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Media multitasking is associated with distractibility and increased prefrontal activity in adolescents and young adults

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Keywords: media multitasking, attention, prefrontal cortex, fMRI

Abstract

The current generation of young people indulge in more media multitasking behavior (e.g., instant messaging while watching videos) in their everyday lives than older generations. Concerns have been raised about how this might affect their attentional functioning, as previous studies have indicated that extensive media multitasking in everyday life may be associated with decreased attentional control. In the current study, 149 adolescents and young adults (aged 13–24 years) performed speech-listening and reading tasks that required maintaining attention in the presence of distractor stimuli in the other modality or dividing attention between two concurrent tasks. Brain activity during task performance was measured using functional magnetic resonance imaging (fMRI). We studied the relationship between self-reported daily media multitasking (MMT), task performance and brain activity during task performance. The results showed that in the presence of distractor stimuli, a higher MMT score was associated with worse performance and increased brain activity in right prefrontal regions. The level of performance during divided attention did not depend on MMT. This suggests that daily media multitasking is associated with behavioral distractibility and increased recruitment of brain areas involved in attentional and inhibitory control, and that media multitasking in everyday life does not translate to performance benefits in multitasking in laboratory settings. [1]

[1]Abbreviations: MMT = media multitasking; DA = digital activity; SDP = sociodigital participation; GPA = grade point average, SPL = superior parietal lobule

1. Introduction

With the use of smartphones and other forms of digital technologies becoming an ever more prevalent activity in young people's everyday lives, concerns have been raised about how this might affect their brain development and cognitive functioning. One of the suggested effects of constant use of digital technologies is an increased tendency to multitask, since the currently available platforms support the nearly seamless use of several simultaneous programs and applications. It has been shown that today's generation of young people grown up immersed in modern technology (i.e., "digital natives"; Prensky, 2001) indulge in more multitasking behavior than older generations (Carrier et al., 2009; Zhang et al., 2015). It is estimated that almost a third of the time young people use media they use two or more media simultaneously (Rideout et al., 2010). This technology-mediated multitasking behavior may have implications for attention-dependent functioning, as studies have shown that training can induce benefits in multitasking and task switching abilities (Cepeda et al., 2001; Minear and Shah, 2008; Lussier et al., 2012; Strobach et al., 2012), albeit transfer effects in such cognitive training studies have often been narrow and specific to the features of the trained task (Green & Bavelier, 2008). It is therefore plausible to think that intensive use of digital technologies could in a sense "train the brain" to become more skilled at multitasking, especially when the brain's attention networks are still developing (Rothbart and Posner, 2015). In recent years, several studies have been conducted on the relationship between daily media multitasking (i.e., using multiple media forms simultaneously) and cognitive functioning. Yap and Lim (2013) demonstrated that high levels of daily media multitasking activity were associated with a tendency for split versus focal visual attention, and concluded that prolonged simultaneous media usage might reduce the effort needed to maintain split attention. Task switching abilities have also been reported to be positively associated with media multitasking (Alzahabi and Becker, 2013).

From a less optimistic point of view, a tendency to multitask can be seen as a result of increased distractibility and poor executive control abilities (Loh and Kanai, 2015). Results from several studies support this notion by showing that excessive media multitasking is related to decrements in attentional processes (Cardoso-Leite et al., 2015). For example, Ophir and colleagues (2009) found that frequent media multitasking is associated with an increase in distractibility and greater task switching costs. Furthermore, according to the results of Alzahabi and Becker (2013) as well as those of Sanbonmatsu and colleagues (2013), media multitaskers exhibit declined performance on actual tests of multitasking. Recent studies have also shown that multitasking behavior is positively correlated with higher self-reported impulsivity (Minear et al., 2013; Yang and Zhu, 2015; Uncapher et al., 2015), suggesting that decreased executive control may lead to a tendency to multitask while using technology, or vice versa. Media multitasking has also been shown to be associated with a decrease in grey matter volume in frontal brain regions (in the anterior cingulate cortex; Loh and Kanai, 2014) belonging to the executive attention network (Bush et al., 2000). This suggests that media multitasking might have a negative impact on brain areas involved in attentional control. It is important to note, however, that an extensive follow-up study (Minear et al., 2013) failed to replicate the results of Ophir and colleagues (2009), and that a recent study failed to find evidence for a relationship between the amount of daily media multitasking activity and the ability to sustain attention (Ralph et al., 2015). These contradictory findings were the motivation for the current study.

The aim of the current study was to examine whether self-reported media multitasking activity is related to adolescents' and young adults' (aged 13–24 years) attentional abilities or attention-related brain activity. More specifically, our participants performed speech-listening and reading tasks which required maintaining attention in the presence of distractor stimuli or dividing attention between the two tasks. Brain activity during these tasks was recorded using event-related functional magnetic resonance imaging (fMRI). The tasks involved performing a sentence congruence judgment task in the auditory or visual modality in the presence of irrelevant inputs in the other modality (distracted attention condition), or performing both tasks in parallel (divided attention condition). A condition where sentences were presented only in one modality (undistracted attention condition) was used as a baseline condition. The relationship between the level of media multitasking, task performance and task-related brain activity was then examined, and discerned from the effects of the overall use of digital technologies. The current study therefore extends previous findings on media multitasking by using a more ecologically valid attentional task with complex linguistic stimuli, and by studying not only young adults but also adolescents in a sample much larger than in most related brain imaging studies. Based on previous studies, we expected media multitasking to be associated with increased distractibility (Ophir et al., 2009) but not with benefits in multitasking performance (Alzahabi & Becker, 2013; Sanbonmatsu et al., 2013) in the current study.

2. Materials and methods

2.1 Participants

The participants were selected from a sample of 2977 respondents who filled out a questionnaire including a wide variety of questions relating to the use of digital technologies in everyday life as a part of the research project titled Mind the Gap between Digital Natives and Educational Practices (2013–2016) and funded by the Academy of Finland (http://wiredminds.fi/projects/mind-the-gap/). The respondents belonged to three different age cohorts: 13- and 16-year-old pupils and 20–24-year-old university students. The questionnaire included a Sociodigital Participation (SDP) inventory (Hietajärvi et al., unpublished results) assessing various dimensions of technology-mediated practices in everyday life. Using a latent profile analysis (Vermunt and Magidson, 2002) the participants (each cohort separately) were first grouped into profiles representing their SDP practices. The identified profiles (across cohorts) were interpreted as basic participants (control), gaming-oriented participators and creative participators. Respondents ineligible for an fMRI measurement were screened out, as well as respondents with any learning difficulties or notably poor school performance with a self-reported grade point average (GPA) below 7 on a 4-to-10 point scale system. As a result, brain activity and performance of 173 participants were measured for the study, out of which 149 returned a filled media multitasking questionnaire (see below) mailed to the participants afterwards. These 149 participants were included in the present analyses. All participants were native Finnish speakers with normal hearing, normal or corrected-to-normal vision, and no self-reported history of psychiatric or neurological illnesses. An informed written consent was obtained from each participant (and from a guardian in the case of underage participants) before the experiment. The experimental protocol was approved by the Ethics Committee for Gynaecology and Obstetrics, Pediatrics and Psychiatry of The Hospital District of Helsinki and Uusimaa, Finland.

