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The Influence of a Visually-Rich Surrounding Environment in Visuospatial Cognitive Performance: A Study with Adolescents

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ABSTRACT
Adolescence is a developmental period characterized by a complex maturation process of various cognitive abilities. Cognitive control, which includes response inhibition and working memory, is one of them. A typical study on response inhibition to visual stimuli presents distractors and targets on the same display (e.g., the computer screen). However, in most daily activities, the potential for distraction exists in the individuals' surrounding environment. This study proposes an alternative experimental paradigm to investigate whether a high- *vs*. a low-load visual surrounding environment influences adolescents' visuospatial performance. Sixty-four adolescents (aged 13–17 years) participated in two experimental sessions (one in a high-load and the other in a low-load visual surrounding environment) in which they responded to four visuospatial cognitive tasks (attention and memory). Overall, the results revealed lower performance when the tasks were performed in the high-load environment (e.g., fewer hits and correct responses, and more false alarms and errors). These results suggest that more attention should be devoted to the potential effect of the external environment in adolescents' everyday activities. We discuss various areas to which these data might be of relevance and make suggestions for future directions of the proposed procedure.

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Introduction

Adolescence is a phase between childhood and adulthood with marked brain development in which cognitive functions are still maturing (Luna, 2009; Rubia, 2013). Although many researchers consider this phase as a bridge between childhood and adulthood, others have shown that it is a complex period and stress the need to study new models and/or re-evaluate existing models of cognitive processing in adolescents (e.g., Crone & Dahl, 2012; Dahl, Allen, Wilbrecht, & Suleiman, 2018). Indeed, not all cognitive skills seem to develop at the same rate within this period (e.g., Crone & Steinbeis, 2017; Luciana, Conklin, Hooper, & Yarger, 2005).

The ability to manage the enormous amount of stimuli around us at a given moment is among the cognitive functions still under development in adolescence and is vital for the interaction with the surrounding environment (Gilbert & Li, 2013; Luna, 2009). Ideally, individuals should be able to maintain their focus to the task at hand and maintain their

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Supplementary material for this article can be accessed here.

course of action while filtering out distractors; this ability has been conceptualized as voluntary response suppression or inhibitory control (Luna, 2009). Two strongly-related mechanisms seem to be essential to obtain such control: bottom-up and top-down (Theeuwes, 2010). The first allows us to select stimuli according to their salience and novelty (i.e., stimulus-driven), whereas in the second, the stimuli are selected according to our goals and expectations (i.e., goal-driven) (Theeuwes, 2010). The still immature cognitive system of adolescents, particularly the top-down cognitive control (Hwang, Velanova, & Luna, 2010), makes them vulnerable to the influence of the visual external environment, that is, to distraction.

Distraction refers to the inability or difficulty to maintain attention to target stimuli when irrelevant information (i.e., distractors) is present (Gilbert & Li, 2013). Most studies on distraction have been framed on the Perceptual Load Theory (Lavie, 2010) and use a procedure in which targets and distractors are embedded in the same display, usually the computer screen (e.g., Spronk, Vogel, & Jonkman, 2012). Typically, target stimuli (e.g., a number or letter) are presented on the center of the computer screen under a low- (e.g., targets and non-targets are dissimilar) or a high-perceptual load (e.g., targets and non-targets are similar) condition; the distractors are usually presented in a peripheral position; Participants are instructed to identify whenever the target stimuli is presented (e.g., Lavie, 2010). The results usually indicate that when targets and distractors are perceptually different, processing of the latter increases as early attention selection is more influenced by their perceptual features (e.g., Couperus, 2011).

More recently, a few studies have attempted to study distraction using procedures that more closely reproduce real-life settings. For example, Fisher, Godwin, and Seltman (2014) studied how the classroom decoration affected children's attention and their learning gains. Children attended to several videotaped lessons over two weeks; half of the lessons were taught in a decorated-classroom (i.e., a laboratory classroom with various visual elements displayed) whereas the other half was taught in a sparse-classroom (i.e., the same room but without visual elements). After each lesson, children's learning of the presented material was assessed. The results indicated that learning gains were lower, and children spent more time off-task, when in the decorated-classroom than when in the sparse-classroom condition.

