbert & Li, 2013). The study of visual distraction in different age groups, particularly in older and young adults, has revealed that the capacity to ignore visual distractors is not the same across the lifespan (Gazzaley et al., 2008; Lavie, 2010). Specifically, older adults are more susceptible to process distractor stimuli when compared with young adults (e.g., Wais & Gazzaley, 2014), as we detail below.

Humans perceive environmental stimuli through a dynamic interaction between two neurocognitive mechanisms: bottom-up and top-down. In the first, processing of stimuli is mostly determined by their perceptive characteristics (e.g., novelty and salience), whereas in the top-down attention is directed to specific stimuli according to the goals of the ongoing task. A series of executive processes modulated by top-down control, such as selective attention, working memory, and inhibition, allows one to focus attention on the stimuli of interest while inhibiting distractors from entering such focus (e.g., Gazzaley & Nobre, 2012). In normal aging, executive processes tend to be less effective due to deterioration of the frontal lobes (e.g., Gazzaley & Nobre, 2012; Reuter-Lorenz, Festini, & Jantz, 2016). Consequently, the ability to inhibit irrelevant information and working memory capacity are less efficient, resulting in greater distractibility – the *inhibitory deficit hypothesis* (Gazzaley & Nobre, 2012; Hasher & Zacks, 1988). This hypothesis has been corroborated by several neurophysiological and behavioral studies (e.g., Brown, 2016; Gazzaley & D'Esposito, 2007; Gazzaley & Nobre, 2012). In this type of studies, targets and distractors are frequently presented in the same display, usually on a computer screen (e.g., Wais & Gazzaley, 2014). For example, several faces and scenes are randomly and singly presented on the screen, and participants are instructed to ignore the faces and memorize the scenes (or vice-versa); this ongoing working memory task requires the selection of the targets among distractors. Overall, results have shown that older adults' performance is worse when compared with young adults, particularly in demanding tasks containing irrelevant information that needs to be inhibited (e.g., Gazzaley & D'Esposito, 2007; Wais & Gazzaley, 2014). Such a result is usually related to the fact that the older adults' top-down control of the attentional and working memory processes is in decline contrasting with the young adults' performance whose cognitive functions are at their highest; thus, the ability of older adults to maintain the goals of a given task in an “online mode” while inhibiting distractors is impaired, resulting in poorer cognitive performance. This is the paradigm that underlies the *inhibitory deficit hypothesis* (Gazzaley & Nobre, 2012; Wais & Gazzaley, 2014).

The Load Theory of Attention, one of the most well-known theories in the study of selective attention (Lavie et al., 2004), also relates to how people perform in the presence of distractors. In a typical experimental procedure, a target letter has to be detected among distractor letters while both are presented on a computer screen (e.g., Lavie, 2010). This theory defends that the capacity to ignore distractors is related to the level of perceptual

load present in a given task. In particular, the distractors' interference is greater in conditions in which targets and distractors are dissimilar than in conditions in which they are similar (Forster & Lavie, 2011; Lavie et al., 2004). When dissimilar targets and distractors are presented, distractors are more likely to be processed, thus affecting cognitive performance, mostly because the cognitive control processes do not allow their effective rejection.

The extensive use of pure laboratory procedures has been crucial in experimental cognitive psychology and has allowed researchers to point out practical implications for the daily life of several age groups (e.g., Lavie, 2010). However, in everyday life, most visual distractors are embedded in the surrounding environment, and research has not yet systematically explored the potential impact of environmental distraction in cognitive performance, as measured by cognitive tasks. In other words, little is known about the capacity to ignore distractors in contexts that mimic real life more closely, as stressed by several authors (e.g., Choi, van Merriënboer, & Paas, 2014; Gifford, 2007).

The influence of several environmental variables (e.g., color, luminosity, the presence or absence of links with nature) has been investigated in different settings, such as in learning, clinical, organizational and forensic settings (Barrett, Davies, Zhang, & Barrett, 2016; Barry, 2008; Devlin & Andrade, 2017; Mastroberardino & Vredeveltdt, 2014). However, the potential impact of environmental distractors in cognitive processes that underlie many other complex processes is still poorly understood. A study by Fisher, Godwin, and Seltman (2014) provides an exception. In a within-subject design, twenty-four children ($M_{age} = 5.37$ years) participated in several lessons over two weeks. Half of the lessons occurred in a decorated classroom (containing visual elements typically found in schools, such as posters, maps and drawings), whereas the remaining lessons happened in a non-decorated classroom (a room without such visual elements). The order of the environmental manipulation alternated among lessons, with the first always occurring in the non-decorated classroom. The authors found that learning (as evaluated by tests on the contents covered throughout the classes) was poorer, that children were more distracted by the visual environment and that they spent more time off-task (as evaluated by video-recordings), when the classes occurred in the decorated classroom, when compared to the classes occurred in the non-decorated classroom. Rodrigues and Pandeirada (2015) also presented a study in which older adults ($M_{age} = 72.98$ years) performed cognitive tasks (e.g., simple reaction time and digit span) in two different visual surrounding environments separated by an interval of 14-21 days (within-subject

design). Importantly, in one of these conditions, the cognitive tasks were performed in a high-load visual environment containing potentially distracting visual elements in the wall that participants were facing while performing the tasks (e.g., posters and paintings), while, in the other (low-load visual environment), such distracting visual elements were absent. The order of the environmental manipulation, as well as of the cognitive tasks, was counterbalanced across participants. Overall, participants performed better in the distractors-absent than in the distractors-present condition, particularly in the visual attentional tasks.