2.2 Media Multitasking score

The level of media multitasking was defined as the mean number of media a person simultaneously consumes while using media. We used the shorter version of the media multitasking questionnaire (Ophir et al., 2009) adapted by Pea et al. (2012) to create a media multitasking variable for each participant. The external validity of the resulting media multitasking questionnaire is yet to be firmly established, but several independent research groups have produced comparable indices for average media multitasking activity in their sample based on this questionnaire. Furthermore, since the questionnaire is designed simply to measure occurrences of certain type of behavior without making any further inferences about possible latent variables underlying that behavior, its external validity is most likely not questionable.

Six categories of media use were included in the media multitasking questionnaire: (1) watching video content (TV, YouTube, movies, etc.), including playing video games; (2) listening to music; (3) reading or doing homework; (4) e-mailing or sending messages/posting on Facebook, MySpace, etc. (not including Facebook chat); (5) texting or instant messaging (including Facebook chat); (6) talking on the phone or video chatting. For each media use category i there were six questions: "*While using* [medium i], *how much time do you spend using* [medium j]?" where j also ran across the six media use categories. To create the final Media Multitasking (MMT) score, scores for multitasking in each media category were summed per participant. The distribution of MMT scores was compared between the three age cohorts using a chi-squared test.

The MMT score used in the current study reflects the absolute time the participant reports spending media multitasking. Ophir et al. (2009) and Pea et al. (2012) calculated a Media Multitasking Index (MMI), which was a measure of time spent multitasking in relation to the time spent using media in general. This means that a participant who uses little media but has a tendency to multitask while doing so gets a high MMI, whereas a participant who spends a lot of time using technology but only a small portion of it multitasking gets a low MMI, even though the absolute time spent media multitasking would be identical for these two participants. Since the aim of the current study was to examine how media multitasking might affect cognitive functions such as attentional control or multitasking, and since it is know that the time spent training affects the degree of experience-dependent brain plasticity (e.g., Kleim & Jones, 2008), the absolute time spent on this activity is a more appropriate measure to use for the purposes of this current study. Nevertheless, analyses of task performance and brain activity using the MMI instead of the MMT score were also included in the current study to allow comparisons of results obtained by using these two measures. The MMI was calculated for each participant by dividing the summed score for multitasking in each media category by the summed score of time spent using each media category, as described in Pea et al. (2012).

2.3 Digital Activity score

A sum of scores from 17 items probing the amount of time spent using digital technologies were calculated based on the SDP inventory and used as the Digital Activity (DA) score. Examples of these items are: "*I send text messages*", "*I talk on the phone*", "*I watch movies on the computer*", "*I send e-mails*" and "*I play games on the computer*". Partial correlations between MMT score and the overall DA score controlling for Gender and Age Cohort were calculated.

2.2 Stimuli

2.2.1 Written sentences

The written sentences were either semantically congruent or incongruent sentences in Finnish. The incongruent sentences were created by taking a subset of the congruent sentences (e.g., "*This morning I ate a bowl of cereal"*) and replacing the last word of the sentences with a semantically incongruent (but syntactically plausible) word (e.g., "*This morning I ate a bowl of shoes*"). Each participant saw a total of 144 congruent sentences and 108 incongruent sentences, because in the divided attention condition, more congruent sentences were needed (for more details see *2.4 Procedure*). The last word of the sentence consisted of xs (as many xs as there were letters in the last word) for the first 2 s of a trial, and at 2 s they were replaced with the last word of the sentence.

The sentences were projected onto a mirror mounted on the head coil and presented in the middle of the screen (font: Arial, size 14). The angular size of the sentences at the viewing distance of ~40 cm was ~1.4° vertically and ~24 ° horizontally.

2.2.2 Spoken sentences

The spoken sentences were semantically congruent or incongruent Finnish sentences spoken by a female native Finnish speaker. The incongruent sentences were created in a similar way as the incongruent written sentences, that is, by replacing the last word in the congruent sentences and then recording the sentence in spoken form. Each participant heard a total of 108 congruent sentences and 72 incongruent sentences, because in the divided attention condition more congruent sentences were needed (see *2.4 Procedure* for details). Sentence presentation was timed so that the onset of the last word was at 2 s after the beginning of the trial (that is, simultaneously presented with the last word of a text sentence).

The sentences were presented binaurally through insert earphones (Sensimetrics model S14; Sensimetrics, Malden, MA, USA). They were broadband stimuli high-pass filtered with a cut-off at 100 Hz and low-pass filtered with a cut-off at 7000 Hz. The intensity of the sentences was scaled so that the square root of the mean of the squared signal was similar (0.1). The intensity of the speech was individually set to a loud, but pleasant level, and was ~80 decibels as measured from the tip of the earphones. All adjustments to the speech stimuli were made using Audacity (http://audacity.sourceforge.net) and Matlab (Mathworks Inc., Natick, MA, USA) softwares.

2.2.3 Music

2.5-s excerpts of instrumental music were obtained from a free-source online music website. The music excerpts were preprocessed using the same procedure as for the spoken sentences and represented various genres from hip-hop to classical music. A total of 48 music clips were used.

2.3 fMRI/MRI data acquisition

Functional brain imaging was carried out with a 3 T MAGNETOM Skyra whole-body scanner (Siemens Healthcare, Erlangen, Germany) at AMI Centre, Aalto NeuroImaging, Aalto University School of Science. A 20-channel head coil was used. The functional echo planar (EPI) images were acquired with an imaging area consisting of 43 contiguous oblique axial slices (TR 2500 ms, TE 32 ms, flip angle 75°, voxel matrix 64 · 64, field of view 20 cm, slice thickness 3.0 mm, in-plane resolution 3.1 mm · 3.1 mm · 3.0 mm). Image acquisition was performed at a constant rate (i.e., image acquisition was not jittered), but was asynchronized with stimulus onsets. Three functional runs of 222 volumes (including 4 initial dummy volumes) were measured for each participant. The duration of one run was 11min, so the total duration of the three functional runs was 33 min and a total of 666 functional volumes were obtained during this time.

High-resolution anatomical images (voxel matrix 256 · 256, in-plane resolution 1 mm · 1 mm · 1 mm) were acquired from each participant after the last functional run.

