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Anterior cingulate activation during cognitive control relates to academic performance in medical students

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ABSTRACT

It is believed that academic performance is in part determined by cognitive control, the skill of flexibly guiding behavior. Although previous neuroimaging research has demonstrated that lateral and medial prefrontal cortex, including ACC, are involved during tasks of cognitive control, little is known about the relation between brain mechanisms underlying cognitive control and academic performance in a real-world educational environment. In the current fMRI study, Freshman students from Medical College performed a Go/NoGo task and Stroop task. A positive correlation was observed between average course grades and activation of dorsal ACC during cognitive inhibition on the Stroop task. No significant correlation was found between grades and activation in rostral ACC during emotional inhibition. Grades were not associated with prefrontal activation during motor inhibition or performance monitoring on the Go/NoGo task. These findings suggest that engagement of dorsal ACC for cognitive control can be linked to individual differences in academic achievement.

1. Introduction

Cognitive control, the ability to direct behavior and override impulses, has been related to positive life outcomes in diverse clinical and societal contexts [31]. Individual differences in this ability are associated with academic performance across childhood [4]. In college students, cognitive control, as measured by questionnaires, predicts self-regulated learning [18] and grades [38]. The skill of adapting one's behavior to reach a desired goal is needed to get through college successfully. Obtaining a degree involves planning, avoiding distractions and focusing on exams. These cognitive control skills engage lateral and medial prefrontal brain regions, including the anterior cingulate cortex (ACC; [7,34]). Particularly, the ACC plays a role in conflict and outcome monitoring [6]. A link might be expected between functioning of these prefrontal areas and academic success. This is important to investigate because it could provide more insight into which specific aspects of cognitive control are related to performance in a real-world educational setting. Questionnaire answers are subjective and behavioral tests of cognitive control may have little variance in a homogeneous sample, such as motivated and intelligent students from Medical College. Indeed, a recent trend in neuroscience is to employ brain measures for predicting long-term and ecologically valid outcomes, which complements self-report data [2]. The aim of the current study is to predict achievement in a homogeneous group of students of similar age from the same college using cognitive control tasks and functional magnetic resonance imaging (fMRI), extending beyond behavioral research.

Cognitive control encompasses several subfunctions and is often assessed using the Go/NoGo task [17] or the Stroop task [28]. During the Go/NoGo paradigm, a visual stream of letters is presented and the participant is instructed to press a button each time a letter appears on the screen, but to withhold a response for one particular letter (e.g., X). The ability to suppress a prepotent response, the tendency to press the button on these infrequent NoGo trials, is a measure of inhibition. During the Stroop paradigm, color words are presented and the participant has to indicate the color of the ink in which the words are written. On incongruent trials, the written word interferes with the ink of the word (e.g., the word blue printed in red). Color labeling requires inhibition of the more salient tendency to read the word. Alternatively, the goal-directed response of labeling the color is strengthened through top-down biasing implemented in the dorsolateral prefrontal cortex [21].

A meta-analysis on neuroimaging research including various cognitive control tasks has demonstrated common activation in the dorsolateral prefrontal cortex, inferior frontal gyrus, ACC and

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inferior parietal cortex [33]. For the Go/NoGo task, the largest cluster was found in right dorsolateral prefrontal cortex extending into right inferior frontal gyrus and insula. Most activation during the Stroop task was observed in left dorsolateral prefrontal cortex, extending into insula, and in the ACC. These tasks engage common as well as distinct brain regions, indicative of the different aspects of cognitive control that are captured by the paradigms. Based on studies using varieties of these paradigms, it is assumed that the role of the ACC is to detect conflict and signal the dorsolateral prefrontal cortex which in turn carries out the actual resolution of conflict [9].