The present study aimed to further investigate if the presence of visual elements in the surrounding environment (using an alternative manipulation procedure) influences performance on a different group of cognitive tasks and in two age groups. It presents two new insights when compared with the previous study of Rodrigues and Pandeirada (2015). Firstly, all of the current tasks had a visual nature (i.e., go/no-go, choice reaction time, Corsi block-tapping, and Rey Complex Figure), whereas in the previous study some tasks were visual (attention tasks) and the remaining were verbal (memory tasks); the go/no-go task (with some procedural differences) was used again for the sake of replicability of the results reported previously. This set of cognitive tasks increases the potential generalization of our findings as they address new processes, such as cognitive speed that involves choice (measured in the choice reaction time task) and visual working memory (assessed in the Corsi block-tapping and Rey Complex Figure). The results will allow us to explore if the difficulties previously reported likely imposed by the external environment in the older adults' performance extend to all of these new other tasks that (in spite of their particularities) have a common ground—they all recruit executive functions, or if they were specific to the tasks used in that study. If they do generalize, the results could support the *inhibitory deficit hypothesis* presented above. Indeed, the literature suggests that two of the employed tasks directly assess executive functions (go/no-go: inhibition; Corsi block-tapping: working memory), whereas the choice reaction time task provides an indirect measure (processing speed); finally, the Rey Complex Figure assesses executive functions (e.g., working memory and attentional control), as well as other cognitive functions (e.g., visuospatial abilities) (e.g., Diamond, 2013; Rey, 1988). Furthermore, the now employed tasks assess cognitive skills that are commonly used (sometimes simultaneously) in daily tasks; for example, both inhibition of distractor stimuli and working memory for visual information are required while

driving a car (e.g., Mäntylä, Karlsson, & Marklund, 2009). Secondly, this study used a cross-sectional procedure by testing two age groups of participants that are typically compared in this type of studies (e.g., Feng et al., 2017): older adults and young adults. The consideration of young adults as the comparison group allowed us to confirm that our tasks were sensitive to the age differences in cognitive performance typically reported between these age groups (Craik & Bialystok, 2006; Hartshorne & Germine, 2015). Also, we have different predictions for the effect of the environment in each group. According to the aforementioned decline of executive functions in older adults (Craik & Bialystok, 2006), we predicted that the older adults would perform worse in all tasks, when compared to the young adults. Furthermore, such decline should also manifest in difficulties to ignore distracting information, leading to the prediction that their performance would be poorer when tasks were performed in the high-load, as compared to when they are responded to in the low-load environment. On the other hand, such environment effect is unlikely to be obtained in the young adults whose cognitive abilities (including the ability to ignore distractors) are at their best level. The procedure included the participation of each person in two sessions in which they performed two visual attention (go/no-go and choice reaction time) and two memory tasks (Corsi block-tapping and Rey Complex Figure)¹. These tasks were chosen as they are relatively simple tasks, easy to implement in the two age groups, they are deprived of educational-dependent content (an aspect particularly relevant to the older group, who had a very low educational level), besides being frequently used in studies that compare performance between these age groups; these tasks involve (as mentioned before) executive functioning, which could be influenced by the presence of “distractors”. Importantly, one of the sessions occurred in a high-load and the other in a low-load visual surrounding environment.

Method

Participants

Our sample included 128 participants: 64 older adults aged 65-94 years (40 female; $M_{age} = 79.75$, $SD = 8.06$), and 64 young adults aged 18-29 years (49 female; $M_{age} = 21.53$, $SD = 3.21$). All participants included in the final sample were cognitively healthy and did not reveal visual problems (see the exclusion criteria in Supplemental Material [SM]-1).

¹ In spite of the differences between tasks already noted, we opted to present all cognitive tasks simply as visual tasks, given that they all are of visual nature.

About 58% of the older adults had less than four years of schooling, 34% had four years, 5% had five or six years, and 3% had seven or more years of schooling; they were recruited from local daycare centers (in these centers, individuals have a relatively independent lifestyle). Most of the young adults had 12 years of schooling (63%), 29% had a higher education level, and 8% had seven to nine years of schooling; they were recruited from academic and local communities. Participants were offered a book for their participation. Informed consent was obtained before participation and participants were debriefed at the end.

Materials

Personal information questionnaire. This questionnaire included sociodemographic questions, such as age, sex and health condition. This instrument was used to characterize the sample, as well as to provide information about the inclusion/exclusion criteria described in SM-1.

Attention tasks. The attentional tasks were visual and included the go/no-go and the choice reaction time tasks; these were programmed and ran using the software E-Prime 2.0 (Schneider, Eschman, & Zuccolotto, 2002).

Go/no-go task. Two different letters - *X* or *K* - were randomly and singly presented on the computer screen for a maximum of 600 ms; this was also the maximum time allowed for participants to provide their responses. Participants were instructed to respond as quickly and accurately as possible by selecting the “white” keyboard key when the *X* was presented (*go* stimulus) and not to respond when the *K* was presented (*no-go* stimulus). The *go* (*X*) stimulus appeared in approximately 66% of the trials and the *no-go* (*K*) in 33%. A white sticker was placed on the “space” bar of the computer keyboard; this corresponded to the “white” keyboard key. Trials began with a pre-fixation cross (500 ms) followed by the letter (for a maximum period of 600 ms) at one of four variable inter-trial intervals (500, 1000, 1500 or 2000 ms). The background of the computer screen was white, whereas the stimuli were in black. After 12 initial training trials, participants responded to 140 experimental trials. For a schematic illustration, see Figure 1(a).

When participants pressed the “white” keyboard key to the *go* stimuli, hits were recorded. False alarms occurred when participants pressed this key in response to the presentation of the *no-go* stimuli. Reaction times refer to the time occurring between the *go* stimulus presentation and the participant’s correct response. This task and dependent variable definitions are similar to the ones reported in several studies (e.g., Hirose et al., 2012; Steele et al., 2013).

Choice reaction time task. A green or a red rectangle was randomly and singly presented on the computer screen for a maximum of 600 ms; this was also the maximum time allowed for participants to provide their responses. Each stimulus was preceded by a pre-fixation cross (500 ms) and followed by one of four randomly picked inter-trial intervals (1000, 1500, 2000 or 2500 ms). Half of the rectangles were green and the remaining were red. Participants were instructed to respond as quickly and correctly as possible to each presented color by selecting the key on the keyboard marked with the corresponding color. A green sticker was placed on top of the “P” keyboard key and a red sticker was placed on top of the “Q” keyboard key. Participants initially responded to 12 practice trials for familiarization with the task, and then they performed 140 experimental trials. For a schematic illustration, see Figure 1(b).

