Sustained Selective Attention in Adolescence: Cognitive Development and Predictors of Distractibility at School

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Abstract

Previous research suggests that the development of attention abilities diverges in adolescence, specifically, whilst sustained attention continues to develop, selective attention has matured by early adolescence. However task-differences between measures of sustained and selective attention preclude a firm conclusion. In addition, given the critical role attention plays in learning, and the significance of schooling throughout the adolescence period, it is also important to establish applicability to attention in the classroom. Here we employed the same task to measure development of both sustained and selective attention in adolescence, while manipulating the presence/absence of entirely-irrelevant distractors, and the task level of perceptual load, a well-established determinant of focused attention. To examine whether our attention measures predict inattention in the classroom, we also administered a classroom-distractibility checklist. 166 adolescents (aged 12-17) and 50 adults performed our sustained-selective attention task, and reported their distractibility levels during a preceding classroom lesson. The results established that while distractor interference, and its modulation by perceptual load, did not differ from adults, sustained attention continued to develop into adulthood, and adolescents' increased response variability was found across perceptual load levels. Both distractor interference and response variability were significant unique predictors of distractibility in the classroom, including when interest in the lesson and cognitive aptitude were controlled for. Overall, the results support the divergence of development of sustained and selective attention in adolescence, and establish both as significant predictors of attention in the important educational setting of school lessons.

Sustained Selective Attention in Adolescence: Cognitive Development and Predictors of Distractibility at School

Adolescence is recognised as a time of neural, cognitive and behavioural change (Steinberg, 2005). An important question concerns the development of the ability to focus attention on the task at hand, even in the face of distraction, as well as the ability to sustain this focus throughout task performance. These have often been studied under different attention paradigms, termed 'selective attention' and 'sustained attention' respectively. However, both together are clearly needed for effective information processing, across perception, comprehension, learning, and memory- all processes that are critical for effective education. The adolescence period involves critical education experiences culminating with the milestone of final school examinations. Understanding the development of adolescents' ability to sustain a selective focus of attention in this period, and relating this to their ability to focus attention in the school classroom, is therefore of particular significance.

In the present study we therefore aimed to study both selective and sustained attention abilities within the same task and test whether our task measures of both attention abilities can predict adolescents' attention in the school classroom. Furthermore, previous studies resulted in some discrepancies regarding the question of whether and which developmental attention trajectories remain in adolescence. Here, by relating the research to important determinants of attention in adults, we hypothesized that the nature of the distractor stimuli and the level of perceptual load in the task might be critical factors, that can allow us to resolve these discrepancies. We therefore designed an attention task, which included the type of distractors that should be sensitive to reveal developmental trajectories of attention, while assessing whether the level of perceptual load in the task, may play a critical role in developmental trajectories.

Next, we briefly review the relevant previous research, highlighting the inconsistencies and how these relate to potential determinants of attention.

Studies Suggesting Mature Selective Attention in Adolescence Period

Adolescents' development of selective attention, has typically been studied with the 'flanker task'(Eriksen & Eriksen, 1974) in which a target letter, or shape (e.g. an arrow) is presented in the display centre, flanked by one or more distractors that are either associated with the same (in 'congruent' conditions) or the other target response (incongruent conditions).[1] The findings typically revealed no developmental effects. For example, Grose-Fifer et al. (2013) found no difference in distractor congruency effects in a letter-based flanker task, between adolescents (aged 15-17) and adults. Huizinga, et al. (2006) used an arrow-based flanker task and similarly found that while both younger (aged 6-8) and older children (aged 10-12) displayed larger congruency effects on RT than mid-adolescents (aged 14-16), and adults (aged 18-26), congruency effects did not differ between mid-adolescents and adults. An ERP study using the same arrow-based flanker paradigm also showed no behavioural difference in congruency effects between adolescents (aged 16) and adults, with both groups responding more quickly and accurately irrespective of the distractor congruency conditions than a group of 12 years old (Ladouceur et al., 2007). Gyurkovics, et al. (2020) also used an arrow-based flanker task, and found that both the flanker congruency and congruency-sequence effects were unaffected by age, across groups of 12–13, 14–15, 18–20 and 25–27 years old.

[1] We note that the Stroop task has also been used to study attention in adolescence. However, the integration of the target and distractor within the same stimulus in the typical Stroop Colour-Word stimuli precludes any clear interpretation in terms of selective attention, since space-based or object-based separation of target and distractors are known as pre-requisite conditions for successful selective attention (e.g. Lavie & Driver, 1996). Instead Stroop effects can be well accounted for by reduced control over response inhibition which continues to develop during the adolescence period (e.g. Aïte et al., 2016).

In an exception, a flanker task in which choice responses to a central target circle were made based on the its colour) adolescents up to age 14-15 showed larger congruency effects than adults (Waszak, et al., 2010). These results may have been due to the higher conspicuousness of the colour match/mismatch, especially given that four flanking circles- surrounded the target circle (all either matching or mismatching with its colour). Thus for attention tasks with fairly inconspicuous distractor stimuli (such as letters or arrows) the ability to ignore a response-competing distractor, which is known to develop in childhood (e.g., Huang-Pollock et al., 2002), appears to reach maturity by adolescence.

Studies Suggesting Continued Development of Selective Attention during Adolescence: Affective or Motivationally-Relevant Distractors

In contrast to the letter or arrow-based flanker tasks, adolescents have been found to be more susceptible to distraction than adults when the distractors are either affective, or motivationally relevant. For example, greater congruency effects were found in both young (11-14) and older adolescents (15-17) compared to adults in a face expression (happy vs. fearful) flanker task with congruent or incongruent distractor face expressions (Grose-Fifer et al. 2013). Distractors of motivational relevance (that were associated with reward, through a 'value learning' procedure, Anderson et al., 2011) were also found to produce longer lasting attentional capture effects on visual search performance in adolescents (aged 13-16) compared to adults (Roper et al., 2014). Specifically, while attentional capture effects produced by irrelevant value-learned stimuli were only found in the first quarter of the subsequent testing phase in adults, these effects persisted throughout the experiment in adolescents. These effects may be attributed to reduced emotional regulation in adolescence (Heller & Casey, 2016; Larson et al., 2002), or reduced cognitive control over task priorities (i.e. prioritising motivationally-relevant stimuli over the neutral task-target stimuli), rather than an immature selective attention ability, (see Lavie, 2005; Lavie et al., 2004, for further discussion of this distinction).

Alternatively, it is possible that selective attention per se (i.e. not just in the face of emotional or motivationally-relevant stimuli that place extra demands on frontal cognitive control) is not fully developed in adolescence, but that typical flanker tasks are less sensitive to reveal this. For example, it may simply be that the distractor stimuli used in most previous research (c.f. Waszak, et al., 2010) were not sufficiently salient, neither visually, nor semantically (e.g. an arrow conveys a restricted meaning compared to an emotional face, or a stimulus associated with reward) to reveal any reduced ability to focus attention. Indeed, in daily life, the sort of distraction which leads to failures to focus attention despite being entirely irrelevant is typically one where the distraction source is more conspicuous than the task stimuli. Arguably congruency effects in the flanker tasks which involve inconspicuous distractors, are still found because these distractors are in fact task relevant, through their association with the target response (Forster & Lavie, 2008). Flanker tasks may thus be less suitable to reveal immature selective attention in adolescence, than tasks which require to ignore salient and meaningful, yet entirely irrelevant, distractors. We therefore concluded that a sensitive measure of selective attention development must involve irrelevant distractors that are conspicuous but emotionally and motivationally neutral.