Functioning of the ACC has been linked to academic results in college students [23]. In this Event-Related Potential (ERP) study, participants carried out a Stroop paradigm while the Error-Related Negativity (ERN), generated from the ACC, was measured. The ERN following errors correlated positively with grades, suggesting that the error detection mechanism is more pronounced in students who perform well in college. However, the precise mechanism underlying this link needs to be substantiated, since different accounts of the ERN exist, including theories of error detection, conflict monitoring, reinforcement learning and affective/motivational responses to errors [19]. ERP research in school-aged children showed that during a Go/NoGo task, another component recorded over the parietal cortex, the P3, was a predictor of reading and arithmetic achievement [22]. These findings suggest that neural correlates of cognitive control can be indicators of academic success, although up till now, this has not been studied with fMRI. More knowledge is needed about which specific cortical regions, amongst those involved in cognitive control, can be associated with individual performance differences in higher education. Different brain areas play a role in separate aspects of cognitive control, therefore an fMRI study can further understanding about the subfunctions that are especially relevant for college achievement.

Previously, patterns of brain activation during a reading task have been used for predicting improvements in adolescents with dyslexia [24]. Stronger recruitment of right inferior frontal gyrus was associated with reading gains over a 2.5 year period, while behavioral language tests were not. Other research, outside the field of education, has employed cognitive control tasks to predict real-world behavior. Berkman et al. [3] reported that increased activation in right inferior frontal gyrus, pre-supplementary motor area and the basal ganglia during a Go/NoGo paradigm was related to a weaker link between craving and smoking.

In the current study, the relation between brain activation during cognitive control and academic achievement was investigated in Freshman students from Medical College. A modified Go/NoGo task [13] as well as a combined cognitive and emotional Stroop task [12] were conducted in the fMRI scanner. These paradigms captured different aspects of cognitive control to elucidate which subfunctions have the strongest link with academic performance. On the Go/NoGo paradigm, the task was to press a button on alternating presentations of *X* and *Y*. This paradigm involved a working memory component since the previous target letter needed to be remembered. For clarity purposes, we will use the term 'motor inhibition' for the process of refraining from pressing the button on repeating letters. Feedback in the form of a green (correct) or red (incorrect) square was added to measure 'performance monitoring'. Performance monitoring is an aspect of cognitive control, involving the ACC, that is assumed to play a role in academic success. On the Stroop task, negative emotional trials were included (e.g., the word death printed in red), next to incongruent trials. Negative emotional words automatically draw attention and therefore cause interference with color labeling [16,29]. Cognitive control is needed to suppress interfering emotions which might also be important to maintain focus on academic work. This is particularly relevant for Freshmen, since many social changes take place during the transition from high school to college. In a period of personal development and emerging relationships, it is crucial to control emotions. Thus, two different processes were measured with the Stroop task, which will be referred to as 'cognitive inhibition' and 'emotional inhibition'.

Prior research employing the same Go/NoGo task demonstrated involvement of the right dorsolateral prefrontal cortex, dorsomedial prefrontal cortex, left insula, right inferior parietal cortex, left inferior parietal cortex, and right middle temporal gyrus in motor inhibition while the dorsal ACC was activated during performance monitoring [13]. For the Stroop task, previous results indicated that the left dorsolateral prefrontal cortex and dorsal ACC are particularly important for cognitive inhibition while the postcentral gyrus plays a role during emotional inhibition [12]. Others have also found engagement of the ACC, in a more rostral subdivision, during the emotional Stroop task [32,42]. For the present study, it was hypothesized that activation of regions in the prefrontal cortex, including ACC, would correlate with grades, as these areas have consistently been associated with cognitive control across tasks [9,11,33]. A homogeneous sample of students from Medical College aged 18 and 19 was recruited and only students who passed the first academic year were included in the final analyses to explore whether students with good grades could be distinguished from students with sufficient grades, thus excluding students who failed. It is particularly relevant to determine markers of success in Medical College because of the difficult curriculum and strict selection procedure. Behavioral measures and self-report questionnaires have limited predictive validity [15], therefore neuroimaging methods are employed here. If we find evidence that certain aspects of cognitive control are associated with academic achievement, this may in the future lead to interventions which can help students improve their learning strategies. We expected a positive relation between grades and brain activation during cognitive control, in the context of similar task performance.