2.4 Procedure

The experimental setting was nearly identical to the one used with adult participants in the study by Moisala et al. (2015). In the current study, participants performed a total of nine experimental conditions, out of which six were used for the present analyses. One block of rest was also included, where only a fixation cross was present on the screen. The three excluded conditions were not relevant to the current study, and they comprised of functional localizers for the visual and auditory cortices as well as a control condition containing pseudotext sentences. Out of the six analyzed conditions, two were *undistracted attention conditions:* the participants were instructed to attend to the sentences in just the auditory (1) or visual (2) modality, and no sentences were presented in the other modality. Three conditions were *distracted attention conditions:* the participants were instructed to attend to the sentences in just one modality and distractor stimuli were present in the other modality which the participants were instructed to ignore. Visual distractors were written sentences (3), and the participants were instructed to ignore them by holding a steady fixation on a fixation cross presented in the middle of the screen. Auditory distractors were spoken sentences (4) or music (5). The final condition was the *divided attention condition*: the participants were presented with simultaneous spoken and written sentences and instructed to attend to both modalities (6).

In the beginning of each task condition (i.e., block), instructions for the current task type were shown for 3.5 s. In subsequent task blocks, 12 sentences (visual or auditory) or pairs of auditory and visual (semantically unrelated) sentences were presented, each with duration of 2.5 s. Each sentence was followed by a 1 s response window during which the participants were instructed to respond with their right index and middle finger whether the attended sentence was congruent or not (respectively), or during divided attention whether both attended sentences were congruent or whether one of the sentences had been incongruent (since the simultaneously presented sentences were never both incongruent in the divided attention condition). Within a block, half of the sentences were congruent and half were incongruent. Thus, in the divided attention condition each modality contained only a quarter of incongruent sentences (so that half of the trials in a divided attention block contained an incongruent sentence in either modality). During the response window, a question mark (angular size 1.4° · 1.0°) was presented at the center of screen. When only speech stimuli were presented, the fixation cross was shown at the center of screen during the entire trial. At the end of each block, the participant was shown the percentage of correct responses in that block. The score was shown for 2 s, and followed by 4 s of a blank screen before the next block.

There were three functional runs, consisting of 11 blocks each. Each run included one rest block and one block of each task type, except the divided attention task was repeated twice in order to have an equal number of incongruent trials within a modality in each condition. This resulted in a total of 72 trials for the divided attention task (3 · 2 · 12), and 36 trials for each of the other task condition (3 · 1 · 12). The order of tasks within the run was random, except that the rest block was always in the middle of the run between the 6th and 7th task block. All stimuli (sentences and distractors) were presented in randomized order. The sentences were randomized in the following way. First, the sentences were divided randomly into 3 sets (1 per run) that were identical for all participants. Then the order of sentences within a set was randomized, and the presentation order of these 4 sets was randomized and counterbalanced across participants. Each sentence was presented only once to each participant. The congruent and incongruent versions of the same sentence were never presented within the same run.

2.5 fMRI data analysis

Image preprocessing and statistical analysis was performed using Statistical Parametric Mapping (SPM8) analysis package (Wellcome Department of Cognitive Neurology, London, UK; Friston et al., 1994) as implemented in Matlab. In order to allow for initial stabilization of the fMRI signal, the first four dummy volumes were excluded from analysis. In pre-processing, the slice timing was corrected, data were motion corrected, high-pass filtered (cut-off at 1/128 Hz), and spatially smoothed with a 6 mm Gaussian kernel. The EPI images were intra-individually realigned to the middle image in each time series and un-warping was performed to correct for the interaction of susceptibility artifacts and head movements.

For the first-level statistical analysis, the general linear model was set up including a regressor for incongruent and congruent sentences in each of the six analyzed experimental conditions and for the three experimental conditions not used in the current study. Separate regressors for the responses of the participants and for instructions (2.5-s periods between the blocks and a 6-s period at the beginning of each run) were also included. 6 movement parameters were added to the model as nuisance regressors. The regressors were convoluted with the canonical hemodynamic response function. Blocks where the percentage of correct responses was more than three standard deviations below average (and below chance-level performance) were removed from analyses, since during these trials participants had most likely forgotten the task instructions and were performing a wrong task or not performing any task.

In the second-level analysis, the anatomical images were normalized to a canonical T1 template (MNI standard space) provided by SPM8 and then used as a template to normalize the contrast images for each participant (tri-linear interpolation, 3 mm · 3 mm · 3 mm using 16 nonlinear iterations). To study group differences, scans were subjected to a multiple regression in SPM with the MMT score, Age Cohort and Gender as covariates, and an additional analysis was carried out which also included the DA score as a covariate. The analysis was also replicated using the MMI instead of the MMT score as a covariate. A p-value threshold of $p<0.01$ (uncorrected) and a cluster size threshold of $k>150$ was set for the resulting statistical images, and the images were familywise error corrected (FWE) corrected at the cluster-level. Anatomical regions corresponding to the activity foci were identified using the xjView toolbox for SPM (http://www.alivelearn.net/xjview).

2.6 Region-of-interest analysis

Cortical regions showing activity modulations that correlated with the MMT score were subjected to region-of-interest (ROI) analyses. This was done by first manually drawing ROIs to cover these regions using Freesurfer software in normalized space. Further statistical analyses were then conducted using repeated-measures analyses of variance (ANOVAs) for the voxels within these ROIs. Activity modulations between task conditions were compared by conducting an ANOVA for each of the ROIs with the factor Task Type (undistracted vs. divided attention) as the within-subjects variable, and Age Cohort and Gender as the between-subjects factors. Data from the distracted attention condition was not included in this ANOVA in order to avoid circular analysis, as brain activity during this condition was used to define the ROI. Partial correlations (controlling for Gender and Age Cohort) were calculated between MMT score and activity during distracted attention in each of the ROIs. This correlation was also calculated using the MMI instead of the MMT score. Note that the MMT score which was used to define the ROI was not included in any subsequent analyses of activity modulations in the ROI, but that only activity related to the different task types was studied within this region. Partial correlation coefficients (controlling for Age Cohort and Gender) were calculated between activity within the ROIs and task performance during the different task types. The grey matter volume within each ROI was examined by using Freesurfer's automatic processing stream for volume and thickness estimates (Reuter et al., 2012), and by subjecting the grey matter volume estimates of the ROIs to an analysis of covariance (ANCOVA) with the between-subject factors Age Cohort and Gender, and with MMT score as a covariate. A ROI analysis was also conducted for the right and left superior parietal lobule (SPL; Brodmann area 7), localized by using the Destrieux atlas (Destrieux et al., 2010). Activity modulations within these SPL regions were studied by conducting a repeated-measures ANOVA for either Task Type or Distractor Type (written sentences vs. spoken sentences vs. music) and Hemisphere (right vs. left) as the within-subjects variables, and Gender and Age Cohort as the fixed factors. Partial correlations (controlling for Gender and Age Cohort) were calculated between activity in the SPL and performance separately for the three task types and for the two hemispheres. An ANCOVA with MMT and DA scores as covariates and Age Cohort and Gender as between-subject factors was conducted for activity modulations separately in the right and left SPL during the distracted attention condition, and this analysis was repeated with MMI instead of MMT score as a covariate. Finally, a repeated-measures ANOVA for activity in the SPL ROIs was conducted with Distractor Type and Hemisphere as the within-subjects variables, Gender and Age Cohort as the fixed factors and the MMT score and overall DA score as covariates.