Perceptual Load

Selective attention is known to critically depend on the level of perceptual load in the current task (Lavie, 1995, for reviews see Lavie, 2005; Murphy et al., 2016). High perceptual load in a task (e.g. tasks involving a larger number of stimuli, or increased demand on perception for the same number of stimuli, e.g. conjunction vs. feature search) has been shown to allow a higher level of attentional engagement, increasing neural signal associated with task-relevant stimuli and reducing the neural response to task-irrelevant distractors (e.g. Bruckmaier et al., 2020; Torralbo et al., 2016). These effects apply across individual differences in the level of distractibility (e.g.

Forster & Lavie, 2016) and perceptual load has also been shown to improve selective attention focus in ADHD (Forster et al., 2014) and in typically developing children (Huang-Pollock et al., 2002), while both populations display greater susceptibility to distraction in comparison to healthy adults. Given that when the distractor stimuli are affective or motivationally-relevant adolescents have also been found to have elevated levels of distractibility (compared to adults) and may also be more susceptible to distractions from conspicuous, yet irrelevant distractors, we sought to examine whether adolescents can also benefit from increased perceptual load to improve their ability to focus attention in the presence of such distractors.

Development of Sustained Attention in Adolescence

In contrast to the mixed findings (which are perhaps attributable to the nature of distractor stimuli used in the selective attention tasks) research of sustained attention has more consistently indicated that sustained attention continues to develop into late adolescence. Sustained attention has been typically measured through fluctuations of attention focus, expressed by a greater variability in the task RT, as well as failures to inhibit responses to infrequent 'no-go' targets. All of these measures have indicated that sustained attention is still developing in adolescence (Cohen-Gilbert & Thomas, 2013; Cohen et al., 2016; Lee et al., 2018; Stawarczyk, et al., 2014; Tottenham, et al., 2011, see also Gyurkovics et al., 2020, for a recent demonstration). While adolescents' failure to suppress responses to the no-go targets may be attributed to their immature inhibitory control, the increased response variability is found in their routine 'go' task responses. It is thus arguably a purer measure of adolescents' ability to pay attention irrespective of an immature inhibitory control.

Evidence for the conclusion that the ability to sustain a stable level of attention on-task focus continues to develop in adolescence comes from several studies that have used variations of the Continuous Performance Test (CPT) and the Sustained Attention to Response Task (SART). For example, in the SART participants respond to a series of stimuli (e.g., digits) appearing one at a time, and asked to withhold responses to one of them (e.g., the digit 3 - their 'no-go' target). The results indicate that adolescent participants (up to age 16 in some of these reports) display elevated RT variability in comparison to adults (Braet et al., 2009; Fortenbaugh et al., 2015; Gyurkovics et al., 2020; Stawarczyk et al., 2014). Interestingly, increased variability in this task has also been associated with greater rates of stimulus-triggered task unrelated thoughts, suggesting that both are driven by a failure to sustain attention focus on the task (Stawarczyk et al., 2014).

It remains unclear, however, whether adolescents will show greater fluctuations of attention states (expressed as elevated response variability) when completing a focused attention task under higher perceptual load that is known to be more attention engaging. Specifically, both the CPT or SART tasks involve a low level of perceptual load (monitoring for a clearly distinct target, each appearing singly on the screen, and with fairly slow presentation rates), while in our task conditions of high perceptual load participants perform a visual search task with multiple items, searching for a target among similar non-target stimuli. The wealth of studies showing that people are able to fully focus attention on the task in conditions of high perceptual load (e.g. Lavie, 1995, Lavie & Cox, 1997; Lavie & Fox, 2000, Lavie, 2005 for review), and that high perceptual load improves focused attention in ADHD (Forster et al., 2014) and in childhood (Huang-Pollock et al., 2002) raise the important question of whether adolescents would also be capable of sustaining attention focus in tasks condition of high perceptual load at a younger age than that reported based on their performance in the CPT or SART tasks of low perceptual load.

Predicting Adolescents Distractibility in the Classroom

As we mention earlier understanding adolescents' ability to sustain a selective focus of attention is of paramount importance also given the critical role attention plays in learning and education, and the significant educational milestones adolescents face in their secondary school period. Indeed, a good deal of educational research has linked teachers' ratings of inattention in the

classroom to educational achievement (e.g., Gray et al., 2017). However teacher ratings of inattention can vary in their reliability both within and between schools (Merrell & Tymms, 2001). For example, some studies reveal that fewer than half of the pupils who receive clinically elevated ratings of attention problems from their teachers in a given year also maintained this level of rating in the following year (Rabiner et al., 2010). This points to the need to augment teachers' ratings with task-based measures of attention.

Some previous research has related attention task performance to teachers' ratings of inattention in the classroom, however so far this research has only been conducted with children. For example, Johnson et al., (2020) found that 8 and 11 years old children's commission errors in the SART were positively correlated with teacher ratings of both inattention and hyperactivity-impulsivity, and negatively correlated with on-task behaviour in the classroom. A measure of response variability was also negatively associated with on-task classroom behaviour. Other measures of inhibitory control (such as the Stroop, and visual and auditory response competition tasks, where participants respond to target stimuli whilst inhibiting responses to other similar stimuli) have been found to correlate with teacher ratings of pupils' attention control skills (at least in terms of differentiating between the top and bottom quartiles) in children (aged 8-12), (Das et al., 1992; Papadopoulos, et al., 2002). A negative correlation between CPT performance and the inattention subscale of the Conners Teacher Rating Scale was also found for 7 and 10 years old children (Lam & Beale, 1991). These findings therefore provide preliminary evidence of an association between cognitive measures of attention control and some measures of classroom inattention, however all these studies have concerned the childhood period. Thus while prior work is promising regarding the use of task measures to predict distractibility in the classroom, it remains unclear whether any immature attention abilities that remain in adolescents can be predictive of their ability to focus attention in the classroom.

Study Aims

We thus set out to investigate: i) whether any developmental trajectories of the abilities to both focus selective attention, and to sustain a stable focus, remain in adolescence when these are measured in an attention task that is sensitive to depict both attentional functions. ii) whether our attention task measures can be used to predict the level of focused attention in the real-life setting of a lesson in the school classroom. iii) whether increased perceptual load in the task would modify any of the developmental trajectories or their predictive value.

As we previously alluded, a promising task-based measure of the type of inattention that may harm learning is the irrelevant distraction task, which measures the interference caused by visual distractors that are salient and meaningful but entirely irrelevant to the task (Forster & Lavie, 2008). It has been shown that the individual magnitude of irrelevant distractor interference effects in this task can predict inattentive symptoms in a non-clinical sample of adults that have been reported for their childhood period (Forster & Lavie, 2016). In order to measure adolescents experience of distractibility in the classroom, we modified a self-report measure of everyday distraction (Hobbiss et al., 2019) to be suitable to measure distractibility in the classroom.

Method

Participants

50 adult students (33 F), aged 20-35 (mean age 24 years and 6 months, SD = 4 years and 3 month), volunteered through the UCL Psychology division subject pool, and 166 secondary school students participated: 59 'early adolescents' (30 F) of between age 12 and 13 (mean age 13 years and 0 months, SD = 6 months), 73 'mid-adolescents' (28 F) of between age 14 and 15 (mean age 14

years and 10 months, SD = 6 months, 34 'later adolescents' (18 F) of between age 16 and 17 (mean age 17 years and 3 months, SD = 3 months).