2. Method

2.1. Participants

Twenty-six Freshman students (13 male, 13 female, mean age = 18.79 years, SD age = 0.32 years, age range = 18.36–19.37 years) from Medical College at VU University Amsterdam participated in this study. At the start of the academic year 2010–2011, all Freshman students aged 18 or 19 received a letter with information about the research and a request to participate in exchange for monetary compensation. The fMRI scans were conducted between December 2010 and April 2011. Volunteers had no history of neurological or psychiatric disorders and no contraindications for MRI. This research was approved by the Medical Ethics Committee of VU Medical Centre. Participants gave written informed consent and permission to obtain grades from the official student information systems. The current participants were part of a larger sample in a study aimed at investigating age- and sex-related differences in brain activation on the Stroop [41] and Go/NoGo task. Those results are described elsewhere. Here, we report for the first time the relation between brain activation and student grades.

For each student, the average grade on six core courses was calculated at the end of the academic year. The grades were based on the first attempts at exams of compulsory preclinical courses, consisting of multiple choice questions. Assessments for professional competence and practical work were not included. The first exam took place in September 2010 and the last exam was in May 2011. In the Dutch educational system, grades can vary between 1 and 10 with 1 considered ‘very poor’ and 10 considered ‘excellent’. A grade of 5.5 or higher indicates ‘pass’; grades between 5.5 and 7 are termed ‘sufficient’ and grades between 7 and 8.5 are referred to as ‘good’. One female student was excluded from further analyses because she did not pass the first academic year (average grade=4.67) and therefore represented an outlier. The analyses of the Stroop task involved the remaining 25 participants (mean grade=7.09, SD grade=0.70, grade range=5.50–8.50). Average grades during the first year of Medical College correlated with average high school grades (mean=7.44, SD=0.65, range=6.50–9.00; $r=0.68$, $p<0.001$). There was no correlation between average grades in Medical College and scores of receptive vocabulary, an estimate of verbal IQ, on the Peabody Picture Vocabulary Test-III-NL (PPVT-III-NL; [35]; mean=111.64, SD=5.74, range=100–124; $r=0.06$, $p=0.76$). One female student did not complete the Go/NoGo task and one male student had too many errors (>2 SD), so 23 participants were included in the analyses of the Go/NoGo task (mean grade=7.09, SD grade=0.73, grade range=5.50–8.50).

2.2. Procedure

The tasks were practiced in a behavioral session that took place 1 or 2 days before the fMRI session. The PPVT-III-NL was also administered during the behavioral session and students filled in a questionnaire about their personal background on which they reported their average grade in high school. During the fMRI session, participants performed a combined cognitive and emotional Stroop task [12] and a Go/NoGo task [13]. Both tasks, programmed in E-Prime 2.0 (http://www.pstnet.com/eprime.cfm), consisted of two runs lasting about 5 min starting with an instruction screen presented for 6 s. The runs of each task were counterbalanced across participants.

2.2.1. Stroop task

Each run of the Stroop task contained 40 congruent color words (e.g., the word red printed in red ink), 40 incongruent color words (e.g., the word blue printed in red), 24 positive emotional words (e.g., friend), 24 negative emotional words (e.g., death) and 24 neutral words (e.g., house). Cognitive inhibition was assessed with the incongruent color words (condition Incongruent) and emotional inhibition was assessed with the negative emotional words (condition Negative). The neutral words (condition Neutral) formed a baseline while the congruent color words and positive emotional words were not analyzed in the current study. Four different colors were used and participants indicated the color by button press using the left middle finger for blue, left index finger for red, the right index finger for green and right middle finger for yellow. A word was shown on a black background every 2 s. The word stayed on the screen until a response was given with a maximum duration of 2 s. When a response was made within this time window, a blank black screen was shown until the next word appeared. The participants were instructed to respond as accurately and as fast as possible to the color of the ink and to remember the stimulus-response correspondence. In case they forgot, the order of colors was written in white letters on the bottom of the screen.