2.7 Analysis of behavioral data

Similarly to the fMRI data analysis, blocks where the percentage of correct responses was more than three standard deviations below average were removed from analyses. The relationship between task performance and MMT score was analyzed separately for each task type (undistracted, distracted and divided attention) using an ANCOVA with the percentage of correct responses as the dependent variable, Gender and Age Cohort as the fixed factors, the MMT score and overall DA score as covariates. The same analysis was conducted using MMI instead of MMT score as a covariate. An additional ANCOVA was carried out for the divided attention condition, where the percentage of correct responses was calculated based only on the first three divided attention blocks. This was done because there were twice as many blocks of the divided attention condition than the other task types (and participants therefore received more practice in this task type), so the possibility of practice effects contributing to our results needed to be ruled out. To study possible interactions between learning effects and MMT score, a repeated-measures ANOVA was conducted with the percentage of correct responses during divided attention as the dependent variable, Run number as a within-subjects variable, Gender and Age Cohort as the fixed between-subjects factors, the MMT score and overall DA score as covariates. Partial correlation coefficients were calculated per task type between the percentage of correct responses and the continuous MMT score (1-tailed test of significance), while controlling for Age Cohort and Gender.

To study the effects of distractor type, an ANCOVA was carried out with Distractor Type as the within-subjects variable, Gender and Age Cohort as the fixed factors, and the MMT and DA scores as covariates.

Eta squared (η^2) was calculated for each ANCOVA as a measure of effect size. For all conducted ANCOVAs the Greenhouse-Geisser corrected p-value was used (as indicated by the correction value ε) if the Mauchly's test of sphericity showed a significant result for a variable with more than two levels. However, original degrees of freedom are reported with the F-value even in these cases. A 95% confidence interval was used in all ANCOVAs. When an ANCOVA yielded a significant result, Bonferroni post hoc tests were conducted. For statistical analyses, IBM SPSS Statistics 21 (IBM SPSS, Armonk, NY, USA) was used.

3. Results and discussion

3.1 Media Multitasking score

Table 1 displays the ages, GPAs and MMT scores per age cohort and gender. The MMT score varied between 30 and 99, the average MMT score (± standard deviation) being 51.5 ±15.0. The distribution of MMT scores can be seen in **Figure 1** separately for the three age cohorts. The distributions of MMT scores did not differ between the three age cohorts ($\chi^2(2, N=149)=11.15$, p=0.52). The MMT score was highly reliable (Cronbach's α=0.92). The average MMT score did not differ significantly between the age groups ($F(2,143)=0.55$, $p=0.58$, $\eta^2=0.008$) or genders ($F(1,143)=0.15$, $p=0.70$, $\eta^2=0.001$). Individual MMT scores showed a strong and significant correlation with DA scores (r=0.73, p<0.001). The mean MMI (cf. Ophir et al., 2009; and Pea et al., 2012) was 3.23 (SD=0.66), which falls roughly in between the mean scores from the two studies (M=4.36 and M=1.4, respectively).

Table 1. Participant characteristics.

	Cohort 1 (n=48)			**Cohort 2 (n=49)**			**Cohort 3 (n=52)**		
	Age (±SD)	**GPA (±SD)**	**MMT score (±SD)** / **MMI (±SD)**	**Age (±SD)**	**GPA (±SD)**	**MMT score (±SD)** / **MMI (±SD)**	**Age (±SD)**	**GPA (±SD)**	**MMT score (±SD)** / **MMI (±SD)**
Female (n=73)	13.1 (±0.5)	8.6 (±0.6)	52.2 (±16.8) / 3.2 (±0.7)	16.6 (±0.5)	9.1 (±0.6)	52.6 (±14.2) / 3.3 (±0.7)	20.6 (±1.2)	8.9 (±0.7)	48.1 (±8.6) / 3.1 (±0.6)
Male (n=76)	13.3 (±0.5)	8.5 (±0.7)	47.7 (±14.8) / 3.2 (±0.5)	16.6 (±0.5)	8.9 (±0.7)	53.7 (±16.8) / 3.5 (±0.9)	21.9 (±0.8)	8.3 (±0.9)	54.3 (±16.9) / / 3.1 (±0.6)

Means and standard deviations (SDs) of ages, self-reported grade point averages (GPAs), and Media Multitasking (MMT) scores and Media Multitasking Indices (MMIs) for each age cohort and gender.

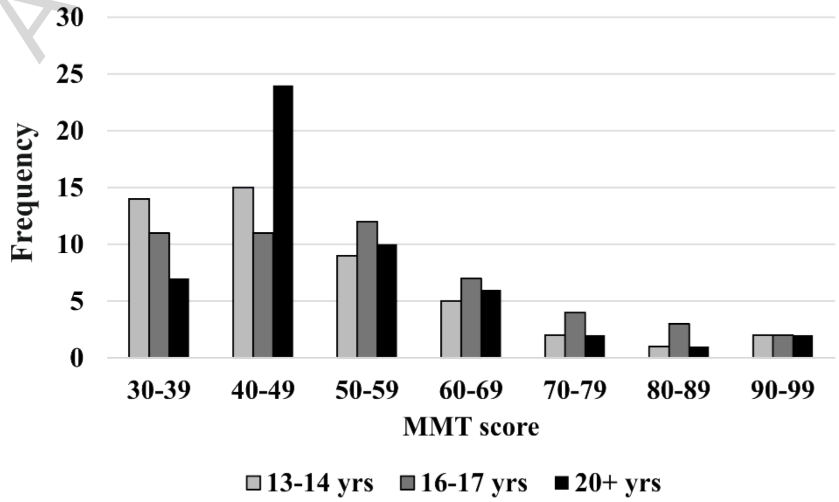

Figure 1. The frequency distribution of Media Multitasking (MMT) scores in each of the three age cohorts.