Adolescent sample sizes were determined using a power analysis using G*power (Erdfelder, Faul, Buchner, & Lang, 2009), based on Forster et al. (2014), who found a significant 2x2 interaction between group and distractor condition (η^2_p = .231). This effect size suggested that a total sample size of 132 (i.e., n=33 per group) would provide 95% power to detect between group differences across four age groups, with a multiple comparisons correction (a = 0.0125). During the testing period, it became possible to exceed these sample size targets[2].

Participants scoring chance level accuracy (50%) or below in any experimental condition were excluded (n = 9), as were those with reaction times more than 3 standard deviations from the mean (n = 1). The exclusions were spread across the ages (13-14yrs = 5, 14-15yrs = 2, 16-17yrs = 2, adults = 1), leaving the final samples of 49 adults (20-35, mean age 24 years and 0 months, SD = 4 years and 1 months) and 157 (62 F) adolescents: 54 'early adolescents' (28F) of between age 12 and 13 (mean age 13 years and 0 months, SD = 6 months), 71 'mid-adolescents' (27 F) of between age 14 and 15 (mean age 14 years and 10 months, SD = 6 months, 32 'later adolescents' (17F) of between age 16 and 17 (mean age 17 years and 3 months, SD = 3 months).

Informed consent was obtained for all participants (parental consent for adolescents). The research was approved by UCL research-ethics committee.

Stimuli and Procedure

Adult participants were tested on site at UCL. For adolescent participants the task was administered at the participants' school during the school day, with participants attending testing immediately after a regular school lesson.

In both sites testing took place in a small, darkened, single-subject testing room. The experiment run on a laptop using MATLAB (Mathworks, Inc.). Attached to the bottom of each monitor was a 60 cm long string, which participants were instructed to use to establish a 60 cm distance from their chin to the monitor. They were asked to maintain this distance for the duration of the experiment.

Participants completed a visual search task which required them to search for either the letter 'X' or the letter 'N', presented in one of six positions around a circular array The circle radius was 4.7 cm, 4.48° of visual angle at a viewing distance of 60 cm. In low load displays the five non-target positions were occupied by lower-case 'o's. In high load displays they were occupied by five different angular letters from a list of ten (H,K,M,W,T,V,L,Z,F,E). The letters subtended 1°x 0.8°. Letters were separated by 4.3° from each other (centre-to-centre). Target position and its identity were fully counterbalanced within blocks for each load condition. A face distractor subtending a 2.3° vertically was presented at fixation on a random 10% of trials. These dimensions resulted in a minimum 1° face to letter edge-to-edge distance. 24 different adult faces of a neutral-expression were selected from the NimStim battery (Tottenham et al., 2009). Each face appeared only once in each of the load conditions. Participants were asked to respond as quickly as possible, while remaining accurate, by pressing the 0 for 'X' and 2 for 'N' using the numeric keypad. They were also asked to ignore the distractor faces, and this was emphatically stressed both in the instructions on the computer screen, and by the experimenter.

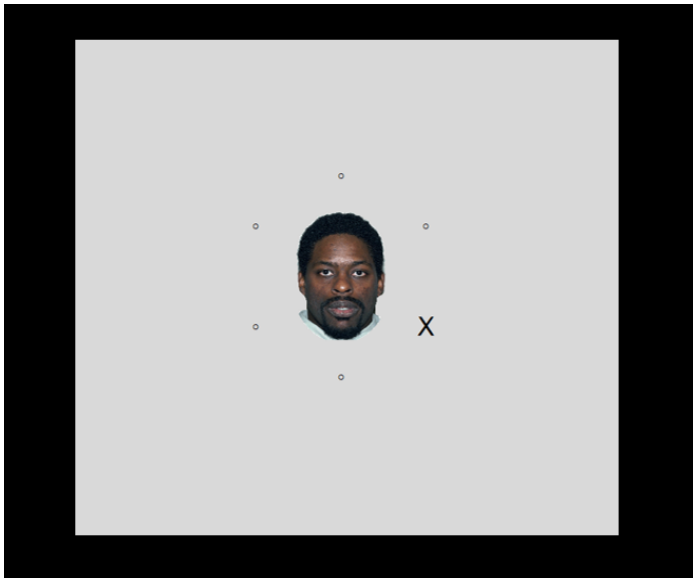
The experiment was presented in eight experimental blocks of 60 trials (four per each load condition) preceded by 18 example trials (9 per each load). Participants alternated between and high and low load blocks in a counterbalanced order of ABBAABBA or BAABBAAB. Half of the participants began with a low-load block (A), and half began with a high-load block (B).

[2] We originally aimed to administer a similar distraction checklist for university lessons too, however initial inspection of the student responses revealed a too large variety of study settings to continue with these analyses.

Each block was preceded by three 'warm-up' trials, which never contained a distractor, and were excluded from the analysis. Each trial started with a fixation cross presented for 1000 ms, the visual search display then was presented for 200 ms, followed by a blank response screen for 3000 ms. A new trial was initiated following a participant's response, or 3 seconds if they failed to respond. A beep tone provided feedback for errors and missed responses.

Figure 1

Stimulus display example



Note. Stimulus display example illustrating a low load letter-search task condition with an irrelevant distractor face.

Distraction Reports

Participants completed a self-report distraction checklist (either before or after the experiment, counterbalanced across participants) about their experience of distractibility in the classroom lesson immediately preceding the experiment. A self-report checklist has previously been shown to provide a reliable measure of distractibility, in a wide range of daily life settings (Hobbiss et al., 2019). Here the checklist was adapted to the school classroom based on a teacher focus group on prominent sources of distraction in lessons. Following an initial brainstorming session where eight teachers reported common distractions in lessons, some items were amalgamated into distraction categories (e.g. 'tapping', 'shouting', 'background music', 'humming' and 'background talking' were amalgamated into a category of 'background noise'). Items were discarded if they did not clearly identify a source of distraction (for example, the teachers identified several factors which were likely to increase distraction, but which did not identify a clear source, such as 'tiredness', 'boredom' and 'cognitive overload'). Subsequently, items were selected for the checklist if at least 50% of the group agreed that the item "could present a significant source of distraction for students in average lessons". This produced seven categories of distraction sources: 'people around you (friends, classmates, teachers etc)', 'background noise (music, talking, tapping, shouting etc)', 'Social networking (alerts, posts, updates, messages etc)', 'other functions/apps on your phone/tablet/computer (games, internet browsing etc)', 'displays in the classroom (posters, maps, artwork etc)', 'unrelated thoughts (mindwandering)' and 'looking out of the window'. For each of the different distraction sources, participants reported for how long their attention was diverted away from their main focus towards the distractor, using a slider bar from 0-15 minutes, and text

box on its right for participants to write a time if more than 15 minutes. Thus a distraction could be reported as having not occurred at all, all the way up to being present for the entirety of the 50 minute lesson (as was indeed reported by some participants). Participants were instructed that it was possible to report multiple sources of distraction occurring simultaneously (so that the total duration reported did not need to add up to the maximum duration of 50 minutes). Finally, background variables relevant to distraction in educational settings were recorded by the questionnaire, namely age, gender, interest in the topic being studied, the subject, and whether the session involved working alone (or with others) or work on a computer.