2.2.2. Go/NoGo task

During each run of the Go/NoGo task, 500 yellow letters were presented on a black background. Participants were instructed to respond by button press on alternating presentations of *X* and *Y*, thus an *X* preceded by *Y* or a *Y* preceded by *X* (Go trials). They had to withhold a response for repetitions of *X* and *Y* (NoGo trials). No response was required on other letters (filler trials). Each run contained 75 Go trials and 12 NoGo trials. Letters were presented for 500 ms with a 0 s interstimulus interval and were occasionally followed by feedback in the form of a green square (correct) or a red square (incorrect), lasting 500 ms. The responses had to be made during the time window that the letters were on the screen. This time limit was set to assure fast responses and the feedback was added to motivate participants. A green square was presented after correct Go and correct NoGo trials. No feedback was given after correctly omitted filler trials and the task proceeded immediately to the next trial. A red square was shown after a response to a NoGo trial, a response to a filler letter and no response to a Go trial.

2.3. fMRI data acquisition

Participants were scanned on a General Electric 3 T head-only MRI scanner. Functional images were collected using a T2*-weighted echo planar imaging (EPI) sequence (time to repetition (TR)=2000 ms, time to echo (TE)=35 ms, flip angle (FA)=80°, field of view (FOV)=22 × 22 cm^2, number of slices=35, voxel size=3.5 × 3.5 × 3 mm^3). To aid with spatial normalization, a T1-weighted anatomical scan was acquired (TR=7.876 ms, TE=3.06 ms, FA=12°, FOV=22 × 22 cm^2, number of slices=166, voxel size=1 × 1 × 1 mm^3).

2.4. Behavioral data analysis

Reaction times and response errors on both tasks were recorded. Performance measures were correlated with grades. Kendall's tau is reported because of the non-normality of the behavioral data and small sample size. Results are thresholded at $p<0.01$, corrected for multiple correlations.

2.4.1. Stroop task

To assess cognitive inhibition time for each participant, the average reaction time during the condition Incongruent minus the average reaction time during the baseline condition Neutral was calculated. Incongruent words were contrasted with neutral words instead of congruent words, since congruent words result in facilitation [27]. The difference between the average reaction times on the conditions Negative and Neutral constituted the emotional inhibition time. Positive words were excluded because these induce less emotional interference than negative words, since threat is absent [29]. Cognitive inhibition error rate was defined as the error percentage during the condition Incongruent minus the error percentage during the condition Neutral. Likewise, emotional inhibition error rate was calculated by subtracting the error percentage of the condition Neutral from the error percentage of the condition Negative. One-way *t*-tests ($p<0.01$) were performed to assess the presence of Stroop effects, i.e., whether inhibition times and inhibition error rates were significantly larger than 0. Cognitive inhibition time as well as emotional inhibition time was correlated with grades. In addition, the correlation between grades and cognitive inhibition error rate as well as emotional inhibition error rate was calculated.

2.4.2. Go/NoGo task

Responses on NoGo trials constituted errors of commission while no responses on Go trials were counted as errors of omission. A paired *t*-test ($p<0.01$) was conducted to examine if there was a difference between the commission error rate and the omission error rate. The error rates on NoGo trials were correlated with grades. The correlation between grades and error rates on Go trials as well as average reaction times on Go trials was also calculated.

2.5. fMRI data analysis

Statistical Parametric Mapping (SPM8, www.fil.ion.ucl.ac.uk/spm) was used for analyzing the fMRI data. Preprocessing steps were similar for both tasks. First, the functional images were realigned with a six-parameter rigid body transformation to correct for head movement. Then, functional images were coregistered to the anatomical image and subsequently normalized to the MNI template. The images were spatially smoothed with a 7-mm FWHM isotropic Gaussian kernel.