3.2 Behavioral results

The overall mean percentage of correct responses was 85.5 ±15.5%. In 0.7% (22/3129) of the blocks, this percentage was three standard deviations lower than the mean (below 39.1%), and these blocks were excluded from further analyses because participants were most likely not performing the correct task in these blocks. Mean performance accuracy was 92.8 ±6.3% for undistracted attention, 89.0 ±7.8% for distracted attention, and 74.2 ±8.5% for divided attention. **Figure 2(A)** shows the correlation coefficients between MMT score and performance in the three task types across all participants**,** and **Figure 2(B)** shows the percentage of correct responses during the distracted attention condition plotted against the MMT score.

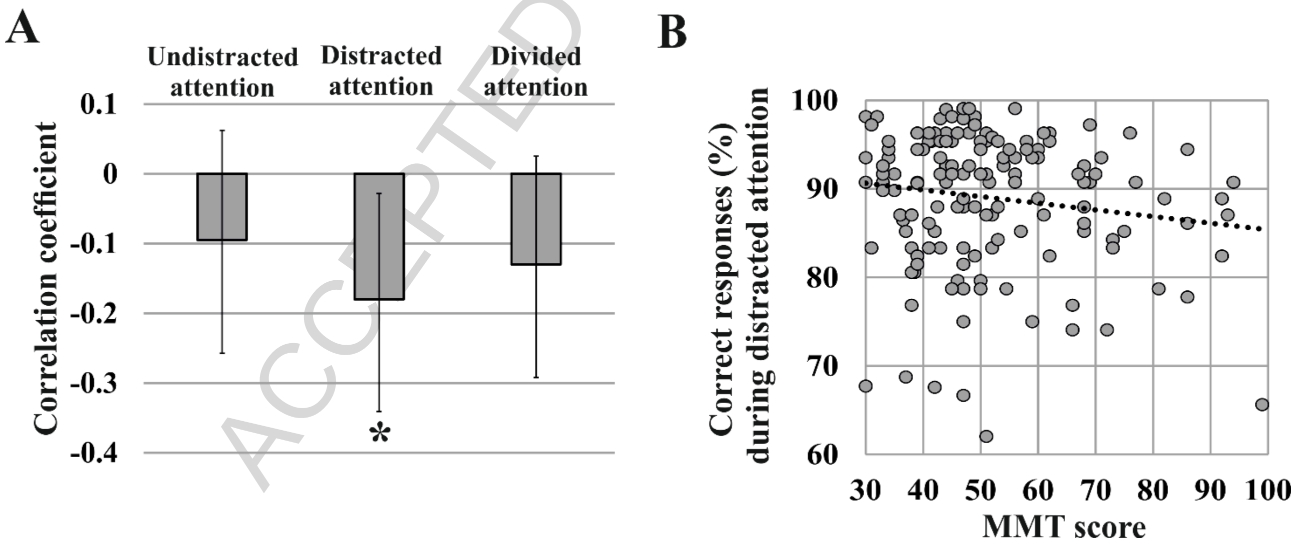

Figure 2. Correlations between the Media Multitasking score and task performance. Partial correlations (controlled for Age cohort and Gender) between Media Multitasking (MMT) score and performance for the three different task types across all participants (n=149) **(A).** Significant correlations are indicated with asterisks (* p<0.05). Error bars represent 95% confidence intervals of the partial correlation coefficients. The percentage of correct responses during the distracted attention condition plotted against MMT with a fitted regression line **(B)**. The regression line is indicated by a dashed line.

Results from an ANCOVA with Age cohort and Gender as fixed factors and MMT and DA scores as covariates revealed that the MMT score did not have a significant effect on the number of correct responses in the undistracted attention condition ($F(1,139)=0.49$, $p=0.51$, $\eta^2=0.003$). This suggests that any observed performance decrements related to media multitasking cannot be explained by differences related purely to language skills. Moreover, analysis conducted using the MMI instead of the MMT score showed no significant main effect of MMI ($F(1,139)=0.37$, $p=0.54$, $\eta^2=0.003$).

During divided attention, MMT had no main effect of performance ($F(1,139)=0.86$, $p=0.36$, $\eta^2=0.006$). No significant main effect of MMI was observed, either ($F(1,139)=0.04$, $p=0.84$, $\eta^2=0.0003$). Practice effects that could have been caused by a greater number of divided attention blocks than blocks for the other task types did not contribute to this result, as MMT demonstrated no main effect even when performance in only the first half of the divided attention task blocks was taken into consideration ($F(1,139)=0.34$, $p=0.56$, $\eta^2=0.002$), and there was no significant interaction between MMT score and Run number (i,e., the 1st vs. 2nd vs. 3rd third of the experiment; $F(2,276)=0.67$, $p=0.49$, $\varepsilon=0.90$, $\eta^2=0.004$). This result therefore suggests that daily media multitasking does not train multitasking abilities. Although this finding may seem counter-intuitive, it has been reported by at least two previous studies by independent research groups. Both Alzahabi and Becker (2013) as well as Sanbonmatsu and colleagues (2013) found no association between media multitasking and performance in a dual task condition. There are several possible reasons for these findings. Firstly, daily multitasking most likely consists not only of dual-tasking in the classical sense but of a combination of divided attention, task switching and performing several automatized functions in parallel (Carrier et al., 2015). In fact, the media multitasking questionnaire used in the present as well as previous studies (Ophir et al., 2009; Pea et al., 2012) might not really tap into genuine multitasking. For example, “texting while doing homework” most likely means intermittently pausing while studying to write a text message, and not actually doing these two activities simultaneously. The true nature of media multitasking could be examined by tracking media multitasking activity in more accurate ways then by relying solely on self-reports, for instance by using mobile devices for repeatedly sampling the participants' media use events (Bolger et al., 2003; Intille, 2011). Dual tasks used in laboratory experiments are also often inherently more demanding than daily multitasking, forcing participants to adopt a more serial rather than parallel mode of task-processing (Fischer and Plessow, 2015). A fundamental difference is therefore likely to exist with multitasking in the laboratory setting and multitasking in real life. Finally, even if heavy media multitaskers were better than others at performing several tasks simultaneously in real life, they might still not exhibit superior multitasking performance in laboratory settings due to the fact that transfer effects in cognitive training studies in general are often quite limited. Future studies may therefore benefit from using experimental tasks that more closely mimic real-life media multitasking in order to determine whether even near transfer effects could be obtained. All of the aforementioned factors may contribute to why media multitasking was not associated with multitasking benefits in the current or previous studies.