The choice reaction time task generated correct responses when the corresponding key was selected, and errors when the opposite occurred. Response times corresponded to the time occurring between the stimuli presentation and the participant’s correct response. This task and definitions are similar to the ones reported by Kawashima et al. (1996).

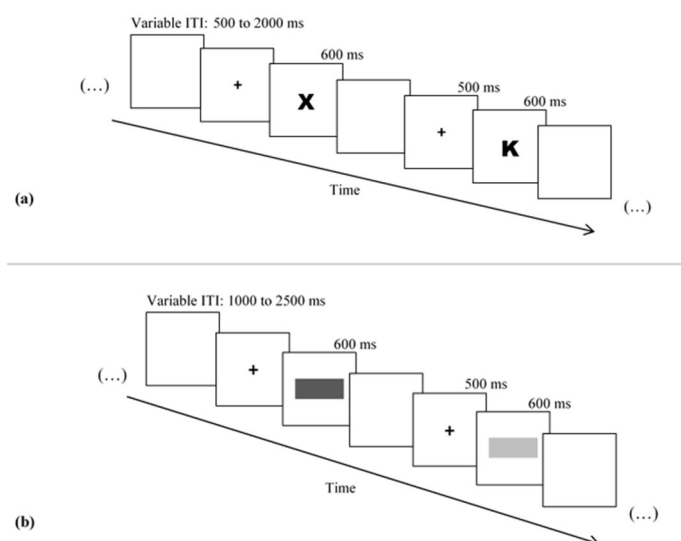


Figure 1: Schematic illustrations of the (a) go/no-go task and (b) choice reaction time task (for illustration purposes, the first rectangle in (b) would be of red color and the second of green color).

Memory tasks. The memory tasks included a computerized version of the Corsi block-tapping (Mueller, 2012), and the copy and the immediate recall of the Rey Complex Figure; the latter was administered in its traditional paper-and-pencil format (Rey, 1988). These memory tasks are of visual nature, although other cognitive processes are involved in the Rey Figure task (e.g., visuospatial skills and orientation) and in the Corsi task (e.g., spatial memory).

Corsi block-tapping. In the computerized version used in this research study (Mueller, 2012), nine blue squares were presented on a white screen background. On each trial, a given number of squares lit up (in yellow), one per second, producing a specific sequence. Participants were instructed to reproduce the sequence by clicking on the squares in the same order they had lit up - forward span. The extension of the sequence increased as the task progressed with two trials presented for each extension. The considered dependent variable was the Corsi span, which corresponds to the highest extension correctly reproduced by the participant (maximum of nine points).

Rey Complex Figure. We applied the *copy* and *immediate recall* administrations of the Rey Complex Figure (Rey, 1988). In the *copy* administration, participants were instructed to copy the *Rey Figure* while seeing the figure-stimulus. In the *immediate recall*, three minutes after finishing the copy, participants reproduced the Rey Complex Figure in the absence of the figure-stimulus. Both administrations were performed without any time limit, and participants were instructed to draw the figure as closely as possible to the original. Performance was scored according to the original instructions of the task (Rey, 1988).

Visual surrounding environments. Two visual environmental conditions created by the authors were used. The high-load visual surrounding environment consisted of a stand containing several visual elements, whereas the low-load visual condition consisted of the same stand without any visual elements (see Figure 2)².

² It should be noted that the designation of the two conditions here used serves the purpose of differentiating the two environments; we did not, objectively, assess their visual load, a concept that has been difficult to quantify (e.g., Murphy & Greene, 2016).

In both cases, the stand was always placed on the top of the table where the participant would be performing the tasks, producing a controlled surrounding environment. Therefore, while performing the tasks, participants were always facing the platform. Materials used in the high-load visual surrounding environment were selected from a pilot-study described in detail in SM-2. Briefly, this pilot-study allowed us to select a set of visual stimuli considered to be appealing by the age groups of participants under study in an effort to maximize their distracting potential.



Figure 2: Illustration of the visual surrounding environments: (a) Low-load visual surrounding environment used in both age groups; (b) High-load visual surrounding environment used with the older adults; (c) High-load visual surrounding environment used with the young adults.

Procedure

Data were collected individually. At the beginning of the first session, an initial screening and stimuli recognition task was conducted: each participant was presented several colors and the letters *X* and *K* in paper sheets, and participants were instructed to simply name each stimulus. These tasks allowed us to screen for visual difficulties or color identification problems (one older adult did not identify at least one of these stimuli and was, thus, excluded from the reported data; see SM-1). Then, each participant performed two sessions, one in each environment, with an interval of 14-23 days, similarly to what was reported by Rodrigues and Pandeirada (2015). Only the cognitive tasks were submitted to the environment manipulation; all four cognitive tasks (the two attentional and the two memory tasks) were administered in both environmental conditions. The three computerized tasks (*go/no-go*, choice reaction time, and Corsi block-tapping) were performed on a 14" laptop, while the Rey Complex Figure was performed in a paper-and-pencil format. The order of the environment and of the cognitive tasks was counterbalanced across participants within each age group in order to minimize potential practice effects on the cognitive tasks (due to the repeated administration) or of the task order (see SM-3 for the counterbalancing versions of the

environment and of the cognitive tasks). Sessions always occurred in an isolated room and at about the same time of the day for each participant to prevent any chronotype effects; that is, if a participant performed the first session during the morning period, the second session was conducted during the same period of the day (Schmidt, Collette, Cajochen, & Peigneux, 2007).

Statistical analyses

The influence of the surrounding environment (high-load vs. low-load visual environment; within-subject factor) and of age group (older adults vs. young adults; between-subjects factor) on the dependent measures were analyzed using mixed analysis of variance (ANOVAs). Additional paired *t*-tests were performed within each age group to clarify interactions when these were found to be significant. For all statistical analyses, an alpha level of .05 was considered. In the two attentional tasks, trials with response times shorter than 150 ms were excluded, because they probably correspond to anticipatory responses (e.g., Hirose et al., 2012) (see detailed information about the outlier exclusion procedure in SM-4).