2.5.1. Stroop task

At the first level, a General Linear Model (GLM) was specified with the onsets and reaction times of congruent color words, incongruent color words, positive emotional words, negative emotional words and neutral words. The events were convolved with a canonical hemodynamic response function. Low-frequency noise was removed using a high-pass filter and motion parameters were included as regressors of no interest. The conditions Incongruent and Negative were contrasted with the baseline condition Neutral for each participant and individual contrast images were entered into second-level analyses.

To investigate the relation between grades and brain activation during cognitive inhibition, a multiple regression design was constructed including the contrast images Incongruent versus Neutral and grades as a regressor. For emotional inhibition, a multiple regression design was defined including the contrast images Negative versus Neutral and grades. Average reaction time, error rate and scan date (number of days before the last exam) were included as covariates. Regions of interest (ROIs) were chosen based on results obtained with the same Stroop task [13]. In this study, the left dorsolateral prefrontal cortex (MNI = −40 24 26) and dorsal ACC (MNI = 0 36 22) were found to be particularly important for labeling incongruent color words. The postcentral gyrus (MNI = −44 −32 46) was involved when labeling negative emotional words. An additional ROI was derived from other research reporting activation of the rostral ACC (MNI = −2 44 20) during emotional inhibition [5,8]. Ten-mm spheres were built around the center coordinates to construct the ROIs in MarsBaR (http://marsbar.sourceforge.net). For the cognitive inhibition model, data was extracted from the prefrontal and dorsal ACC ROIs. The main effect of Incongruent versus Neutral and the effect of the regressor grades were investigated using *t*-tests. Data was extracted from the postcentral and rostral ACC ROIs to examine the main effect of Negative versus Neutral as well as the effect of grades during emotional inhibition. A threshold of $p < 0.01$, Bonferroni corrected for multiple ROIs was used. Mean parameter estimates were imported into Excel to calculate correlations with grades. For ROIs in which there was a significant effect of grades, the correlation between mean parameter estimates and high school grades was also assessed. This post-hoc analysis was performed to determine if the observed effect could be explained by a third variable.

2.5.2. Go/NoGo task

For each participant, a General Linear Model (GLM) was specified with the onsets of correct Go trials, correct NoGo trials and errors, convolved with a canonical hemodynamic response function. A high-pass filter was applied to remove low-frequency noise and motion parameters were included as regressors of no interest. Correct NoGo trials were contrasted with correct Go trials to assess motor inhibition and errors were contrasted with correct trials (Go and NoGo) to assess performance monitoring. Individual contrast images were entered into group analyses.

To investigate the relation between grades and brain activation during motor inhibition, a multiple regression design was constructed including the contrast images NoGo versus Go and grades as a regressor. A multiple regression design was defined including the contrast images Errors versus Correct and grades to examine the effect of grades during performance monitoring. Average reaction time on Go trials, commission error rate, omission error rate and scan date (number of days before the last exam) were included as covariates. ROIs were chosen based on results obtained with the same Go/NoGo paradigm [13]. These included right dorsolateral prefrontal cortex (MNI = 48 34 22), dorsomedial prefrontal cortex (MNI = 2 26 42) and left insula (MNI = −30 26 −6) for motor inhibition and the dorsal ACC (MNI = 6 26 40) for performance monitoring. Using MarsBaR, ROIs were defined by 10-mm spheres around the center coordinates. *t*-tests for the main effects and the effects of grades were thresholded at $p < 0.01$, Bonferroni corrected for multiple ROIs. Correlations between grades and activation of these ROIs were calculated by importing the mean parameter estimates into Excel.