Rodrigues and Pandeirada (2015) explored the influence of visual environmental distractors in various cognitive tasks in older adults. Specifically, participants responded to visual attention tasks (e.g., simple reaction time) and verbal working memory tasks (e.g., digit span) in two different sessions; importantly, in one session they responded to the tasks while facing a wall displaying various visual elements and, in the other session, the wall was free from distractors. Older adults performed worse when the tasks were completed in the first than in the second environment, particularly in the visual attention tasks. More recently, these authors presented a study with children (Rodrigues & Pandeirada, 2018) which investigated the influence of the surrounding environment on the performance of visuospatial cognitive tasks (e.g., go/no-go); children were either surrounded (front and lateral sides) by various visual stimuli (high-load surrounding environment) or by a "clean" environment (low-load surrounding environment)[1]

[1]We should note that we are using the terms low- and high-load differently from the definition adopted in the typical paradigms; the specific interpretation of the terms is provided when each paradigm is described.

when responding to the tasks. Overall, children's performance was lower when the tasks were performed in the high-load as compared with the low-load surrounding environment.

Overall, these studies that implemented an alternative paradigm replicated the difficulties to ignore distractors reported when children and older adults are tested using the typical computerized paradigm. Such a pattern is usually attributed to the fact that the ability to ignore distractors is still under development in children and deteriorating in the older adults; the just described studies reinforce these ideas now using a more ecologically-valid paradigm. However, studies with adolescents using the typical "distraction" paradigm are less frequent (Murphy, Groeger, & Greene, 2016) and inexistent with alternative procedures. Considering the complexity of the maturation processes occurring during adolescence (e.g., Dahl et al., 2018), and the fact that this is an age group that has been neglected to some extent in this area of research, more empirical work is needed with this group.

The current study aimed to explore the influence of the visual surrounding environment in the performance of visuospatial tasks in adolescents. As recently noted by some authors, visuospatial skills "have often been tested in children and adults but have been less frequently evaluated during adolescence" (Burggraaf, Frens, Hooge, & van der Geest, 2018, p. 129). Although theoretically the cognitive abilities of adolescents are placed between those attained by children and those of young-adults, research has revealed that this could depend on the type of task and paradigm used (e.g., Luciana et al., 2005; Luna, 2009). Overall, though, studies suggest that the maturation processes that occur from childhood to adulthood progressively enhance the toolkit of abilities that allows the effective management of distractors; therefore, adolescents should already hold some of these abilities (we turn to the developmental considerations in the discussion). However, research has also suggested that this age group is still susceptible to attend to irrelevant information (Luna, 2009); thus, we expected that the high-load environment would impair their cognitive performance as compared to the low-load visual environment. Nevertheless, room is open to alternative results considering that the procedure we are implementing, not only on how distraction is being implemented but also on the type and variety of processes being evaluated, differs in many ways from the typical procedure. To this end, sixty-four adolescents completed two sessions (one in a high- and the other in a low-load visual surrounding environment) in which they performed four different visuospatial tasks.

Method

Participants

The sample included sixty-four adolescents aged 13–17 years (33 girls; $M_{age} = 14.44$, $SD = 1.36$). This convenience sample was recruited from two groups of schools from the Aveiro district (Portugal). None had a history of neurological, psychiatric or learning disorders (according to the parents' reports). This study was authorized by the Portuguese Directorate-General for Education and by the Directors of the participants' schools. Informed written consent was obtained from all participants and from their legal guardians prior to participation.

Materials

In a *visual screening* applied at the beginning of the first session, the researcher presented several colors and the letters *X* and *K* (the stimuli used in the tasks); participants were instructed to simply name each stimulus. A brief *sociodemographic questionnaire* was also administered and included questions about age, sex, and health condition for sample characterization purposes. The experimental part consisted of two attentional and two memory visuospatial cognitive tasks briefly described next (see more details on the tasks in Supplementary Material[SM]1).

Go/no-go

The letter *X* or *K* appeared randomly and singly on the computer screen for a maximum duration of 600 ms; this was also the time window for participants to respond. Each letter was preceded by a fixation cross for 500 ms and then by one of the following intervals: 500, 1000, 1500 or 2000 ms. The following instruction was given for this task: "Press as soon as possible and accurately in the *white*[2] keyboard key when the letter *X* is presented on the computer screen and do not respond when the *K* letter is displayed". The *go* (*X*) stimulus appeared in 66% of the trials and the *no-go* (*K*) in 34%. The task included 140 experimental trials that were preceded by 12 practice trails. The behavioral variables of this task that assesses response inhibition were: hits, false alarms, and reaction times for hits (e.g., Steele et al., 2013). A schematic illustration of the task is provided in Figure 1.