Results

The descriptive values of all dependent variables are presented in Tables 1-3 along with the main statistical results; these are described in detail next.

Attentional tasks

Go/no-go. For the percentage of hits and omissions, the main effects of environment and of age group were significant as well as the interaction between them (see Table 1). The additional paired *t*-tests within each group conducted to clarify these interactions revealed that the older adults had fewer hits, $t(63) = 2.72, p = .008$, *Cohen's d* = 0.35, and more omissions when responding in the high-load visual surrounding environment, when compared to the low-load environment, $t(63) = 2.74, p = .008$, *Cohen's d* = 0.35. No differences were obtained in the young adults group ($ps > .293$). Regarding the false alarms, only the main effect of age group was significant, reflecting a higher percentage of false alarms in the older adults. All effects were also significant

for the reaction times to the hits, including the Group X Environment interaction (see Table 1). This interaction results from the fact that the older adults were significantly faster to provide their responses when the task was performed in the low-load than in the high-load visual environment, $t(63) = 2.50, p = .015, \text{Cohen's } d = 0.49$; but, again, no difference between environments occurred in the young adults ($p = .936$).

[see Table 1]

Choice reaction time. The repeated measure ANOVAs revealed a significant main effect of the age group for the three variables, indicating that the young adults obtained more correct responses, fewer errors, and were faster to provide correct responses than the older adults. For the percentage of correct responses, a significant main effect of the environment, as well as a significant Group X Environment interaction, was obtained (see Table 2). The follow-up paired t -tests confirmed that the older adults had fewer correct responses when responding in the high-load than in the low-load visual surrounding environment, $t(63) = 4.07, p < .001, \text{Cohen's } d = 0.53$; however, this same result was non-significant for the young adults ($p = .938$). Regarding the reaction times for the correct responses, a significant main effect of the environment was found, but the interaction was non-significant; the follow-up paired t -tests revealed no significant differences between environments in either group (lowest $p = .05$, for the older adults). For the errors, neither the main effect of environment, nor the Group X Environment interaction, was significant (see Table 2).

[see Table 2]

Memory tasks

Corsi block-tapping. Significant main effects of the environment, age group and interaction between them were found on the Corsi span; in particular, the older adults performed worse than the young adults, but the significant effect of the high-load visual surrounding environment (as compared with the low-load environment) was obtained only for the older adults, as revealed by the significant additional paired t -test performed for this group $t(63) = 6.52, p < .001, \text{Cohen's } d = 0.83$. Such result was non-significant for the young adults ($p = .630$). See Table 3.

Key Complex Figure. Young adults' copy and immediate memory performance were significantly better than that of the older adults (main effect of age group), but the main effect of the environment and the interaction were not significant (see Table 3 for the descriptive values and statistical results). Of note, the copy procedure was applied as a requirement to the immediate recall. However, this was an important result to consider as *a priori* differences in this task could mediate possible differences in the memory task. Similarly to the results obtained in the immediate memory task, only the main effect of age was significant in this task with the young adults performing better than the older adults.

[see Table 3]

Discussion

Our work explored if the presence of visual elements in the surrounding environment would affect cognitive performance in older adults and young adults. Although the effect of irrelevant information (distractors) has been widely studied in different ways involving computer display (e.g., Konstantinou, Beal, King, & Lavie, 2014; Wais & Gazzaley, 2014), and its effect on cognitive performance widely reported (e.g., Lavie et al., 2004; Gazzaley & Nobre, 2012), little is known about what happens when these distractors occur in the surrounding environment; this is particularly true when both older adults and young adults are tested with the same procedure.

The current work combines the experimental rigor of validated cognitive tasks, with a manipulation of the surrounding environment. Although we remained within the laboratory context, this type of manipulation brings the procedure one step closer to everyday situations as compared to the distraction manipulations embedded on the computer screen that are typically used in this line of research. Following the idea that distracting stimuli that differ from the target stimuli have a higher interference potential (e.g., Lavie et al., 2004), we created a surrounding environment condition containing a variety of stimuli that differ from those present in the main tasks; such a setting should pose a higher demand on participants' cognitive resources (Lavie, 2005, 2010). Furthermore, we compared the effect of our environment manipulation in older adults and young adults, two age groups that differ markedly in their cognitive abilities. The characteristic top-down suppression deficit in the older adults (inhibitory deficit

hypothesis), which underlies difficulties in inhibiting distractors or in exerting an effective cognitive control of attention, lead us to predict that these participants would be particularly affected by the presence of a distracting environment. Contrarily, the young adults' performance would not be (as) influenced by the presence of the distractors, as their cognitive abilities are at their best (Gazzaley & Nobre, 2012; Hasher & Zacks, 1988; Treitz et al., 2007).

Our results were mostly consistent with our predictions. First, we replicated the oft-reported age differences in cognitive performance between the young and the older adults in all four tasks, with the older adults performing poorer than the young adults in all tasks (Craig & Bialystok, 2006; Sander, Lindenberger, & Werkle-Bergner, 2012). Secondly, the older adults obtained significantly fewer correct responses in both the attentional tasks when the tasks were performed in the high-load than when they were performed in the low-load visual environment. In the go/no-go task, they also took longer to respond correctly and provided more omissions in the high-load than in the low-load environment. In this task, in which participants need to inhibit two sources of distraction (the no-go stimuli and the environmental elements), we obtained environmental effects in three of the four variables. Thus, known to assess inhibitory capacity, performance in this task was affected in a larger number of variables by the environmental manipulation. These results replicate those reported by Rodrigues and Pandeirada (2015) in the go/no-go task and provide support for the inhibitory deficit hypothesis. Of note, in the study of Rodrigues and Pandeirada (2015), a significant effect of the environment manipulation on the false alarms was also reported ($d = .364$), a result that was not obtained in the present study (although, descriptively, our results were in the predicted direction). This disparate result could relate to differences in the task, that is, the percentage of the go-stimuli was of about 50% in that study and of 66% in the current work, likely leading to different expectations in responses (Young, Sutherland, & McCoy, 2018); it is also possible that the likelihood of false alarm responses in this task is not strongly influenced by our environmental manipulation.