3. Results

3.1. Behavioral results

3.1.1. Stroop task

The mean reaction times and error rates of the conditions Incongruent, Negative and Neutral are presented in Table 1. There was a cognitive and an emotional Stroop effect, i.e., reaction times were longer for Incongruent than Neutral ($t = 8.42$, $p < 0.001$) and for Negative compared to Neutral ($t = 4.87$, $p < 0.001$). The cognitive inhibition error rate and emotional inhibition error rate were also significantly larger than 0 ($t = 3.72$, $p = 0.001$ and $t = 5.29$, $p < 0.001$, respectively). As predicted, there was no relation between academic performance and behavioral inhibition measures. Grades did not correlate significantly with cognitive inhibition time ($\tau = 0.06$, $p = 0.71$) or emotional inhibition time ($\tau = 0.28$, $p = 0.05$). There was also no correlation between cognitive inhibition error rate ($\tau = -0.10$, $p = 0.49$) or emotional inhibition error rate ($\tau = 0.16$, $p = 0.30$).

3.1.2. Go/NoGo task

Error rates on NoGo trials, Go trials and mean reaction time on Go trials are shown in Table 1. The commission error rate was larger than the omission error rate ($t = 3.22$, $p < 0.01$). No correlation was

Table 1
Mean reaction times (ms) and error rates (%) on the Stroop task and the Go/NoGo task, including the standard deviations in parentheses.

	Reaction times	Error rates
Stroop task		
Incongruent	758.30 (165.83)	11.80 (8.24)
Negative	689.95 (131.14)	12.33 (6.07)
Neutral	658.87 (125.33)	5.50 (5.48)
Cognitive inhibition (Incongruent − Neutral)	99.43 (59.01)	6.30 (8.47)
Emotional inhibition (Negative − Neutral)	31.08 (31.89)	6.83 (6.46)
Go/NoGo task		
NoGo	–	23.37 (19.73)
Go	389.29 (17.07)	9.42 (4.80)

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found between grades and commission error rate ($\tau = -0.06$, $p = 0.69$). There was also no significant correlation with the omission error rate ($\tau = -0.32$, $p = 0.04$) or reaction times on Go trials ($\tau = 0.09$, $p = 0.58$).

3.2. fMRI results

3.2.1. Stroop task

A significant main effect of cognitive inhibition was observed in the left dorsolateral prefrontal cortex ($t = 3.87$, $p < 0.001$), but not in the dorsal ACC ($t = -0.80$, $p = 0.78$). There was a significant positive association between grades and activation in the dorsal ACC during cognitive inhibition ($t = 3.38$, $p < 0.01$). This region was activated more for the condition Incongruent with increasing grades (See Fig. 1). A post-hoc test revealed that the correlation between high school grades and activation of the dorsal ACC was not significant ($r = 0.31$, $p = 0.13$). There was no correlation between grades and activation in the left dorsolateral prefrontal cortex ($t = -0.22$, $p = 0.41$). For emotional inhibition, a main effect was found in the postcentral gyrus ($t = 3.10$, $p < 0.01$), but not in the rostral ACC ($t = -0.73$, $p = 0.76$). No correlation was present between grades and activation in the postcentral gyrus ($t = -1.55$, $p = 0.07$). The association between grades and activation of rostral ACC was not significant ($t = 1.18$, $p = 0.13$). The correlations between grades and mean parameter estimates of all ROIs are presented in Table 2.

3.2.2. Go/NoGo task

Correlations between grades and mean parameter estimates of the ROIs from the Go/NoGo task are shown in Table 3. During motor inhibition, there were significant main effects in the right dorsolateral prefrontal cortex ($t = 6.34$, $p < 0.001$), dorsomedial prefrontal cortex ($t = 5.05$, $p < 0.001$) and insula ($t = 6.34$, $p < 0.001$). There was no association between grades and activation in the right dorsolateral prefrontal cortex ($t = -1.79$, $p = 0.05$), dorsomedial prefrontal cortex ($t = 0.15$, $p = 0.44$) and left insula ($t = -0.11$, $p = 0.46$). For performance monitoring, there was a main effect in the dorsal ACC ($t = 8.95$, $p < 0.001$). The correlation with activation in the dorsal ACC during performance monitoring did not reach significance ($t = 1.07$, $p = 0.15$).