Choice reaction time

This task required two specific responses to two distinct stimuli (response selection). Participants were instructed to press as soon as possible and correctly the *red* keyboard key when a red rectangle appeared on the computer screen, and to press the *green* keyboard key[3] when a green rectangle was presented. Each stimulus was presented randomly and individually in 50% of the trials for a maximum of 600 ms (time window to respond). Each rectangle was preceded by a fixation cross of 500 ms and followed by an interval ranging between 1000–2500 ms. After completing 12 practice trials, participants performed 140 experimental trials. This task provides the following measures that relate to response selection: correct responses, errors, and reaction times for correct responses (e.g., Woods, Wyma, Yund, Herron, & Reed, 2015). See Figure 2 for a schematic illustration.

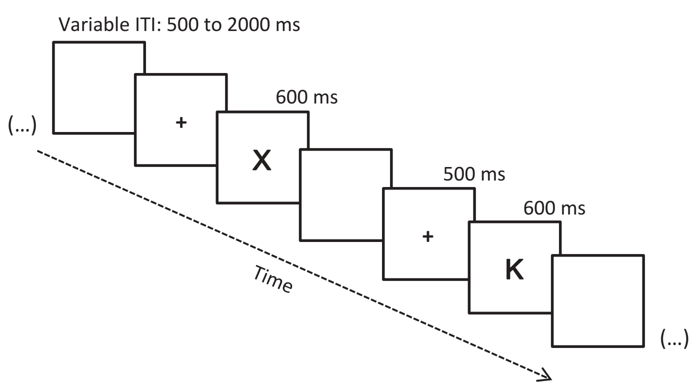

Figure 1. Schematic illustration of the go/no-go task.

[2]A white sticker was placed on the "space" bar keyboard key for easiness of response.
[3]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 for easiness of response.

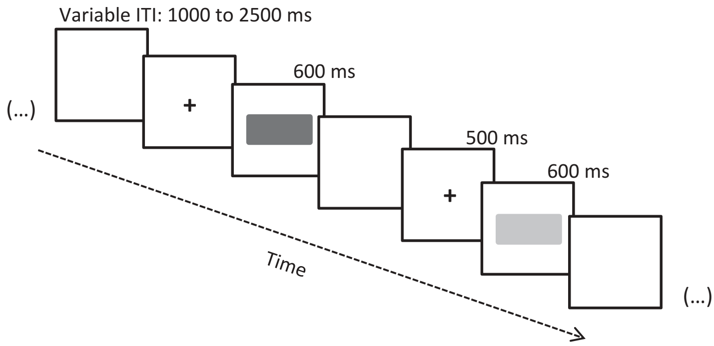

Figure 2. Schematic illustration of the choice reaction time task (for illustration purposes, the first rectangle would be of red colour and the second of green colour).

Corsi block-tapping

We used the computerized version of this task, typically known to assess visuospatial working memory, presented by Mueller (2012). In this task nine blue squares appear on the white screen of the computer; in each trial, some squares lit up (in yellow), one per second, creating a specific sequence. Participants were asked to repeat the same sequence by clicking on the squares in the same order they lighted up (forward span). The initial two trials comprised a sequence of two squares; the following two trials consisted of three squares, and so on. After two incorrect trials of the same length, the task was ended. The memory span was the dependent variable.

Rey complex figure (RCF)

We were interested in the immediate recall procedure, which is usually considered to provide several indicators of memory ability (e.g., visuospatial immediate recall), although the copy procedure was applied as a requirement for the immediate recall. In the copy, participants were instructed to reproduce into a sheet of paper the original RCF as closely as possible; the figure-stimulus was present at this time. Three minutes after concluding the copy, participants were asked to replicate the figure on another sheet of paper (the figure-stimulus was not present at this time); this was the immediate recall procedure. No time limit was imposed for each procedure. The scoring method followed the rules of the original version. The total score was the dependent variable: higher values correspond to better performance (Rey, 1988).

Visual environmental conditions

Two distinct environmental conditions were created: the high-load and the low-load visual surrounding environments[4]. The first consisted of a white stand displaying several pictures considered to be attractive to adolescents according to the data obtained in a previous pilot-study (described in SM2). The low-load condition was a replica of this white stand but contained no pictures or other visual elements (see Figure 3 for an illustration of the conditions). The stand was placed on top of the table creating the surrounding environment during the execution of the four cognitive tasks.