For distracted attention, there was a significant effect of MMT score on performance ($F(1,139)=4.01$, $p<0.05$, $\eta^2=0.03$), with a higher MMT score associated with more incorrect responses. This main effect of MMT score did not interact significantly with Gender ($F(1,139)=0.36$, $p=0.55$, $\eta^2=0.002$) or Age Cohort ($F(2,139)=0.38$, $p=0.69$, $\eta^2=0.005$). The nature of the distractor was not a significant factor either, since there was no significant interaction between MMT score and the amount of errors during the three different distractor types (written sentences, spoken sentences or music) ($F(2,278)=0.15$, $p=0.84$, $\varepsilon=0.91$, $\eta^2=0.001$), or between visual tasks with auditory distractors and auditory tasks with visual distractors ($F(1,139)=0.19$, $p=0.67$, $\eta^2=0.001$). DA score did not have a significant main effect on performance ($F(1,139)=0.60$, $p=0.44$, $\eta^2=0.004$), demonstrating that the effect of MMT on performance was not explained by the level of overall daily digitally mediated activity. When MMI was used as a covariate instead of the MMT score, no significant main effect of MMI was observed ($F(1,139)=3.17$, $p=0.08$, $\eta^2=0.02$).

The behavioral results of the current study are in line with the findings of Ophir and colleagues (2009), who showed that heavy media multitaskers were more susceptible to distraction from irrelevant stimuli than light media multitaskers. Furthermore, we extend these findings to more life-like tasks than the more simplified ones used by Ophir et al. (2009), suggesting that media multitasking may be associated with distractibility during everyday life situations as well (e.g., when trying to read in a noisy environment). Future research would benefit greatly from examining the connection between media multitasking and real-life distractibility by, for example, incorporating self-report questionnaires probing everyday failures of attention (such as the Cognitive Failures Questionnaire; Broadbent et al., 1982).

The fact that some previous studies have obtained contradicting results (Alzahabi and Becker, 2013; Minear et al., 2013; Ralph et al., 2015), however, means that the effects of media multitasking on attention-dependent functioning are by no means unequivocally established. It should also be noted that the effect sizes in the present study were small, but this is not surprising considering that the present study did not examine primary effects, but rather transfer effects of the amount of media multitasking to simplified attention tasks in laboratory settings.

3.3 Brain activity

The results of the whole-head fMRI analyses mirror those of the behavioral results: no significant foci of activation correlating with the MMT score were found during the undistracted attention or divided attention conditions, but only during distracted attention. Cortical regions showing a significant positive association with the MMT score during distracted attention are shown in **Figure**

3(A). These regions comprise of the right superior and middle frontal gyri (BA 6/8), and the medial portion of the frontal gyrus (BA 8/9). The multiple regression with DA score added into the model as a covariate showed a main effect of MMT score in the same region of the right superior and middle frontal gyri, but this effect was not statistically as strong and therefore did not pass the correction for multiple comparisons. Similarly, the same analysis conducted using the MMI instead of the MMT score produced a main effect of MMI around the same prefrontal regions, but this result did not pass the correction for multiple comparisons. There was no significant correlation between activity and task performance during distracted attention in either the lateral or medial prefrontal ROI (r=-0.08, p=0.31 and r=-0.12, p=0.15, respectively). Therefore, the association between MMT score and activity in the prefrontal ROIs during distracted condition is not simply an artifact caused by a correlation between performance accuracy and activity within these brain regions. Furthermore, the grey matter volumes of these two prefrontal regions did not explain the observed effect of MMT on their activity, as MMT score did not have an effect on the grey matter volume of either the lateral frontal ($F(1, 141)=0.25$, $p=0.62$, $\eta^2=0.002$ or medial frontal cluster ($F(1, 141)=0.23$, $p=0.63$, $\eta^2=0.002$). The correlation between MMT score and activity in the right prefrontal ROIs during distracted attention is displayed in **Figure 3(B).** This correlation (when controlling for Age cohort and Gender) was significant for both the lateral ($r=0.22$, $p<0.01$) and medial ($r=0.21$, $p<0.05$) prefrontal ROI, as was to be expected since the MMT score was used to define the ROIs. The corresponding correlation calculated using the MMI was not significant in either the lateral ($r=0.07$, $p=0.40$) or medial ($r=0.09$, $p=0.29$) prefrontal ROI. One individual demonstrated mean signal changes of 2.6% in the lateral and 5.1% in the medial prefrontal ROI, and since BOLD signal changes within this percentage range are within reason but nonetheless uncommon outside the sensory cortices (Casey et al., 2002), the partial correlation analysis between the MMT score and mean signal changes (while controlling for Age cohort and Gender) in both ROIs were repeated without this individual. The correlation between MMT score and activity remained significantly positive for the lateral prefrontal ROI (r=0.16, p<0.05), but not for the medial prefrontal ROI (r=0.13, p=0.11).

