Exploring the interplay of age and pedagogy in the maturation of error-monitoring

Solange Denervaud[1], David A. Tovar[2], Jean-François Knebel[1,3], Emeline Mullier[2], Yasser Alemán-Gómez [1,4], Patric Hagmann[1*], & Micah M. Murray[1,2 ,3,5*]

[1]Department of Radiology, Lausanne University Hospital and University of Lausanne, 1011 Lausanne, Switzerland

[2]Department of Hearing and Speech Sciences, Vanderbilt University, Nashville, TN, USA

[3]CIBM Center for Biomedical Imaging, Lausanne, Switzerland

[4]Center for Psychiatric Neuroscience, Department of Psychiatry, Lausanne University Hospital and University of Lausanne, Prilly, Switzerland.

[5]The Sense Innovation and Research Center, Lausanne and Sion, Switzerland

**both authors contributed equally*

Lay abstract (75 words max)

We explored whether the ability to monitor and manage errors was sensitive to age and/or pedagogy by measuring behavioral, brain imaging, and neurophysiological responses to errors from 6-12-year-olds enrolled in Montessori or traditional schooling in Switzerland. The anterior cingulate cortex - a brain region responsive to errors – exhibited maturational changes that seemed also related to neurophysiological responses to errors. We also provide preliminary evidence for neurobiological, but not behavioral, interactions of pedagogy on error processing.

Abstract

Error-monitoring is a crucial cognitive process that enables us to adapt to the constantly changing environment. The anterior cingulate cortex (ACC) plays a vital role in error-monitoring, and its prolonged maturation suggests that it can be influenced by experience-dependent plasticity. To explore this possibility, we collected morphometric magnetic resonance imaging (MRI) measures of the ACC and error-related response-locked event-related potentials (ERPs) in twenty-six schoolchildren, aged 6-12 years, enrolled in either a Montessori or a traditional curriculum in Switzerland. We show that the caudal ACC undergoes significant morphometric changes during this developmental age range that seem related to error detection ERP activity. Furthermore, we observed differences in source localization activity related to error detection within the caudal ACC between Montessori and traditionally-schooled children, indicating a potential difference in the development of error-monitoring in these groups. Our study provides preliminary evidence for a potential window of opportunity to influence error-monitoring during development and calls for more work in that direction.

Keywords: Self-monitoring – error-monitoring – brain development – the anterior cingulate cortex – experience-dependent plasticity – school pedagogy

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To function well in contemporary society, children need to gain independence and flexibility. Central to these adaptive processes stands the error-monitoring system, which detects unexpected outcomes and provides an opportunity to swiftly adjust behaviors (Ullsperger, Danielmeier, & Jocham, 2014). Error-monitoring relies strongly on the caudal subregion of the anterior cingulate cortex (cACC), a central hub of the salience network (Margulies et al., 2007), which achieves functional maturity between the ages of 6 and 12 years (Kelly et al., 2009). This maturation window suggests a possible sensitive period when incorrect versus correct responses and subsequent self-adaptive processes (e.g., self-correction) could be better discriminated and learned through experience-dependent plasticity. To address this possibility, we ran an exploratory study using an existing multimodal neuroimaging dataset. We investigated the relationship between cortical thinning within ACC subregions, measured via MRI, and established error-related EEG components in 6-12-year-old children experiencing different pedagogical approaches at school. We hypothesized that scholastic backgrounds may lead to differences in how children monitor errors at the neurophysiological level.

Behaviorally, studies on error-monitoring have generally focused on reaction times (RTs), which are usually slower after incorrect compared to correct responses (referred to as *post-error slowing*; Notebaert et al., 2009). There is also a long history of EEG studies examining the time course of events following incorrect responses. Provided speed and accuracy are emphasized, a similar sequence of brain components time-locked to the behavioral response has been reported in adults (Ullsperger et al., 2014). The first is early frontocentral negativity (typically peaking 50-100ms post-response onset), dubbed the *error-related negativity* (ERN; Ullsperger & Danielmeier, 2016). The second is a later and slower response (~200-400ms post-response onset) with a more central scalp distribution, called the *error positivity* (Pe). They are thought to reflect an early task non-specific detection of the need for adjustments (ERN) and a later task-specific selective attention for orientation and learning (Pe) or conscious evaluation (Ullsperger & Danielmeier, 2016). ERN and Pe together reflect a built-in error-detection system (Elton, Band, & Falkenstein, 2000) of respectively, the low-level perceptual ability for fast detection of mismatch (Falkenstein, Hohnsbein, Hoormann, & Blanke, 1991; Murphy, van Moort, & Nieuwenhuis, 2016), and later top-down processes of adaptation/evaluation (Falkenstein, 2000). While these markers are well-studied in adults, developmental data are scarcer.

Both components have been observed in preschoolers (Brooker, Buss, & Dennis, 2011), including 3-4 year-olds (Grammer, Carrasco, Gehring, & Morrison, 2014; Smulders, Soetens, & van der Molen, 2016). Error processing becomes more efficient with age, reaching adult-like levels in late adolescence (Tamnes, Walhovd, Torstveit, Sells, & Fjell, 2013). However, the trajectory of this maturation seems non-linear and varies across ERN and Pe components (Tamnes et al., 2013). Likewise, the cACC is a major contributor to error-monitoring processes (Danielmeier, Eichele, Forstmann, Tittgemeyer, & Ullsperger, 2011) and undergoes significant changes during childhood from around 6 to 12 years of age (Kelly et al., 2009; Velanova, Wheeler, & Luna, 2008). The cACC may thus be subject to environmental influences, such as learning strategies reinforced within schooling pedagogies.