[4]The designations of the two environments were used only to differentiate the two conditions as we did not objectively measure visual load. Of note, the load concept is tricky to quantify objectively mentioned by Murphy et al. (2016).

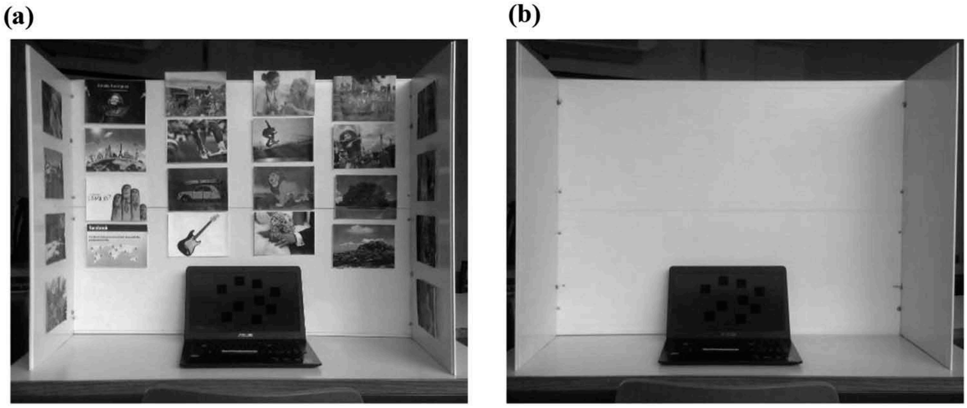

Figure 3. Illustration of the two environmental conditions: (a) high-load visual surrounding environment; (b) low-load visual surrounding environment.

Procedure

Following a within-subject design, each adolescent performed two individual sessions (interval of 14–23 days). Each session was led by the researcher, lasted about 60 minutes, and was conducted in an isolated room of the school at about the same period of the day for each adolescent; one session occurred in the high-load and the other in the low-load visual environment. Only the four cognitive tasks were submitted to the environmental manipulation (Figure 3). The three computerized tasks (i.e., go/no-go, choice reaction time and Corsi block-tapping) were performed on a 14" laptop, whereas the RCF was administered in its traditional paper-and-pencil format. The orders of the environmental condition and of the cognitive tasks were counterbalanced across participants (see SM3 for more details).

Statistical analysis

Paired *t*-tests were conducted to examine the environmental effect in the behavioral variables of each cognitive task. Within each task we applied the Holm-Bonferroni correction to prevent against type I error due to multiple comparisons; all of the *p*-values reported already consider such correction.

Results

Go/No-Go

Adolescents performed better in the low-load than in the high-load visual surrounding environment in two of the three dependent variables of this task (see descriptive values in Table 1). Specifically, participants had a significantly higher percentage of hits, $t(63) = 3.279$, $p = .004$, $d = .521$, and lower percentage of false alarms, $t(63) = 4.313$, $p = .003$, $d = .604$, when the task was performed in the low-load as compared with the high-load condition. Regarding reaction times, no statistically significant difference was obtained ($p = .331$).

Table 1. Means (and SD's) for the variables obtained in the two attentional tasks by environmental condition.

	High-load environment	Low-load environment
Go/no-go		
Hits (%)**	93.16 (9.07)	96.77 (3.72)
False alarms (%)**	20.48 (14.65)	12.87 (10.15)
Reaction times (for hits; *ms*)	333.08 (39.49)	337.61 (33.00)
Choice reaction time		
Correct responses (%)**	83.95 (17.58)	91.69 (6.46)
Errors (%)*	7.99 (7.48)	5.48 (5.29)
Reaction times (for correct responses; *ms*)	347.01 (34.23)	345.62 (33.84)

* $p < .05$; ** $p < .01$.

Choice reaction time

The participants provided a significantly higher percentage of correct responses, and a significantly lower percentage of errors, when the task was performed in the low-load than in the high-load visual surrounding environment, $t(63) = 3.348$, $p = .003$, $d = .584$, and $t(63) = 2.740$, $p = .016$, $d = .389$, respectively. No significant differences were obtained for the reaction times for correct responses ($p = .742$). See Table 1 for the descriptive values.