Cognitive Abilities

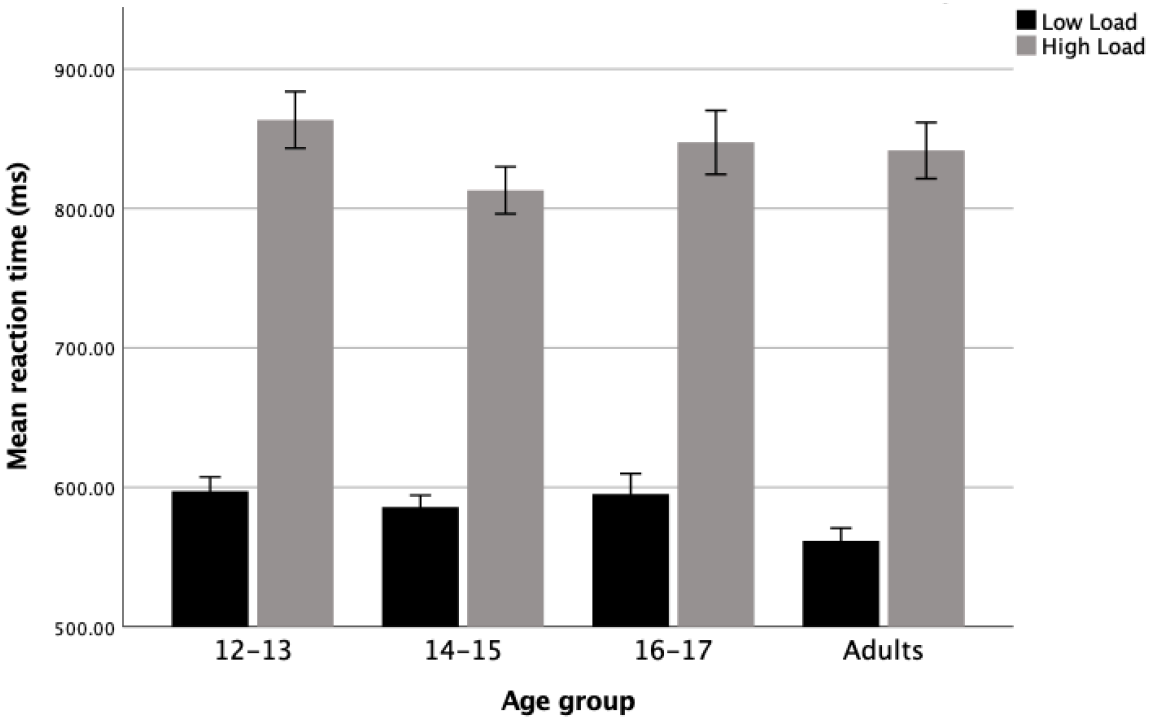
Results of the adolescents' performance on the Cognitive Abilities Test (CAT 4th Edition, GL Assessment, 2016) were supplied by the school. The CAT is a widely used test of intelligence and reasoning skills in the UK and Ireland, consisting of four batteries of multiple-choice questions assessing verbal, non-verbal, quantitative and spatial reasoning, which can be combined into an 'global' cognitive ability score. It was this global score that was supplied by the school.

Results

RT

All RT analyses were conducted on the correct responses only. RT as a function of load and age are presented in Figure 1.

Figure 2
Mean RT in the Attention task as a function of load and age



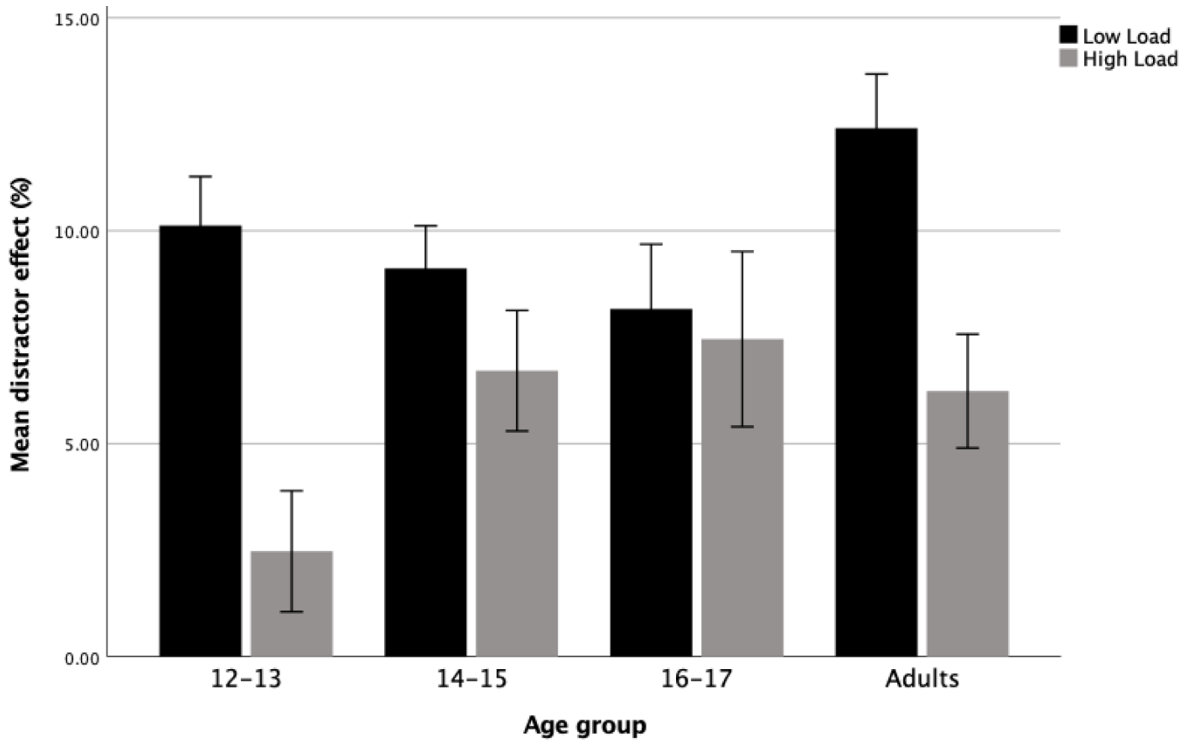
A mixed model ANOVA on the RT with load (low/high) as a within-subjects factor, and age (early adolescents, mid-adolescents, later adolescents, and adults) as a between-subjects factor, revealed a main effect of load, $F(1,202) = 801.74$, $p < .001$, $\eta^2_p = .799$, reflecting longer RT in high load ($M = 860$, $SE = 11$) compared to low load ($M = 608$, $SE = 6$) conditions. There was no main effect of age ($F < 1$), and no interactions between load and age, $F(3,202) = 1.51$, $p = .21$, $\eta^2_p = .02$.

To avoid any potential scaling effects of distractor cost due the longer RT in high load, distractor cost was analysed as the proportional increase in RT in the distractor present compared to absent conditions at each load level.

A mixed-model ANOVA on proportional distractor cost with load (low/high) as a within-subjects factor, and age (early adolescents, mid-adolescents, later adolescents, and adults) as a between-subjects factor, revealed a significant main effect of load, $F(1,202) = 19.37$, $p < .001$, $\eta^2_p = .09$, reflecting a significant reduction of distractor effects found in low load (10.0%) under the condition of high perceptual load (5.7%), as expected. There was no main effect of age, $F(3,202) = 1.50$, $p = .22$, $\eta^2_p = .02$, however there was a significant interaction between age and load $F(3,202) = 2.74$, $p < .05$, $\eta^2_p = .04$. Figure 2 suggests that this interaction may have been driven in large from the greatest reduction of distractor effects with higher load found for the young adolescents, compared to all the other age groups, as well as a reduction in the load effect in mid to late adolescents compared to adults. However none of the post hoc comparisons of the load modulation of distractor effects between the ages passed the Bonferroni corrected alpha threshold of $p = .016$ (load modulation between young and mid-adolescents, $t(123) = -2.03$, $p = .04$, $d = -.37$, between mid and older adolescents, $t(101) = -.57$, $p = .57$, $d = -.12$, or between older adolescents and adults, $t(79) = 2.09$, $p = .04$, $d = .47$). However since the increased load modulation of distraction in the young adolescents compared to the older age groups is as expected on the basis of previous research that included 12 years old participants (Huang-Pollock et al., 2002, Study 2), it is more suggestive as an account for the interaction.