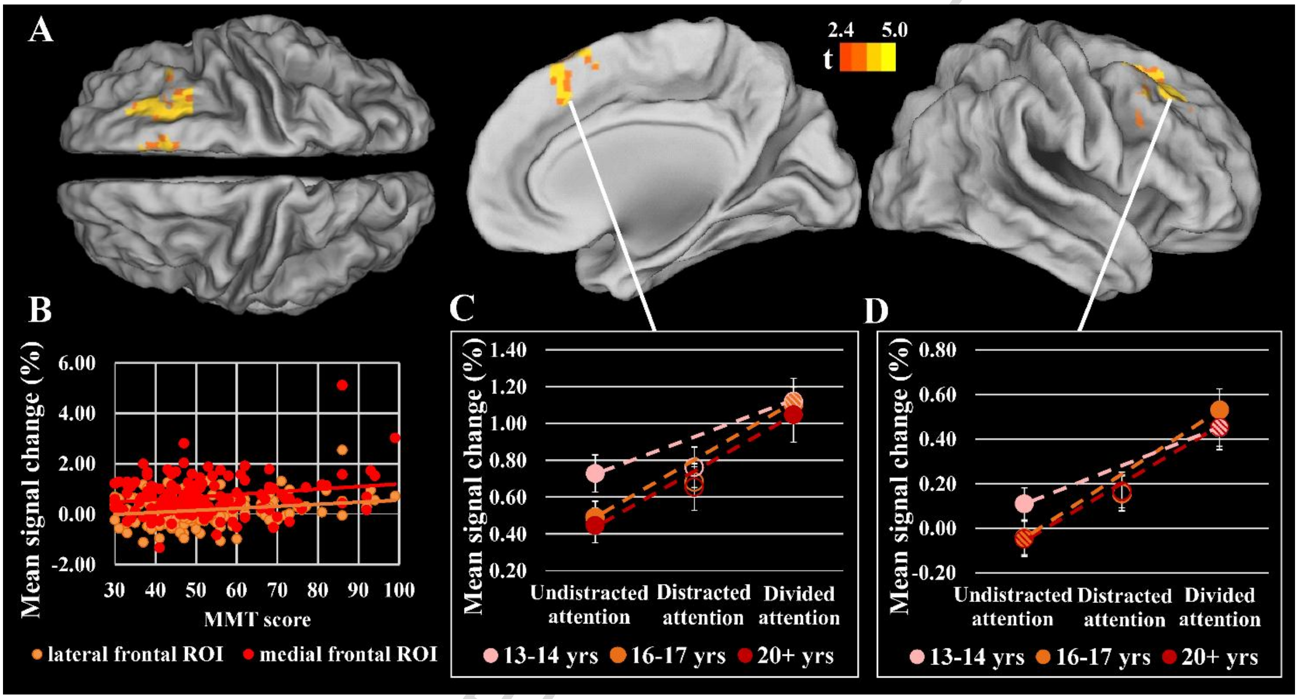

Figure 3. Associations between the Media Multitasking score and brain activity. Prefrontal cortical regions in the right hemisphere showing a significant positive association between the Media Multitasking (MMT) score and brain activity during the distracted attention condition **(A).** Voxel-wise height threshold t=2.35, cluster size >150, p<0.005 (familywise error corrected at the cluster-level). The mean signal change during distracted attention is plotted against MMT score separately for the lateral (shown in orange) and medial (shown in red) prefrontal regions, with regression lines fitted separately for the two regions **(B)**. Mean signal changes within these medial **(C)** and lateral **(D)** frontal regions during three task types (undistracted, distracted and divided attention) for each age cohort. The distracted attention condition is included in the two graphs (C and D; open circles) for illustrative purposes, but it is not included in the conducted ANOVAs because this condition was used when selecting the ROI. Overlapping data points are denoted with striped circles. Error bars represent standard errors of the mean.

An extensive body of literature has demonstrated that right prefrontal regions play an important role in attentional functioning. Imaging studies have shown that a right-dominant network including the middle and inferior frontal gyri is linked to inhibitory control (Garavan et al., 1999; Aron et al., 2003) and to top-down control in a more general sense (Fassbender et al., 2006). Furthermore, several studies have associated insufficient functioning of the right hemisphere frontostriatal circuitry to inadequate response suppression in attention deficit hyperactivity disorder (Casey et al., 1997; Clark et al., 2007), and patient studies have linked right prefrontal lesions to deficits in sustained attention (Wilkins et al., 1987; Rueckert and Grafman, 1996). In the current study, further ROI analyses for the two prefrontal regions showing an effect of MMT score were conducted in order to further validate their role in attentional functioning. More specifically, activity modulation was studied in these areas during two task types differing in the level of difficulty: undistracted attention and divided attention. The results are shown in **Figure 3(C)** and **Figure 3(D)**. There was a main effect of Task Type in both the lateral prefrontal ROI ($F(1,143)=163.31$, $p<0.001$, $\eta^2=0.52$) and the medial prefrontal ROI ($F(1,143)=135.49$, $p<0.001$, $\eta^2=0.48$). Pairwise comparisons revealed that for both ROIs, mean signal changes were smaller during undistracted attention than during divided attention ($p<0.001$ in both cases). This association with increased task difficulty and activity enhancements in the prefrontal ROIs suggests that these regions were indeed more heavily recruited as the need to exert attentional control became more crucial. There was a significant interaction of Age Cohort and Task Type for the lateral ROI ($F(2,143)=3.62$, $p<0.05$, $\eta^2=0.02$). This is because even though the two task types differed significantly in all three age cohorts ($p<0.001$ for all pairwise tests), the youngest age cohort did not show such a steep increase in activity in response to the divided attention condition as the older age cohorts. It is not surprising to find that the pattern of prefrontal recruitment in response to the most difficult task condition was not identical between the 13-14-year-olds and older participants, since it is well know that prefrontal regions continue to undergo significant neural maturation during early adolescence (Gogtay et al., 2004; Squeglia et al., 2013). Furthermore, it has been shown that young adolescents fail to recruit dorsolateral prefrontal regions to the same extent as adults during executive control of attention (Konrad et al., 2005) or when task difficulty increases during working memory tasks (Crone et al., 2006; Scherf et al., 2006).

In sum, the results regarding brain activity suggest that the distracted attention condition required more effort and executive control from the participants the higher their MMT score was. The increase in prefrontal recruitment may, in other words, reflect an increased need to redirect attention and maintain it on the central task in the presence of a distractor. Alternatively, the increased prefrontal activity may also be indicative of less efficient functioning of right prefrontal regions during distracted attention, since less effective and less accurate synaptic transmission may result in more widespread cortical activity (Konrad et al, 2005). There was no evidence for increased effort or increased prefrontal activity with higher MMT score during undistracted or divided attention, which is most likely because the difficulty of these task types (as indicated by task performance) was not correlated with MMT score.

Due to the fact that MMT score was found to have an impact on performance and brain activity specifically during distracted attention, further ROI analyses were conducted for the SPL bilaterally, since this area is known to be involved in covert and overt shifts of attention (Corbetta et al., 1998) and attentional capture by distractor stimuli (de Fockert et al., 2004). Importantly, gray matter volume in the left SPL has been shown to correlate with distractibility in daily life, and disrupting function of this area has been shown to lead to increased attentional capture by irrelevant distractors (Kanai et al., 2011), suggesting the MMT score could be related to decreased recruitment of this region in our study. Our analyses of activity modulations in the right and left SPL showed that distracted attention did indeed lead to activity increases in these regions when compared to undistracted attention (main effect of Task type: $F(2,290)=51.93$, $p<0.001$, $\eta^2=0.14$, $\varepsilon=0.95$; pairwise comparisons distracted vs. undistracted attention: $p<0.001$ in both hemispheres). The type of distractor was a significant factor ($F(2,290)=3.95$, $p<0.05$, $\eta^2=0.02$, $\varepsilon=0.97$), because speech distractors were associated with larger signal increases than music distractors ($p<0.05$ for the pairwise comparison). There was an interaction between Hemisphere and Task type ($F(2,290)=9.96$, $p<0.001$, $\eta^2=0.002$, $\varepsilon=0.86$), but pairwise comparisons revealed that in both ROIs, activity during all three task types differed significantly from each other ($p<0.001$ for all pairwise comparisons), so that activity was greatest during divided attention, followed by distracted attention and then by undistracted attention. Activity specifically in the right SPL was significantly positively correlated with task performance during distracted attention ($r=0.19$, $p<0.05$) but not during undistracted ($r=0.13$, $p=0.13$) or divided attention ($r=0.11$, $p=0.20$), validating the importance of the right SPL in the ability to ignore distractors. For the left SPL, no significant correlations between activity and performance were found for undistracted ($r=0.12$, $p=0.15$), distracted ($r=0.15$, $p=0.08$) or divided ($r=0.04$, $p=0.64$) attention. Contrary to the initial hypothesis of a link between SPL recruitment and distractibility, no main effect of the MMT score on activity during distracted attention was observed in the left SPL ($F(1,139)=0.09$, $p=0.77$, $\eta^2= 0.0005$) or the right SPL ($F(1,139)=0.02$, $p=0.90$, $\eta^2= 0.00009$), irrespective of the distractor type (Interaction between the MMT score and Distractor Type: $F(2,278)=1.56$, $p=0.21$, $\eta^2=0.008$, $\varepsilon=0.96$). Similarly, when the MMI was used as a covariate instead of the MMT score, no significant main effect of the MMI was observed (left SPL: $F(1,139)=0.94$, $p=0.33$, $\eta^2=0.007$, right SPL: $F(1,139)=0.28$, $p=0.60$, $\eta^2=0.002$). This suggests that in the current study, the distractibility related to media multitasking is not related to SPL functioning, but that it is specifically dependent upon right prefrontal recruitment.