Corsi block-tapping

The adolescents' performance in this task was reduced in the high-load environment as revealed by a significantly lower memory span obtained in this condition as compared with the low-load environment condition, $t(63) = 3.717$, $p < .001$, $d = .486$ (see Table 2 for the descriptive values).

Rey complex figure

As denoted by the values in Table 2, no statistically significant differences were obtained between conditions (*ps* > .05) on the performance of the immediate recall and of the copy.

Discussion

This study used a recently-developed research procedure (Rodrigues & Pandeirada, 2015, 2018) to explore the influence of the surrounding environment in fundamental cognitive abilities in a group of adolescents. This type of procedure more directly addresses principles

Table 2. Means (and SD's) for the variables obtained in the two memory tasks by environmental condition.

	High-load environment	Low-load environment
Corsi block-tapping		
Memory span***	5.06 (1.12)	5.56 (0.93)
Rey Complex Figure		
Immediate recall	28.58 (3.22)	29.09 (3.45)
(Copy)#	32.88 (2.60)	33.07 (2.88)

***$p < .001$; # The administration of this task was a requirement to the immediate recall task and is not of particular interest to our goals.

from the environment-behavior theories which stress the role of the surrounding environment in our behaviors (Barrett, Davies, Zhang, & Barrett, 2015). The tasks administered assessed inhibition, response selection and visuospatial memory (working and immediate) which are crucial skills in adolescents' everyday activities (e.g., Arrington, Kulesz, Francis, Fletcher, & Barnes, 2014). Understanding the potential impact of the surrounding environment in processes that underlie their ability to effectively carry out, for example, planned behaviors, is of major importance at a time when their "working environment" is increasingly filled with stimulation (e.g., tablets, smartphones; Kay, Benzimra, & Li, 2017), and more responsibilities tend to be assigned to this age group assuming their cognitive abilities are fully maturated (Luna, 2009). For example, in some countries, adolescents aged as young as 14 years are allowed some drive permission and, in many others, this happens at the age of 16. Importantly, the rate of incidents involving this age group is particularly worrisome and some cognitive abilities, such as the ability to inhibit sources of distraction and working memory, seem to be strongly involved in this problem (Walshe, Ward McIntosh, Romer, & Winston, 2017). The potential disruptive influence of the external environment has also been discussed in the domain of eyewitness testimony although with different paradigms and age groups (e.g., Murphy & Greene, 2016; Murphy et al., 2016).

Traditional experimental procedures reveal that adolescents still lack the ability to completely ignore distractors (Luna, 2009), and research like the present one that uses alternative methods will contribute to a better understanding of these processes and ultimately have practical implications (e.g., devise effective road accident prevention programs). Our results indicate that adolescents' (13–17 years old) performance is susceptible to the influence of the visual elements displayed in their surrounding environment (our high-load visual surrounding condition), particularly when cognitive control abilities are involved. This occurred in the two attentional tasks, namely in hits, correct responses, false alarms, and errors, whereas no effect was found on the reaction times of the two tasks. The former results are consistent with those obtained in the traditional paradigms that study distraction (where targets and distractors are shown in the same display) but the last are not (e.g., Spronk et al., 2012). Such discrepancy might be due to differences in the procedures but might also suggest that the way the external distractors influence cognition differs from when distractors are imbedded in the same display. The environmental effect was also observed in the memory task that assesses working memory-the Corsi/block-tapping task. This overall impairment caused by the external environment might accrue from the fact that adolescents' top–down cognitive control, which allows the focus of attention on goal-relevant information, the filtering of distractors and the temporary retention of information (Hwang et al., 2010; Luna, 2009), is still under development. Similarly to what is proposed in the Load paradigm (Lavie, 2010), we can speculate that in our paradigm participants also faced a response-competition situation between the visuospatial stimuli of the tasks and those of the surrounding environment.

No influence of the environment was obtained in the RCF although, descriptively, performance was slightly better when it was performed in the low-load environment. This lack of an effect could be related to the format of the task that was used: being a paper-and-pencil task, attention was likely more directed to the top of the table (which was free from distractors) than to the frontal visual field where the visually-loaded panel was located. Therefore, it is possible that adolescents were more capable of keeping their focus on the task and be less influenced by the surrounding environment during its execution. Another difference between the RCF and the remaining tasks is the modality of response; whereas in the RCF participants were drawing "from memory" on a sheet of paper, the other tasks implicated the interaction with the computer and the management of stimuli and motor responses at the same time. It is also possible that the cognitive abilities measured by this task is not so permeable to the influence of external visual distractors as those assessed by the other tasks. All these possibilities merit further investigation.