4. Discussion

The current study demonstrates a link between neural correlates of cognitive control and academic performance. A correlation between grades and brain activation on a Stroop task was observed in Freshmen from Medical College. Importantly, there was no relation with any of the behavioral measures, which shows the value of using fMRI in a homogeneous sample of medical students who all passed the first academic year. Students with good grades recruited the ACC more during cognitive inhibition compared to students with sufficient grades. An association with achievement was only found in the dorsal ACC, indicating that involvement of this region can potentially predict differences in educational success. No correlation was present in the left dorsolateral prefrontal cortex during cognitive inhibition or in the postcentral gyrus and rostral ACC during emotional inhibition.

Both the dorsolateral prefrontal cortex and the ACC are often activated on the Stroop task [26]. However, not all studies show involvement of the ACC during cognitive and emotional inhibition [10,30]. The ACC does not seem to be necessary for cognitive control, since patients with damage to this region perform normal on the Stroop and Go/NoGo task [14]. Our findings revealed that there was no main effect of cognitive inhibition in the dorsal ACC ROI. In a previous study with 74 students from Medical College, including the current sample, we used the same Stroop task reported here [41]. No activation of the ACC was observed on the group-level when all students were included, independent of

Table 2
Correlations between grades and activation in the regions of interest (ROIs) for the Stroop task. Center coordinates of the ROIs in MNI space are provided.

Region	*x*	*y*	*z*	*r*
Cognitive inhibition				
Left dorsolateral prefrontal cortex	−40	24	26	0.03
Dorsal ACC	0	36	22	0.56*
Emotional inhibition				
Postcentral gyrus	−44	−32	46	−0.21
Rostral ACC	−2	44	20	0.29

* $p < 0.01$.

Table 3
Correlations between grades and activation in the regions of interest (ROIs) for the Go/NoGo task, with center coordinates in MNI space.

Region	*x*	*y*	*z*	*r*
Motor inhibition				
Right dorsolateral prefrontal cortex	48	34	22	−0.38
Dorsomedial prefrontal cortex	2	26	42	−0.01
Left insula	−30	26	−6	−0.14
Performance monitoring				
Dorsal ACC	6	26	40	0.33

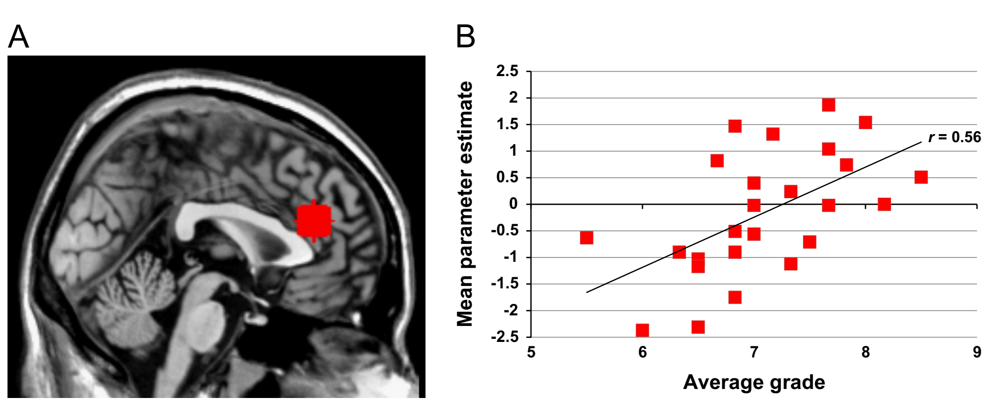

Fig. 1. (A) The region of interest (ROI) in the dorsal anterior cingulate cortex (ACC; MNI=0 36 22). (B) Correlation between average grade and activation of the dorsal ACC during cognitive inhibition on the Stroop task.

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academic performance. Our present results provide a clear indication that there are individual differences in the engagement of this area, since we demonstrated variation of ACC recruitment related to grades. Hence, other brain regions such as the dorsolateral prefrontal cortex may be crucial for cognitive control, but additional involvement of the ACC relates to positive real-world outcomes.