Regarding the memory tasks, and in contrast to the results reported by Rodrigues and Pandeirada (2015) of no effect of the environment in performance, in the current study, the memory span (from the Corsi task) was impaired when the task was performed in the high-load (than in the low-load) environment. This discrepancy in the results might be due to the different memory tasks used in the two studies; whereas the memory task used by Rodrigues and Pandeirada was of auditory nature (and thus potentially less

influenced by the visual distractors), here it relied on visual stimuli (as the distractors) which likely increased the competition between targets and distractors.

The Rey Complex Figure is a particular case as it assesses visual memory, but also visuospatial skills that are related to attention and working memory. This task allowed us to explore if our environmental manipulation would influence cognitive performance in a broader way. No effect of the environment was obtained on the performance of this task which could be related to the form of responding. Being a paper-and-pencil task, attention is directed to a visual field that is less exposed to the distracting panel displayed in front of the participant. Thus, it is possible that participants were more capable of maintaining their focus on the task and be less influenced by the surrounding environment.

In agreement with the notion that the young adults' cognitive abilities are at their peak (Craik & Bialystok, 2006; Hartshorne & Germine, 2015), including the capacity to unattend to distractors, their performance was not influenced by our manipulation of the environment. On the other hand, our results suggest that dealing with a visually-rich external environment can be particularly challenging for older adults when performing cognitive tasks that require their attention and memory. Indeed, several authors argue that attention and memory are the pillar of most everyday tasks and, thus, their impairment has potential impacts on the daily lives of the older adults (e.g., Gazzaley & Nobre, 2012; Wais & Gazzaley, 2014). This study joins the few studies that have shown that the surrounding environment affects basic (e.g., simple reaction time in older adults; Rodrigues & Pandeirada, 2015), as well as more elaborate processes (learning gains in children; Fisher et al., 2014). This work also extends the experimental paradigm presented by Rodrigues and Pandeirada (2015) to tasks that tap other cognitive processes and to a different manipulation of the environment. Importantly, it reveals that the detrimental effect of the presence of distractors in the surrounding environment is obtained in cognitive functions, which had not been tested in their initial work (e.g., spatial span). Finally, the inclusion of the young-adults group provides a developmental dimension that helps to understand our data.

Our findings may have direct and indirect applications, such as in clinical settings. For example, the result of a neuropsychological assessment based on computerized visual tasks/tests might not be reliable if it is conducted in a visually-rich surrounding environment. Similarly, if a doctor's appointment is held at an office containing visual displays, these could compromise the attention that the older adults are able to give to

important medical information. We can also ponder about what it is like for older adults to drive in a road surrounded by advertising posters. According to studies in which digital and static billboards are displayed and various variables of interest are assessed during a driving simulation, driver distraction is a very relevant cause of motor vehicle collisions (e.g., Decker et al., 2015). Additionally, Edquist, Horberry, Hosking, and Johnston concluded that “the presence of billboards changed drivers’ patterns of visual attention, increased the amount of time needed for drivers to respond to road signs, and increased the number of errors” (2011, p. 619), particularly in older drivers. Such conclusion is consistent with the data obtained in our study. This issue is particularly relevant considering that the percentage of older drivers is increasing in several parts of the world (e.g., in the USA, National Center for Statistics and Analysis, 2017) and they constitute one of the high-risk groups for car crashes (see Insurance Information Institute, 2018). However, this latter example should be taken as an indirect implication as the setting we used differs in important ways from what happens in real driving: in our case, the “distractors” were static, whereas during a driving simulation, even though the distractors might also be static (e.g., billboards), the information in the visual field is constantly changing with the car’s movement³. Furthermore, while driving involves some of the cognitive functions considered in our study (e.g., inhibition and working memory; Mäntylä et al., 2009), it also encompasses other abilities not covered in our work.

This study presents an alternative paradigm to explore the influence of the surrounding environment on basic cognitive tasks, but additional work is needed to further establish it as we tested only one type of visual display in a limited set of tasks. For example, future studies should employ other types of distracting settings, as well as manipulate its characteristics similarly to what is done in more traditional procedures in the area (e.g., manipulate the amount and variability of the surrounding distractors; Forster & Lavie, 2011; Forster & Lavie, 2014; Lavie et al., 2004; Nagy & Thomas, 2003). In the same vein, one could explore if the relation/similarity between the elements displayed in the environment and those of the task-at-hand (both visual and sensorial modality similarity) differently impact cognitive performance; this procedure could be employed with laboratorial and ecological tasks. Also, exploring how visual elements typically found in specific contexts influence more basic cognitive performance would

³ A special acknowledgment is due to the Editor and Reviewers for their constructive comments on the implications of our findings.

add external validity to our procedure and increase the potential applied implications of the obtained results. Although we have been stressing the negative potential impact of the stimulation afforded by the surrounding environment, we should note that it may also have positive effects. For example, environmental stimuli (e.g., colors) could be used as cues to perform certain actions, such as to identify objects related to daily activities (e.g., patients with dementia; Motzek, Bueter, & Marquardt, 2015) or to enhance creative thinking (e.g., Ceylan, Dul, & Aytac, 2008).

We speculate that the negative effect of our visually-charged surrounding environment on the older adults' performance was due to distraction. Such hypothesis should be examined in future studies using, for example, objective behavioral measures, such as eye-tracking and video-recording, similarly to what has been done with children (e.g., Hanley et al., 2017; and Fisher et al., 2014, respectively). Another variable of potential relevance to future studies is the participants' circadian preferences. In the present study, the time of the day in which each participant performed the tasks was the same but we did not consider whether this corresponded to each participant's preferred time of the day or not. It is conceivable that their abilities to inhibit distractors could be higher during their preferred time as compared to their less preferred time of day (e.g., Song et al., 2018). A (possible) demonstration of such chronotype synchrony effect could have applied implications.

The current study should be considered as an initial effort towards the understanding of how the surrounding environment impacts our cognition. Although other types of applied studies have been conducted in several contexts, our work investigated the influence of the surrounding environment on cognitive processes that underlie more complex tasks explored in other studies (e.g., driving; Decker et al., 2015). Understanding how the external environment affects the bricks that together build more complex processes is essential to help more vulnerable populations thrive in their daily lives.