Figure 3

Mean Percentage distractor effect on RT as a function of load and age



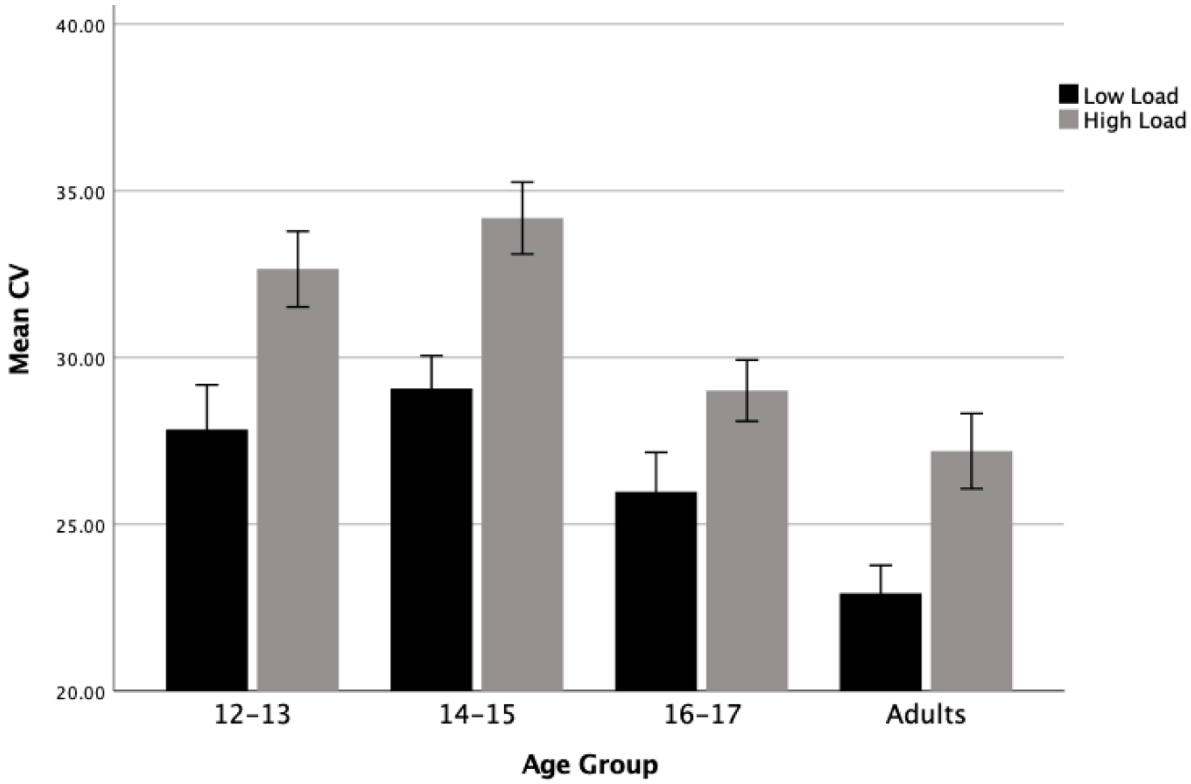
Response Variability

The coefficient of variation (CV; CV = SDRT/MRT) was calculated for distractor absent trials only in each load level[3] in order to produce a measure of intra-individual variability which

[3] Using distractor absent trials only, also allowed us to examine variability in a manner that was unaffected by the distractor, and so which did not overlap with measures of any distractor effect.

was independent of variations in mean RT. CV results are shown in Figure 3.

Figure 4
Mean CV of RT as a function of load and age



Note. CV as a function of load level and age, for distractor absent trials only. The average CV found was well within the range of previous reports (e.g. figures for CV in adolescents of between 0.25 and 0.35 were reported across five different attention control tasks by Epstein et al., 2011). Error bars represent 1 SE.

A mixed model ANOVA on CVs with load (low/high) as a within-subject factor and age (early adolescence, mid-adolescence, later adolescence, and adults) as a between-subjects factor revealed a main effect of load $F(1,202) = 35.41$, $p < .001$, $\eta^2p = .15$) which reflected larger CV in high load ($M = 0.31$, $SE = .6$) than in low load ($M = 0.27$, $SE = .6$) conditions, across all ages. There was a main effect of age, $F(3,202) = 11.38$, $p < .001$, $\eta^2p = .15$, which did not interact with load ($F < 1$).

As can be seen in Figure 3, and confirmed with post-hoc comparisons with the Bonferroni corrected alpha of $p = .016$, there was no significant difference between early and mid-adolescent CV (early adolescence $M = 0.31$, mid-adolescence $M= 0.32$, $t(123) = -.47$, $p = .64$, $d = -.09$), however late adolescents displayed reduced CV ($M = 0.28$) compared to mid-adolescents, $(101) = 2.74$, $p = .007$, $d = 0.58$. Adults ($M = 0.25$) had a smaller CV compared to late adolescents, however this difference did not reach the corrected significance threshold, $t(79) = 1.98$, $p = .05$, $d = .45$.

Accuracy

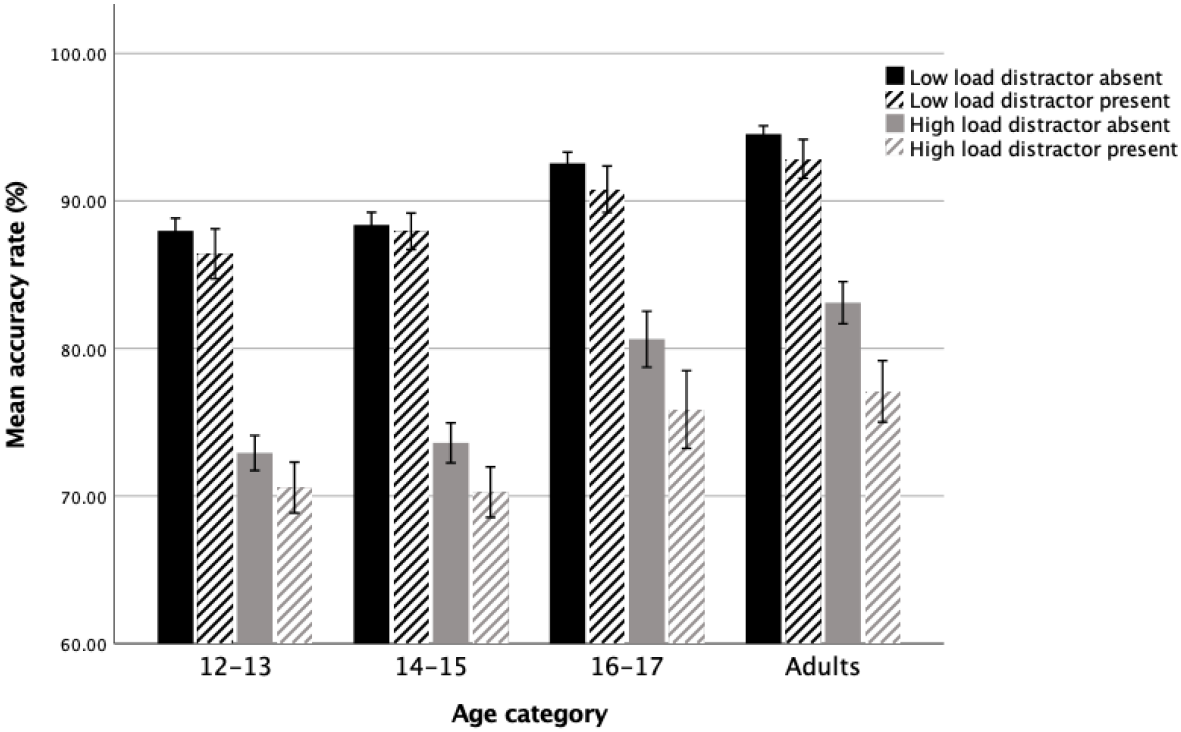
Accuracy results are shown in Figure 4. These were analysed with a mixed model ANOVA on percentage accuracy with load (low/high) and distractor (present/absence) as within-subjects factors, and age group (early adolescents, mid-adolescents, later adolescents, and adults) as a between-subjects factor. The ANOVA revealed main effects of load, $F(1,202) = 362.73$, $p < .001$, $\eta^2_p = .64$, with lower accuracy rates in high load ($M = 76\%$) than in low load ($M = 90\%$), and