The current results can also provide some insights about the developmental trajectory of the influence of the external distractors in the performance of the applied tasks, in particular with respect to children. Even though data from this age group were not collected in this same study, we can draw some tentative comparisons with those of previous work that used a similar procedure (Rodrigues & Pandeirada, 2018). Both qualitative and quantitative differences are observed when such comparisons are made. In light of the traditional theories of cognitive development, one would expect a larger impairment of the external distractors in the performance of children than of adolescents considering the adolescents' higher maturation of the cognitive processes (e.g., Rubia, 2013). Regarding the strict developmental comparison, in all tasks, adolescents' overall performance was better than that of children, as one could predict. However, the distracting environment seems to affect the two groups in a somewhat differential manner. For example, regarding the attentional tasks, both groups were impaired on their ability to respond correctly when under the distracting condition. Nonetheless, adolescents (but not children) provided significantly more false alarms and errors in the attentional tasks when in the distracting environment as compared to the non-distracting condition. Regarding the memory tasks, both age groups' performance on the Corsi block-tapping task was affected by the presence of distraction, but the same result only occurred in children for the RCF. We also noted that, overall, whenever there was an effect of the environment on both groups, the size of the effect tended to be larger in the adolescents (e.g., Cohen's *d* regarding the correct responses of the choice reaction time was of .318 for the children, and of .584 for the adolescents). These qualitative and (apparent) quantitative differences could denote that the processes underlying the ability to supress the (potential) distracting surrounding environment differ between these age groups. Such conclusion is consistent with the reported different brain dynamics involved in cognitive control throughout the development (Hwang et al., 2010). Thus, even though adolescent's global performance was, as expected, better than that of children, the findings regarding the effect of the external distractors were different from our initial predictions. As noted before, these comparisons should be taken as speculative and future research should explore this issue in a more systematic way.

Regarding the procedural aspects used in this study, the nature of the pictures displayed in the participants' surrounding environment were diverse and not related to the tasks at hand as we are still exploring this new procedure and opted to simulate a broad "distracting" setting; therefore, some of the displayed pictures were interesting to adolescents whereas others were not (see SM2). More empirical evidence is needed with this procedure, and many aspects can be investigated. Future studies should explore variables typically considered in this "distraction" literature (e.g., age comparisons, perceptual load) but also expand the potential applied component and ecological validity of this procedure using other manipulations. Thinking of an educational learning context, one could explore if the nature of the environmental stimuli (e.g., do their content relate to the content being learned or not) impact performance differently (i.e., does it help or hinder learning of the information). It would also be interesting to investigate if such impact maintains at longer delays; for example, related content might be distracting in the short term but help memory retrieval latter on. The sensorial compatibility between the distractors and the target stimuli could also be considered. In our case, both the target items and the distractors were of visual nature which should, in theory, afford a larger disruption (according to the modality-specific model of processing resources; Craik, 2014), but this is an open empirical question in our proposed paradigm.

There are other areas in which this type of "distraction" procedure could be relevant. In the clinical area, for example, it has been suggested that external distractors might impair sustained attention, particularly when attention-related clinical conditions exist (e.g., Berger & Cassuto, 2014). The way external distractors affect other cognitive abilities is still an unexplored question, but these initial data suggest that the surrounding environment should be considered in neuropsychological assessments and/or interventions (at least) for such participants. One might also wonder about the reliability of data collected for research purposes in less visually-controlled environments.

This study presents an alternative experimental paradigm to study "distraction" in adolescents. As noted in the Introduction, various authors have stressed the importance of exploring this stage of development given the recently reported maturation particularities that occur during this period (Dahl et al., 2018). This work joins the few studies that have revealed an effect of the surrounding environment in basic (e.g., simple reaction time; Rodrigues & Pandeirada, 2015), as well as in more elaborate processes (e.g., learning gains; Fisher et al., 2014) in other age groups. In their daily activities, adolescents deal with many situations in which distractors are present in their surrounding environment. These initial results suggest that such stimulation impacts cognitive processes that are crucial to many of their behaviors. However, as noted throughout, much more work needs to be done with this procedure which could lead to implications in many areas.

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