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Table 1

Means (and Standard Deviations) obtained for the hits, false alarms, and reaction times for the hits in older and young adults, and in each environmental condition, for the **go/no-go task**. The statistical results of the mixed ANOVA (main effect of environment, of age group, and interaction between them) are also presented.

	High-load environment		Low-load environment		
	Older adults	Young adults	Older adults	Young adults	
Hits (%)	59.05**	97.98	68.11**	98.43	<i>Environment:</i> $F(1,126) = 8.01, p = .005, \eta_p^2 = 0.06$ <i>Age group:</i> $F(1,126) = 147.70, p < .001, \eta_p^2 = 0.54$ <i>Interaction:</i> $F(1,126) = 6.55, p = .012, \eta_p^2 = 0.05$
	(26.23)	(5.49)	(25.85)	(3.81)	
Omissions (%)	40.94**	2.02	31.88**	1.57	<i>Environment:</i> $F(1,126) = 8.01, p = .005, \eta_p^2 = 0.06$ <i>Age group:</i> $F(1,126) = 147.70, p < .001, \eta_p^2 = 0.54$ <i>Interaction:</i> $F(1,126) = 6.55, p = .012, \eta_p^2 = 0.05$
	(26.23)	(5.49)	(25.85)	(3.81)	
False alarms (%)	9.98	7.05	8.95	6.42	<i>Environment:</i> $F(1,126) = 2.04, p = .156, \eta_p^2 = 0.02$ <i>Age group:</i> $F(1,126) = 6.62, p = .011, \eta_p^2 = 0.05$ <i>Interaction:</i> $F(1,126) = .112, p = .728, \eta_p^2 = 0.001$
	(8.61)	(5.03)	(7.60)	(5.48)	

Reaction times	456.50*	346.10	436.20*	346.32	Environment: $F(1,126) = 5.49, p = .02, \eta_p^2 = 0.04$
(ms)	(51.24)	(28.18)	(56.19)	(29.47)	Age group: $F(1,126) = 251.98, p < .001, \eta_p^2 = 0.67$
					Interaction: $F(1,126) = 5.73, p = .02, \eta_p^2 = 0.04$

Notes: ** paired t-test with $p < .01$; * paired t-test with $p < .05$; statistically significant effects are noted in bold. Percentage of hits = #hits/(#go trials - #go outliers)*100. Percentage of omissions = #omissions/(#go trials - #go outliers). Percentage of false alarms = #false alarms/(# no-go trials - #no-go outliers)*100.

Table 2

Means (and Standard Deviations) obtained for the correct responses, errors, and reaction times for the correct responses in older and young adults, and in each environmental condition, for the **choice reaction time task**. The statistical results of the mixed ANOVA (main effect of environment, of age group, and interaction between them) are also presented.

	High-load environment		Low-load environment		
	Older adults	Young adults	Older adults	Young adults	
Correct responses (%)	44.40***	94.06	57.60***	94.17	<i>Environment:</i> $F(1,126) = 14.51, p < .001, \eta_p^2 = 0.10$ <i>Age group:</i> $F(1,126) = 248.23, p < .001, \eta_p^2 = 0.66$ <i>Interaction:</i> $F(1,126) = 14.05, p < .001, \eta_p^2 = 0.10$
	(23.80)	(6.94)	(25.69)	(8.64)	
Errors (%)	6.07	2.72	5.37	2.95	<i>Environment:</i> $F(1,126) = 0.59, p = .45, \eta_p^2 = 0.005$ <i>Age group:</i> $F(1,126) = 22.00, p < .001, \eta_p^2 = 0.15$ <i>Interaction:</i> $F(1,126) = 2.32, p = .13, \eta_p^2 = 0.02$
	(5.07)	(2.18)	(4.84)	(2.50)	
Reaction times to correct responses (ms)	447.75	359.85	438.13	354.61	<i>Environment:</i> $F(1,126) = 4.51, p = .036, \eta_p^2 = 0.04$ <i>Age group:</i> $F(1,126) = 175.82, p < .001, \eta_p^2 = 0.58$ <i>Interaction:</i> $F(1,126) = 0.390, p = .533, \eta_p^2 = 0.003$
	(54.19)	(29.97)	(45.68)	(31.80)	

Notes: *** paired *t*-test with $p < .001$; statistically significant effects are noted in bold. Percentage of correct responses = #correct responses/(140 - #outliers)*100. Percentage of errors = #errors/(140 - #outliers)*100.

Table 3

Means (and Standard Deviations) obtained for the memory tasks in older and young adults, and in each environmental condition - **Corsi block-tapping and Rey Complex Figure.**

	High-load environment		Low-load environment			
	Older adults	Young adults	Older adults	Young adults		
Corsi block-tapping	3.86***	5.58	4.56***	5.56	Environment:	$F(1,126) = 20.29, p < .001, \eta_p^2 = 0.14$
	(0.90)	(0.86)	(0.73)	(0.89)		Age group:
Memory span					Interaction:	$F(1,126) = 22.20, p < .001, \eta_p^2 = 0.15$
Rey Complex Figure	26.30	34.43	26.66	34.66	Environment:	$F(1,126) = 2.79, p = .10, \eta_p^2 = 0.02$
	(5.56)	(1.84)	(5.19)	(1.16)	Age group:	$F(1,126) = 142.09, p < .001, \eta_p^2 = 0.53$
Copy [#]					Interaction:	$F(1,126) = 0.143, p = .71, \eta_p^2 = 0.001$
Immediate recall	18.35	29.30	19.06	29.02	Environment:	$F(1,126) = 0.27, p = .61, \eta_p^2 = 0.002$
	(5.80)	(5.25)	(5.61)	(5.80)	Age group:	$F(1,126) = 134.24, p < .001, \eta_p^2 = 0.52$
					Interaction:	$F(1,126) = 1.42, p = .24, \eta_p^2 = 0.01$

Notes: *** paired *t*-test with $p < .001$; statistically significant effects are noted in bold; # this procedure was applied only as a requirement to the immediate recall (our central variable which is related to visual memory).