distractor presence, $F(1,202) = 28.60$, $p < .001$, $\eta^2_p = .12$, with lower accuracy in distractor present (M = 19%) than distractor absent (M = 16%) conditions. There was also a main effect of age group, $F(3,202) = 11.48$, $p < .001$, $\eta^2_p = .15$. As can be seen in Figure 4 and confirmed in post-hoc comparisons with the Bonferroni corrected alpha of $p = .016$, there were no differences in error rates between early (M = 80%) and mid-adolescents, (M = 81%), $t(123) = .4$, $p = .67$, while accuracy for mid-adolescents was significantly lower than for later adolescents (M = 86%), $t(101) = 3.36$, $p < .002$ $d = 0.71$ and later adolescents did not significantly differ from adults (M = 88%), $t(72) = 1.42$, $p = .16$, $d = 0.35$. Thus, in terms of performance accuracy, the later adolescent group cannot be distinguished from the adult group, whereas early and mid-adolescents were significantly more error prone than both older adolescents, and adults.

There was a significant two-way interaction between load and distractor presence, $F(1,202) = 7.30$, $p = .008$, $\eta^2_p = .04$, reflecting a greater decrease in accuracy in the presence of a distractor when in high load (4% reduction) compared to low load (1% reduction). Although this effect is in the opposite direction to the RT, given that the 4% distractor-related decrease in accuracy in the high load condition corresponds to just one more error made on the 24 distractor-present trials in each load condition, this small reversed trend does not undermine the load effect on the main experiment performance measure of RT. No other two- or three-way interactions were significant (all $F < 1$).

Figure 5

Mean Percentage Accuracy as a function of distractor presence, load and age



Adolescent Distraction During Classroom Learning

Mean distraction duration reports across all distraction sources was 7% (range 0-45%, SD = 7%). A factor analysis of the distraction reports revealed that all distractions loaded onto a single factor at above 0.4, the threshold suggested for the practical significance of a loading value (Stevens, 2009). The scree plot (Figure 5) revealed an inflexion after the first factor which, together with the factor loadings, suggested a single 'classroom distractibility' latent variable could be formed for further analysis (see Appendix Table 1 for all the zero order correlations).

This is consistent with previous findings that attention lapses, including both mind wandering and distractibility reported from external distractors, can be described as arising from a single underlying construct when measured in everyday settings (Hobbiss et al., 2019).

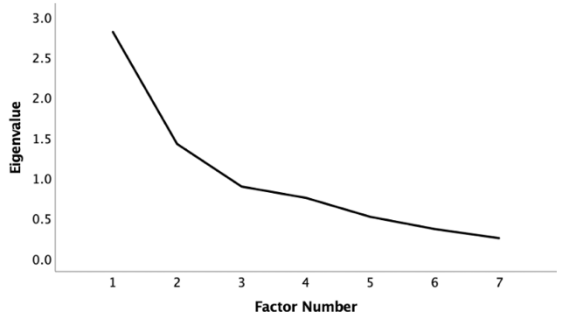
Figure 6

Factor loadings and Scree plot for EFA on distraction variables in adolescents

A

	Factor	
	1	2
Other mobile functions	0.749	-0.383
Social media	0.720	-0.281
Mindwandering	0.693	0.318
Background noise	0.659	-0.386
People around you	0.540	-0.285
Looking out of the window	0.509	0.662
Classroom displays	0.523	0.652

B

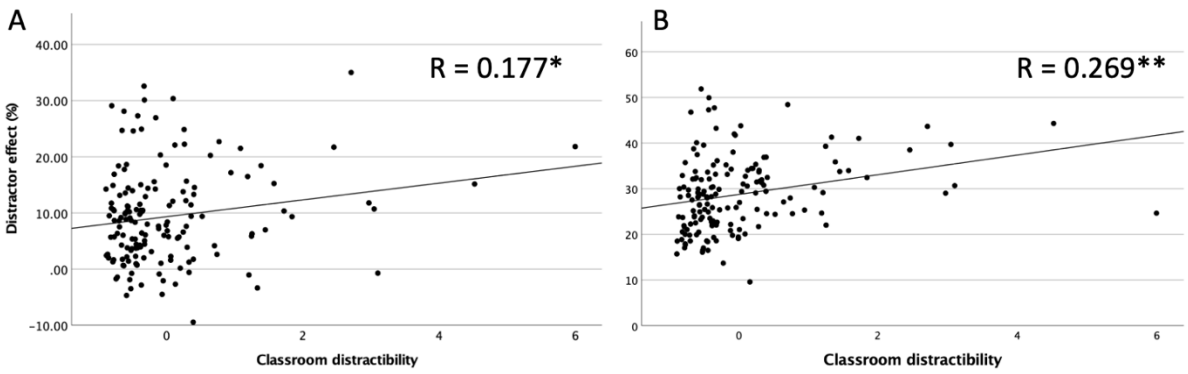


Note. Component loadings (panel A) and scree plot (panel B) for the EFA of the distraction sources reported from the last classroom lesson for adolescent school students. As all distraction reports were positively correlated with one another, an oblique (direct oblimin) rotation was used.

Distractor interference effects and RT variability were both significantly correlated with the 'classroom distractibility' latent variable: greater distractor interference effect on RT, and greater RT variability in the task performance, were both associated with greater duration of distractibility reported in the classroom (r_s = 0.18, p = .03; r_s = .27, p < .01, respectively; See Figure 6).

Figure 7

Scatterplots for experimental variables with classroom distractibility latent variable



CAT score was significantly negatively correlated with distractibility in the classroom (r_s = -0.19, p = .02). The load modulation effect (the difference between the distractor effect in high load compared to low load) and accuracy showed no significant correlation with the classroom distractibility latent factor (r_s = .06, p = .5 and r_s = .01, p = .9 respectively) and so were not analysed further.

A simultaneous regression analysis (Table 1) was conducted to assess whether classroom distractibility latent variable could be predicted from experimental performance, when controlling for background variables (age, sex, group work, computer use, generalized cognitive abilities and interest in the lesson). Age and sex were dummy coded.