It has been suggested that the ACC plays a role in detection of conflict while the dorsolateral prefrontal cortex is important for the implementation of control [9]. More generally, the function of the ACC can be defined as a monitoring mechanism related to decision making [6]. Students from our sample with sufficient grades, as opposed to good grades, demonstrated less activation of the ACC during incongruent words compared to neutral words. It appears that these students failed to selectively engage this region when control is needed on a task involving cognitive inhibition. Thus, brain measures of conflict signaling, but not top-down control of conflict, can be linked to academic performance.

Our finding of more ACC activation on the Stroop task in Freshmen who perform better is in line with the ERP study of Hirsh and Inzlicht [23]. They reported a larger ERN, presumably resulting from the ACC, for undergraduates with higher grades. We showed that a correlation with academic success was present in the dorsal subdivision of this area during cognitive inhibition, but not in the rostral subdivision during emotional inhibition. Together, these results support the notion that stronger engagement of a neural monitoring mechanism is related to increased achievement in a real-world college environment.

No correlation with grades was found during motor inhibition and performance monitoring on the Go/NoGo task. The different patterns of findings on the Go/NoGo task and the Stroop task might be related to differences in the paradigms. Although both paradigms measured cognitive control, the Go/NoGo task was aimed at inhibition and keeping items in working memory while the Stroop task involved inhibition of incongruent and emotional stimuli or strengthening of goal-directed responses. The response that had to be inhibited on the latter paradigm was a cognitive process, i.e., word reading, as opposed to a motor response, i.e., a button press, on the Go/NoGo paradigm. Additionally, active monitoring of conflict and errors may be less needed for the Go/NoGo task, since feedback was provided. This could explain why a link with college performance was observed on the Stroop task only.

4.1. Suggestions for future research

This study is correlational in nature and therefore no strong conclusions can be drawn about the directionality of effects. The fMRI sessions took place before the end of the first academic year and each student was scanned in a different period. The grades were collected after the end of the academic year and were based on exams conducted over that entire year. Possibly, good students are better in cognitive control at the onset of college, evident by stronger ACC engagement for cognitive inhibition, and consequently obtain higher grades. Alternatively, students who obtain good grades have studied more and thereby trained their control skills, resulting in greater recruitment of the ACC. Future research could further investigate whether neural patterns can predict grades, by testing upcoming freshmen in an fMRI session before the start of classes.

Our participants formed a homogeneous sample consisting of highly motivated and intelligent 18 and 19 year old Medical College students. Only students who passed the first academic year were investigated, in order to examine good and sufficient performance, but not insufficient performance. Although behavioral cognitive control scores may correlate with grades in the general college population, there might not have been enough variance in our sample of passing medical freshmen. Even in this highly selected group, neural correlates of academic success could be identified. It must be noted that these results cannot be easily generalized to older students, since the brain is not yet fully mature at the age of 18 or 19 [1,20,37].

4.2. Conclusions and implications

We found a relation between ACC activation during cognitive inhibition and average grades in Freshman year, which was not driven by a third variable, i.e., high school grades. Nevertheless, other variables, such as general intelligence rather than receptive vocabulary as measured here, might partly explain the reported link. No behavioral differences between students with good and sufficient grades were observed on the Stroop task or the Go/NoGo task. Clearly, investigating neural mechanisms provides additional insights into individual differences in academic achievement. This study adds to previous work that has used fMRI for the prediction of real-world behavior [2]. The current results also contribute to behavioral research on factors associated with success in Medical College [25,39]. Identifying determinants of performance is crucial considering the time, effort and monetary investments students put into their education as well as the responsibilities that go along with their future profession. Our findings emphasize that cognitive control is a vital skill for students to do well in a difficult curriculum, as evident by brain measures. This implies that educational interventions aimed at strengthening this ability could have a positive impact on learning outcomes. Although challenges exist for connecting theory and practice in the emerging field of educational neuroscience [36,40], interdisciplinary questions like the one addressed here may ultimately lead to foreseeing which students would benefit most from what type of guidance.

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