Supplemental Material 1

Detailed characterization of the sample and exclusion criteria

The final sample was composed of 128 participants (64 older adults and 64 young adults). The older adults (40 female) aged between 65 and 94 years and were recruited from five social institutions of the Aveiro district (Portugal). The young adults (49 female), aged between 18 and 29 years, were mostly students from the University of Aveiro.

The following exclusion criteria were applied to both age groups: a) to be unable to recognize the stimuli used in the cognitive tasks; b) to have a clinical score in the Vocabulary and Cubes subtests of the Wechsler Adults Intelligence Scale-III (WAIS-III; Wechsler, 2008); c) to have a history of neurological and/or psychological disorders; d) to be illiterate. One additional exclusion criterion was used for the participants aged 25 years-old or older: to obtain a score in the Mini-Mental State Examination indicative of a clinical condition. Participants who complied with at least one of these criteria were excluded. Information about the history of neurological or psychological problems and about illiteracy was obtained through the Sociodemographic Questionnaire and also confirmed by institutional technicians in the case of the older adults. The procedures used to screen for the remaining criteria are briefly described next and were applied at the beginning of the first session.

Visual screening and stimuli recognition: This brief screening consisted of the presentation of several colors and the letters *X* and *K*; participants were instructed to simply name each stimulus. One older adult did not identify at least one of these stimuli and was, thus, excluded from the reported data.

Mini-Mental State Examination (MMSE; Guerreiro et al., 1994): This brief paper-and-pencil instrument is one of the most used tests to screen cognitive performance (5-10 minutes). It is composed of 30 questions divided in 6 cognitive domains: orientation, registration, attention and calculation, recall, language, and constructive capacity. In a Portuguese validation study (Guerreiro et al., 1994), values of sensitivity ranging between 63.6% and 77.4%, and of specificity between 90% and 96.8% were obtained (Freitas, Simões, Alves, & Santana, 2015). This instrument is usually applied in different contexts

and has been subjected to several validation studies in Portuguese population^{**}, ^{††}. Considering that the MMSE has been validated only for people aged 25 years or older, it was applied only to participants of this age range; younger adults performed a simple attentional task (paper-and-pencil format) that took approximately the same amount of time to complete as the MMSE.

The cut-off points for the Portuguese population (≥ 25 years old; Freitas et al., 2015) considered for the inclusion/exclusion criterion, differed across participants depending on their age and educational level. Three older adults were excluded from the data analysis due to clinical score in the MMSE.

Vocabulary and Cubes – Subtests of the Wechsler Adults Intelligence Scale-III (WAIS-III; Wechsler; 2008). The measurement of intelligence is characteristic in cross-sectional studies (e.g., Leiva, Andrés, Servera, Verbruggen, & Parmentier, 2016). The WAIS-III is a battery of tests that allows the assessment of global intellectual functioning and includes two different subscales: verbal and realization. In this study we applied a short-form of this battery that includes the *vocabulary* and *cubes* tasks; combined, the results of these tasks have revealed a very good correlation with the total scale (Coutinho & Nascimento, 2010; Hoffman & Nelson, 1988). The *vocabulary* subtest belongs to the verbal subscale and is composed of a group of words; each word is presented individually to the participant (oral and visually) who is instructed to provide its meaning orally. The *cubes* subtest belongs to the realization subscale; during this task, geometric models are presented in a notepad and the participant is instructed to reproduce the presented model using bicolor cubes. For both subtests, we used the cut-offs for the European Portuguese population (≥ 16 years old) which were determined according to the age of each participant (Wechsler, 2008). No participants were excluded due to this criterion.

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^{**} Cut-offs for people aged ≥ 25 years (Freitas et al., 2015).

^{††} Cut-offs for people aged ≥ 36 years (Santana et al., 2016).

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Supplemental Material 2^{††}

Environmental conditions: High- vs. low-load visual surrounding environments

This Supporting Information describes the procedure followed to select the stimuli that were placed on the stands were used to produce the high-load visual surrounding environment. An illustration of the various platforms used in the study is also provided.

The high-load visual surrounding environment included a stand displaying potentially distracting pictures,^{§§}; the low-load visual surrounding environment consisted of a replica of that same stand but free of pictures. The stand was always placed on top of the table where the participant would be performing the tasks (cf. Figure S1). This procedure allowed us to present a similar visual field (a controlled environment) to all participants, an important detail considering that the experiment was implemented in different institutions that varied in their conditions.

The pictures used in the high-load visual surrounding environment were submitted to a previous study in order to select sets of pictures that would be considered equally interesting by different age groups. To this end, we collected from the internet a set of 110 pictures freely available. Various themes of potential interest were used for two reasons: 1) we did not want to present irrelevant information related to one specific theme as this would likely not be equally appealing to the different age groups being tested; and, 2) the presentation of appealing pictures that vary in their perceptual characteristics (as compared, for example to only presenting scenery pictures) would also increase the possible effect of the surrounding environment in cognitive performance. Also of note is the fact that the selected visual images were not related with any of the used tasks. Such procedural option reinforced their distractor nature as a distractor tend to refer to irrelevant information to the performance of a given task (e.g., Gilbert & Li, 2013).

^{††} The description of this pilot-study procedure might resemble the information presented in the Supplemental Materials of other publications as it supported the selection of stimuli used in other studies.

^{§§} Distractors refer to all stimuli presented in a given situation but that are not directly related to the task-at-hand. In a given moment this non-target information often competes with the target stimuli (those that actually require a response from the individual) for cognitive resources (Gilbert & Li, 2013).

Different age groups will likely have different interests, their attention will be “automatically” drawn by different stimuli, and we are frequently immersed in environments containing a mixture of these stimuli. To ensure that we were selecting sets of pictures that varied in their relevance to different age groups, independent samples of different ages participated in the pilot-study. Each age group included 15 participants as follows: children (7 females) aged 8-12 years ($M_{age} = 9.00$, $SD = 1.25$); adolescents (7 females) aged 13-17 years ($M_{age} = 14.07$, $SD = 1.39$); young-adults (9 females) aged 18-30 years ($M_{age} = 24.07$, $SD = 3.49$); and, older adults (8 females) aged 65-92 years ($M_{age} = 78.87$, $SD = 8.37$). The pilot-study was performed in groups of 4 to 10 participants.