Table 1

Multiple regression model for factors predicting classroom distractibility using experimental variables

	β	T	p	VIF
Computer use	-0.07	-0.83	0.41	1.06
Age	0.04	0.43	0.67	1.15
Sex	0.07	0.90	0.37	1.08
Group work	0.08	0.94	0.35	1.12
CAT aptitude score	-0.15	-1.78	0.08	1.09
Interest in lesson	-0.16	-2.06*	0.04	1.03
Distractor RT effect	0.18	2.16*	0.03	1.16
Response variability (CV)	0.26	3.29**	0.001	1.06
Model Statistics	**R^2**	**Adjusted R^2**	**F**	**p**
	0.173	0.124	3.53**	<.001

Note. β = Beta, the standardized regression coefficient; Adjusted R^2 significance levels are for R^2 change F-tests

This analysis revealed that both distractor RT interference and response variability (CV), were significant positive predictors of Classroom Distraction, when controlling for all other variables. Interest in the lesson was also a significant (negative) predictor of classroom distractibility. A further level of the regression model included interaction terms between age and distractor RT effect, CV and interest in the lesson. No interaction terms were significant, so they were omitted from Table 1. The variance explained by CV was largely independent of that explained by distractor interference; distractor interference explained 2.3% and CV 6.3% of the variance in classroom distractibity (above and beyond all control variables) when entered individually, and 7.8% when entered together. As the variance explained by the two together only exceeded the sum of the variance that each factor explained individually, by .08% they represent relatively independent predictors of distraction in our model. In addition, they were also not significantly correlated with one another, r_s = -.11, p = .13. Interest in the lesson was not correlated with either of these variables (r_s Distractor RT effect = -.02, p = .8; r_s CV = .04, p = .6), and explained 1.5% of unique variance. It is notable that both experimental variables (Distractor RT effect and CV) appeared therefore to be stronger predictors of classroom distraction than interest in the lesson.

General Discussion

The present findings establish that adolescents from age 12 onwards are equally as susceptible to interference by an irrelevant yet salient face distractors as are adults, and like adults, they are also better able to ignore the distractors in conditions of high perceptual load in the task. A trend towards a greater modulation of distraction by higher load in the youngest age group, was also found and this may reflect that perceptual capacity is still more limited for the very young

adolescents, similarly to children from age 9-12 (see Huang Pollock et al. 2002, Study 2). These results suggest that selective attention is fully developed by adolescence, with an additional component of reduced perceptual capacity that is still found for the younger adolescents of age 12-13.

In contrast, adolescents had reduced ability to sustain a stable level of attention focus, as reflected in their higher level of response variability, and their sustained attention ability continued to develop until later adolescence. Moreover, this developmental trajectory was found irrespective of the level of attentional demand in the task (i.e. across both conditions of low and high perceptual load). This suggest a genuine immature ability to sustain a stable focus of attention (rather than for example reduced control over performance in tasks that are not inherently rewarding) and may lead to higher susceptibility to the effects of boredom, both of which are more likely in the typical variants of monotonous, vigilance tasks used in the sustained attention paradigm. Young to mid-adolescents (up to and including age 15) also showed a greater error rate in the task overall, compared to older adolescents and adults, in further support of immature sustained attention abilities. Importantly, both measures of sustained attention and selective attention were established as significant unique predictors of adolescents self-reported experience of distractibility during a classroom lesson, thus establishing their external validity, and applicability to prediction of attention focus in the important educational settings of the school classroom. We discuss these findings in turn below.

Selective Attention in Adolescence

The ability to focus attention while ignoring an irrelevant distractor was found to be fully developed already by early adolescence. This is consistent with previous research using the flanker task (Grose-Fifer et al., 2013; Gyurkovics et al., 2020; Huizinga et al., 2006), extending it here to salient distractor faces that are entirely task-irrelevant since they were not associated with any task response (c.f. the flanker task measures of response competition effects). The contrast between the lack of developmental effects with these types of distractors and the previous findings of reduced focused attention in adolescence when affective or motivationally-relevant distractors are presented (e.g. Grose-Fifer et al., 2013; Roper et al., 2014) suggests that adolescence involves an interactive impact of the development of control over emotion and reward-related processing on attention, rather than reduced ability to focus attention per se. Indeed the findings that perceptual load was as effective in reducing distractor interference effects for adolescents across all ages, as for adults, is in further support that the ability to focus attention has matured by early adolescence.

Our findings are also with findings (Couperus, 2011) that increased perceptual load in a task reduces the P100 evoked potential related to distractor processing to an equal extent across children (aged 7-9, 10-12), adolescents (of 13-15, and 16-18 age groups) and adults (over 19 years old). Since the P100 is considered a sensory component these findings suggest that the early-selection mechanism that allows for perceptual filtering through reduced sensory-cortex responses is fully mature already in late childhood and early adolescence. Importantly, Load Theory makes a clear dissociation between early (perceptual) selection attention mechanism that benefits from increased perceptual load, and late-selection cognitive control mechanisms (associated with frontal cortex 'executive control' regions) such as working memory that serves to maintain performance in line with the task-priorities (e.g. Lavie et al., 2004). This dissociation can further clarify the contrasting findings of immature selective attention in tasks involving affective or motivation-related distractors, by attributing these to the continued development of the late-selection mechanisms (associated with the continued maturation of the frontal cortex cognitive control regions). Since this type of distractors are stronger competitors for attention than the target, their suppression places greater demand on the immature cognitive control mechanisms. Finally, our results suggested that while early-selection filtering is fully developed in early adolescence, perceptual capacity might be

still smaller in the youngest age group who displayed greater load modulation of distraction. This is consistent with previous findings within the flanker task paradigm (Huang-Pollock et al., 2002) and suggests that perceptual capacity continues to develop in early adolescence (see also Remington et al., 2014, for a demonstration that perceptual capacity may also continue to develop beyond early adolescence).

Selective attention and inattention in the classroom

The magnitude of distractor interference effects on task performance was found to predict the duration of reported distractibility in the school classroom. Moreover, distractor interference was a significant predictor when controlling for age, gender, interest in the topic of study, computer use, and group work, as well as when controlling for generalized cognitive abilities (as measured with CAT score) in adolescence. These findings demonstrate that the measure of focused attention through the interference effects produced by task-irrelevant distractors clearly does not depend on immature development for its prediction of classroom distraction across all ages tested.

In addition, the findings that adolescents' susceptibility to distraction both from a variety of external sources (e.g. background noise, mobile devices), and from internal sources in the form of mindwandering, all converged on a latent factor of classroom distractibility which could be predicted from our task measure of distractor interference suggests that our measure reflects an internal mechanism of focused attention. Previous research has established that the magnitude of distractor interference effects in adults correlates with their reports of mindwandering in daily life (Forster & Lavie, 2014), and adult self-reports of childhood inattentive symptoms (Forster & Lavie, 2016). The present results extend this pattern to the important situation of adolescents' experience of distractibility during their school lessons.

The extension to the school classroom also complements previous findings that behavioural task measures (such as Stroop-like paradigms, requiring response inhibition) can correlate with teacher ratings of students' attention control skills (at least in terms of differentiating between the top and bottom quartiles for children up to age 12 (Das et al., 1992; Papadopoulos et al., 2002). Importantly, these findings advance previous research by clarifying that the prediction of attention in the classroom cannot be explained any of the factors controlled for in our regression model, at least when the measure is based on the pupils', rather than teachers', report. An important factor is the CAT scores. These were found to correlate with attention focus in the classroom, but not significantly when attention is taken into account in the simultaneous regression model, while the distractor interference remained a significant predictor of classroom inattention when CAT scores were controlled for. Considering also the well-established correlations of intelligence and cognitive abilities measures and educational achievement (see Roth et al., 2015 for a meta-analysis), one plausible account for our pattern of findings may be that the ability to focus attention is a critical factor both for education in the classroom and for performance of cognitive abilities and intelligence tests. Although rather speculative at present, this suggestion is consistent with previous findings that sustained attention tasks (error rates in a task which required the continuous solving of easy arithmetic problems) predicts academic performance above and beyond intelligence (Steinmayr et al., 2010).