Taken together, the results from the current study support the notion that the higher the MMT score of a participant, the more effort or attentional top down control was needed to accomplish adequate task performance specifically during distracted attention. In addition, the current results were obtained only when using an absolute measure of media multitasking, indicating that when studying phenomena assumed to relate to plastic changes in the brain, this measure is indeed more appropriate than the previously used relative indices. It is important to note, however, that due to the correlational nature of the current study, the direction of causality between media multitasking and attention remains elusive. One interpretation of our results is that extensive daily media multitasking directly reinforces task switching behavior and deteriorates the ability to sustain attention on a focal task. Frequent multitasking behaviors enabled by modern technology may, in other words, lead to reduced executive control and greater susceptibility to interference (Carr, 2010; Loh and Kanai, 2015). However, an equally plausible interpretation of the results is that decreased executive functioning leads to more media multitasking activity. A longitudinal study design might shed more light on which interpretation is more likely. Although the current study is not able to disentangle the cause from the effect in this association, it does provide valuable evidence for the notion that a relationship exists between daily media multitasking and decrements in attentional functioning, and demonstrates that this relationship is reflected in the recruitment of right prefrontal regions during attentionally demanding tasks. Considering the prevalence of media multitasking activity among the adolescents and young adults of today, this finding is of extreme importance, and it demands that this phenomenon be studied more thoroughly.

4. Conclusions

In the current study, the amount of everyday media multitasking was associated with more errors when adolescent and young adult participants were performing a sentence congruency judgment in one modality while a distractor stimulus was present in the other modality. This result was not explained by the amount of overall daily digitally mediated activity, or by differences in language skills, and it was not affected by the age or gender of the participants. During distracted attention, a higher MMT score was not only associated with worse performance, but also with increased activity in the right prefrontal cortex during task performance. This brain region is known to be important for attentional control, which was validated by our analyses demonstrating that activity in this region increased incrementally in response to task difficulty. It therefore seems likely that the higher the MMT score of a participant, the more effort or attentional top down control was needed when the participant needed to focus on a focal task in the presence of a distractor. The current study extends previous findings on media multitasking in three important ways. First, our results show that distractibility may be associated with media multitasking not only in adulthood, but already during middle adolescence. Second, our results indicate that this distractibility is evident even when using a more ecologically valid attention task as opposed to the more traditional attention tasks used in previous studies (e.g., Ophir et al., 2009). Third, our study is the first to reveal how the increased distractibility linked to media multitasking is reflected in brain activity.

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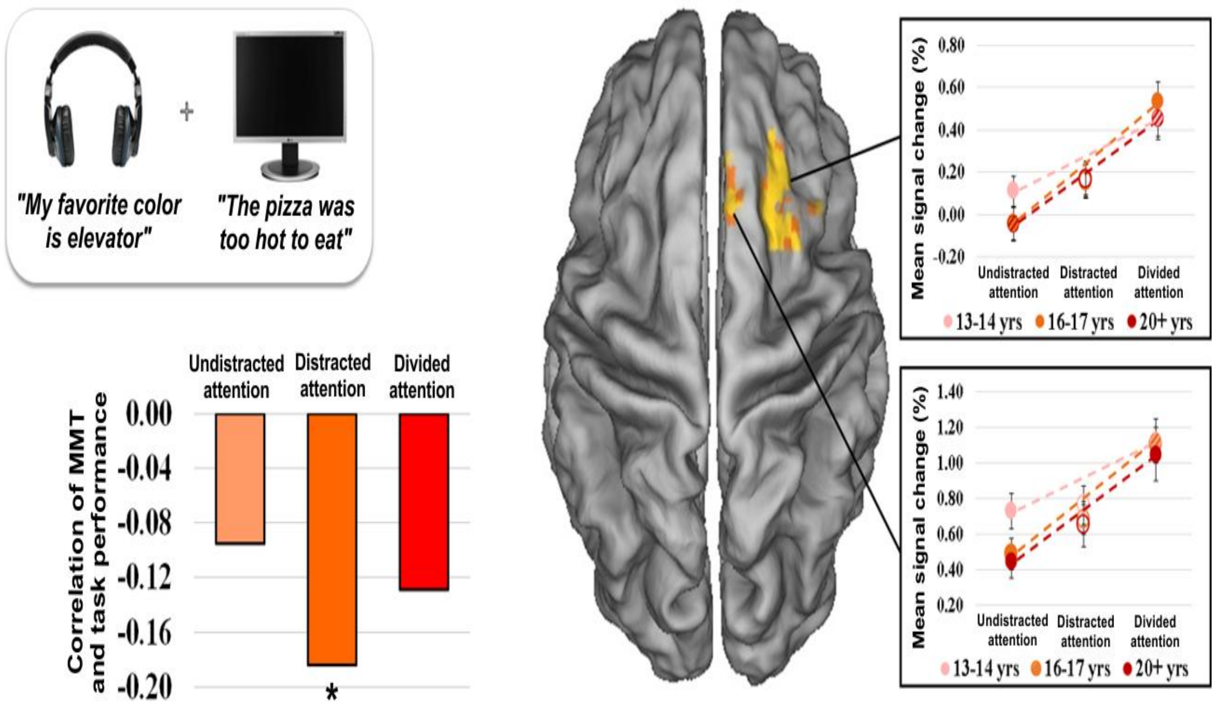

Graphical abstract

Highlights

- Media multitasking (MMT) and attention was studied in young participants
- Higher levels of daily MMT was associated with distractibility
- This distractibility was paired with increased brain activity in right prefrontal regions
- Dual-task performance in laboratory settings was unaffected by MMT