During the pilot-study, the 110 pictures were presented one at a time to participants who were instructed to rate how appealing each picture was to them; to this end, they used a scale in which responses varied between “nothing appealing/interesting” (1 point) to “very appealing/interesting” (5 points). Responses were made on a paper sheet containing the picture numbers and the possible rating values. Participants responded by making a circle or cross on their selected number. The older adults were assisted by a researcher in the marking of their responses.

As shown in Figure S1, the platform used in the high-load visual surrounding environment included 4 rows of pictures in the front panel plus four pictures in each of the two lateral panels. For each age group, we selected the four pictures that were rated the highest and that, at the same time, had not been considered by another age group as highly interesting. Each of these sets was presented in one of the front panel rows. To maximize the potential effect of our manipulation of the surrounding visual environment on cognitive performance, the set of pictures considered most appealing to the age group being tested was placed in the most “visible” position. Therefore, for the older adults group, the first bottom row (the one closer to the laptop screen where most tasks were displayed) included the four pictures considered more appealing to them; the second, third and fourth rows included those that had been considered most attractive by young adults, adolescents and children, respectively. However, for the young adults, the disposition of the pictures corresponded to the preferences of the following age groups (from the bottom to top rows): young adults, adolescents, children and older adults. The two lateral panels of the stand contained pictures that were classified as equally appealing by the four age groups. Overall, in the high-load visual environment each participant was exposed to 24 pictures.

Reference

Gilbert, C. D., & Li, W. (2013). Top-down influences on visual processing. *Nature Reviews Neuroscience*, 14, 350-363. doi:10.1038/nrn3476



Figure S1. Visual surrounding environments: (a) The low-load visual surrounding environment used in both age-groups – stand without visual elements; (b) The high-load visual surrounding environment used with the older adults; (c) The high-load visual surrounding environment used with the young adults.

Supplemental Material 3

Counterbalancing versions of the environment and of the cognitive tasks

As described in the Method of the main manuscript, the order of the environment and of the tasks was counterbalanced across participants to avoid the effects of order of task and of fatigue. Furthermore, only the four cognitive tasks were subjected to the environmental manipulation; the remaining instruments (e.g., Sociodemographic Questionnaire and Mini-Mental State Examination) were completed on a side table without the exposure to the stand. We also applied other instruments to participants that were not related to the tasks of main interest; because their results are out of the aims of the present work, these are not presented in the paper. It is important to mention that the two sessions were of similar duration, particularly before the application of the cognitive tasks. Each participant concluded each session (which included the four cognitive tasks and the remaining instruments) in about 60 minutes.

In Table S1, we present the eight possible counterbalancing orders of environmental manipulation and of cognitive tasks that were used.

Table S1

Counterbalancing versions of the environmental manipulation and of the cognitive tasks.

<u>Participant#</u>	<u>Order of environment</u>		<u>Order of cognitive task</u>			
	<u>High-load</u>	<u>Low-load</u>	<u>Corsi blocks</u>	<u>Go/no-go</u>	<u>Rey</u> <u>Complex Figure</u>	<u>Choice</u> <u>reaction time</u>
1	1	2	1	2	3	4
2	1	2	2	3	4	1
3	1	2	3	4	1	2
4	1	2	4	1	2	3
5	2	1	1	2	3	4
6	2	1	2	3	4	1
7	2	1	3	4	1	2
8	2	1	4	1	2	3
(...)	(...)	(...)	(...)	(...)	(...)	(...)

Notes: The first column corresponds to the participant number; the remaining columns indicate the order in which the environment was manipulated and the cognitive tasks were implemented. For example, participant# 1 performed the first session in the high-load surrounding environment, whereas the second session was realized in the low-load environment. In each of the sessions, the participant performed firstly the Corsi blocks, secondly the go/no-go, then the Rey Complex Figure and finally the choice reaction time. As for participant# 5, the first session occurred in the low-load environment whereas the second occurred in the high-load environment; the order of the tasks for this participant was the same as for participant# 1.

Supplemental Material 4

Exclusion of outlying reaction times

In attention tasks, it is usual to exclude trials with reaction times < 150 ms, which possibly correspond to anticipatory responses (e.g., Amano et al., 2006; Hirose et al., 2012). We also adopted this procedural option and present results without these trials (< 150 ms).

Below, we present the means (and *SD*'s) of the trials that were excluded; these descriptive data is provided by environment and by age-group, for each attention task (go/no-go and choice reaction tasks). For each task, we also conducted a repeated measures ANOVA to understand if the number of the eliminated trials differed by age-group and by environment; the number of excluded trials was consider a within-subjects factor and the age-group a between-subjects factor.

Go/no-go

A main effect of the age-group was found, $F(1, 126) = 11.79, p = .001, \eta_p^2 = .086$, whereas no-statistical effects were found to environment ($p = .396$) nor to interaction ($p = .253$) (see Table S2 for descriptive values).

Table S2

Means (and SD's) of the trials that was excluded by environment and by age-group – Go/No-Go task.

	Young-adults	Older adults
High-load environment	0.63 (0.24)	1.64 (4.23)
Low-load environment	0.00 (0.00)	2.06 (4.86)

Choice reaction time task

A similar pattern of results was found to the choice reaction time task; a main effect of the age-group was also found, $F(1, 126) = 13.65, p < .001, \eta_p^2 = .098$, whereas no-statistical effects were found to environment ($p = .940$) nor to interaction ($p = .822$). See Table S3 for descriptive values.

Table S3

Means (and SD's) of the trials that was excluded by environment and by age-group-Choice reaction time.

	Young-adults	Older adults
High-load environment	0.05 (0.21)	1.83 (5.33)
Low-load environment	0.14 (0.69)	1.78 (3.30)