Sustained Attention in Adolescence

Adolescence was found to involve a clear developmental trajectory in the ability to sustain stable levels of attention, as measured with response variability in the attention task in the distractor-absent conditions. Adolescents of 12-15 years of age showed greater response variability compared to 16-17 year olds who in turn had a trend for greater response variability compared to adults.

Importantly this developmental pattern was found across perceptual load levels, even though high perceptual load was shown to be effective in increasing the ability to focus selective attention, and reduce distractor interference effects for adolescents of all ages. These findings are consistent with previous research showing increased response variability in adolescents' performance of sustained attention tasks such as the SART or CPT (Braet et al., 2009; Stawarczyk et al., 2014; Fortenbaugh et al., 2015; Gyurkovics et al., 2020) and extend it to establish that the ability to sustain attention is still developing in adolescence, even in tasks of high perceptual load that clearly improve their ability to focus selective attention similarly to adults. The contrast we establish between selective and sustained attention within the same task allows us to rule out alternative accounts for immature sustained attention in adolescence, in terms of reduced motivation to engage and maintain attention focus in monotonous vigilance type tasks that are not inherently rewarding, such as the CPT and SART task paradigms.

Sustained attention and inattention in the classroom

The present results also establish our sustained attention measure as a predictor of adolescents' ability to focus attention in the classroom, including when other factors (such as age, gender, computer use, group work, CAT, and interest in the lesson) are controlled for. Our findings that response variability predicts inattention in the classroom when interest in the lesson is controlled for (in itself also a predictor of inattention, as expected) further supports the conclusion that our measure reflects immature attention rather than reduced motivation to engage in tasks of little interest. These findings are consistent with an earlier finding (Stawarczyk et al., 2014) that response variability during SART correlates with adolescents reports of stimulus-triggered mindwandering, since these appear to be a form of distraction. Although Stawarczyk and colleagues did not find a correlation between response variability and external distractions this can explained with the reduced sensitivity to assess external sources of distraction in the rather austere conditions of the laboratory.

There are a number of potential causes for the relationship found here in adolescents between increased variability and greater distractibility during learning. A compelling account may be made on the basis of the well-known protracted development of executive control and the associated frontal control networks in adolescents. Fluctuations of executive control may lead to both increased response variability on the task and vulnerability to distraction in the classroom. Indeed 'task-positive' prefrontal cortex networks associated with attention control in line with the task demands undergo prolonged maturation during adolescence (e.g., Choudhury et al., 2008; Constantinidis & Luna, 2019). These networks have also been found to be important for sustaining attention on task: greater levels of response variability are associated with reduced regulation of spontaneous neural fluctuations by the task-positive networks (e.g., Esterman et al., 2014) as well as being negatively correlated task-related signals in frontal and parietal cortices. The reduced task-positive regulation in frontoparietal networks can explain not only the increased response variability but also the greater vulnerability to distraction in the classroom, attributing both to fluctuations of cognitive control. On this account one might expect to find an effect of age on the distractor interference effects on task, however given that our distractors were less motivationally-relevant than the potential sources of distraction in the classroom, it is plausible that immaturity of cognitive control specifically concerns distractions by motivationally-relevant stimuli, which require greater exercise of cognitive control in order to be ignored.

Attributing sustained attention to immature cognitive control is in accord also with the proposed dissociation offered by Load Theory (e.g. Lavie et al., 2004) between early selection attention which improves by high perceptual load and cognitive control which is shown here to continue to develop. The unique sources of variance explained by each of the sustained and selective attention task measures is in further support of this dissociation.

Errors

Younger adolescents (age 12-15) were found to differ from older adolescents and adults in producing higher error rates, while the older adolescents performed at adult levels. The findings of improved accuracy with age is generally consistent with previous research, (e.g. Aïte et al., 2018) though different tasks and measures differ somewhat with respect to whether older adolescents reach adult levels of performance accuracy already at age 16-17 (e.g. Leon-Carrion et al., 2004; or even somewhat earlier e.g. at age 15 in Huizinga et al., 2006); or continue to improve up to around age 21-22 (e.g. Duell et al., 2018; Stawarczyk et al., 2014).

It is plausible that performance accuracy in the latter tasks is more sensitive to reveal any remaining developmental trajectory in older adolescents, compared to our task, either due to being more monotonous (e.g. as in the SART) and thus tapping more on immature sustained attention abilities, or involving greater demand on response inhibition and other executive control functions such as working memory.

Conclusions

The present research establishes that while selective attention appears to have matured by the adolescence period, even in the presence of salient yet entirely irrelevant distractor faces, their ability to sustain attention is still developing up to and including age 16-17, as indicated by elevated levels of response variability. Importantly our research established the developmental dissociation between mature selective attention and continued development of sustained attention within the same task and under conditions of high perceptual load that improved their attention focus to the same extent as in adults. Moreover both our task measures of selective attention and sustained attention were found to be unique predictors of adolescents' inattention levels in the school classroom, even when important background factors including cognitive aptitude and level of interest in the lesson are controlled for, thus establishing the external validity of our attention task measures and their potential applicability to the understanding of attention in the important educational settings of the school classroom.

Since each of the sustained and selective measures predicted a unique source of variance in classroom inattention, and were dissociable also in their development our results suggest that sustained attention may depend on the development of cognitive control and the associated frontal cortex maturation, while selective attention and focusing on tasks under more attention demanding conditions (of high perceptual load) depends on the 'early selection' mechanisms of focused attention (Lavie et al., 2004) and these have fully matured by the adolescence period.

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Appendix Table 1. Zero-order correlations between all variables of interest - Adolescents

	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1. Age	-0.06	-0.15	-0.02	-0.20*	0.05	-0.02	-0.11	-0.01	-0.01	0.19*	-0.03	-0.01	-0.11	-0.05	0.01
2. Computer use		-0.11	0.12	-0.04	0.13	0.19*	-0.03	-0.13	-0.08	-0.05	-0.02	-0.08	-0.03	0.01	-0.08
3. Working in a group			0.16	0.26**	0.03	-0.10	-0.04	0.24**	-0.07	-0.04	0.00	-0.04	-0.07	-0.01	-0.01
4. Wellness				0.09	0.00	0.03	0.09	0.12	0.16	0.04	0.10	-0.01	-0.08	0.22*	0.09
5. CAT aptitude score					0.14	-0.12	-0.04	-0.04	-0.02	-.191*	-0.07	-0.23*	-0.13	-0.14	-0.19*
6. Interest in lesson						-0.02	0.07	-0.17	-0.20**	-0.14	-0.12	-0.08	-0.21*	-0.23**	-0.18*
7. Distractor interference							0.05	0.04	-0.14	0.09	0.19*	0.19*	0.02	0.07	.175*
8. CV								0.23**	0.07	.237**	0.14	0.17	0.07	0.15	0.24**
9. Other people									0.22*	.310**	0.47**	0.26**	0.04	0.17	0.49**
10. Window										.253**	0.09	0.14	0.52**	0.31**	0.30**
11. Social Networks											0.36**	0.68**	0.23**	0.34**	0.75**
12. Background noise												0.46**	0.03	0.50**	0.75**
13. Other functions on device													0.11	0.52**	0.88**
14. Displays														0.29**	0.20*
15. Mindwandering															0.68**

16. Classroom Distraction Factor

Appendix Table 1. Pearson correlation coefficients are shown. * $p < 0.05$ level ** $p < 0.01$ (2-tailed). N.B. The subject of the lesson was not analysed due to the large range of class settings reported (26 different subject lessons).