Pedagogical approaches differ in how they teach children to learn from their correct and incorrect responses. The traditional pedagogy predominantly involves teacher-led curricula, evaluations in the form of quantitative testing/grading, delayed feedback, and a competitive environment of same-aged peers. The Montessori pedagogy centers on a children-led trial-and-error approach, self-evaluation with qualitative feedback (i.e., no grades), and a cooperative environment of mixed-aged peers (Lillard, 2005; Marshall, 2017; Montessori, 1936). These traditional and Montessori pedagogies are both of high quality in Switzerland (i.e., in terms of teachers' training and school settings that must meet national legal quality criteria and are checked regularly by the authorities) but differ in how they train children to confront errors.

Developmental studies have largely focused on error-monitoring characterization (i.e., specific features, etc.) or individual trait or state differences between healthy or clinical populations (anxiety, mindsets, obsessive-compulsive disorders, etc.), without explicitly studying differences in developmental trajectories related to schooling experience. Previous comparative studies (Montessori- versus traditionally-schooled children) reported younger error-detection and self-correction (Denervaud, Knebel, Immordino-Yang, & Hagmann, 2020), greater and faster engagement with errors originating within the ACC (Denervaud, Fornari, et al., 2020), and better academic achievement (Denervaud, Knebel, Hagmann, & Gentaz, 2019), which may translate into stronger brain responses (Hirsh & Inzlicht, 2010). Specifically, we tested the following 4 hypotheses regarding 6-12-year-old schoolchildren: (1) *ACC maturation:* (i.e., cortical thinning; Gogtay et al., 2004) would occur independently of the pedagogy experienced and mainly within its caudal subregion, based on previous studies (Kelly et al., 2009; Velanova et al., 2008), while any effect of pedagogy could be observed in other subregions of the ACC; (2) *Effect of Age and Pedagogy on ERP markers of error processing:* ERN would increase with age and would be modulated by pedagogy experienced; (3) *Structure-Function relation between the ACC and the ERP markers of error processing:* ERN would relate to cACC cortical thinning (maturation of the error-monitoring system); and finally (4) *Pedagogy-dependent enhancement of error-monitoring biomarkers within cACC:* independently of behavioral outcomes, experience-dependent activity would be observed within the cACC according to the pedagogical experiences of the children. We expected to observe enhanced error-monitoring biomarkers (i.e., greater ERN) in Montessori-schooled children, compared to the traditionally-schooled children.

Methods

The experiment was conducted in accordance with the Declaration of Helsinki, with procedures approved by the local ethical committee (CER VD - PB_2016-02008 204/15).

Participants

Parents provided written consent for each child. Children provided informed assent and received a ~$35 gift voucher for their participation. No child had a history of neurological or psychiatric illness. In total, 31 children completed the experiment as part of a larger study investigating the impact of school environments on development. The selection criteria were age (6-12 y.o.) and schooling system (children had to be enrolled in a Montessori or traditional school system since the onset of their schooling, recruited within more than 15 schools). Children with error rates <10% (N=3), EEG technical difficulties (N=1), or orthodontics interference with MRI recording (N=1) were removed from the study. The final group included 26 children (mean age ±SD = 8.9±1.6 years, age distribution being equal between groups; 12 children from Montessori schools; and 15 boys in total) all right-handed with normal or corrected-to-normal vision. All 26 had participated in the aforementioned behavioral study (Denervaud, Knebel, et al., 2020), and 12 had participated in the aforementioned fMRI study (Denervaud, Fornari, et al., 2020). However, all the EEG and anatomical MRI analyses are reported here for the first time.

Group variables

Aside from the schooling background of the child, we also collected information about children's fluid intelligence (Raven, Raven, & Court, 2003), trait anxiety (STAI-Y2; Spielberger & Vagg, 1984) and mindsets (implicit theories of intelligence; Blackwell, Trzesniewski, & Dweck, 2007), as well as parental socio-economic status (Genoud, 2011), education style and the at-home environment through a tailor-made questionnaire (e.g., "How many books about education do you have?"; "How many meals are you sharing with your child?"). Demographic data were collected online post-recording.

MRI acquisition and processing

Structural imaging was collected on a Siemens 3T Prisma-Fit MR scanner with a 64-channel head coil. For each child, a 3-dimensional high-resolution isotropic T1-weighted sequence (MPRAGE) was acquired (TR = 2000ms, TE = 2.47ms, 208 slices; voxel size= $1mm^3$, flip angle=8°, percent phase FOV = 100). Individual T1-weighted images were processed using the FreeSurfer 6.0.0 software (http://surfer.nmr.mgh.harvard.edu).

Once white matter, grey matter, and cerebrospinal fluid volumes were generated, cortical surfaces were reconstructed with the methods described by Fischl and colleagues (Fischl et al., 2002; Fischl, Sereno, & Dale, 1999). Cortical parcellation in gyral-based ROIs was calculated according to the Desikan-Killiany cortical atlas (Desikan et al., 2006). Based on our *a priori* hypothesis, the rostral ACC (rACC), cACC, and posterior cingulate cortex (PCC) were selected as ROIs for further analyses. The cortical thickness, which represents a direct measure of the amount of grey matter contained in cortical layers along the perpendicular direction to each point on the surface, was used, taking the mean between the cortical surfaces for all vertices belonging to an ROI.

EEG procedure and processing

Children performed a speeded continuous recognition task, modified for children from Thelen et al. (2014), requiring the discrimination of whether each image was seen for the first or second time via button-press on a serial response box (i.e., two buttons) as fast and accurately as possible. Trials where children pressed '1' when the image was seen for the first time, and '2' when the image was seen for the second time were considered as 'correct responses'. Conversely, trials where children pressed '2' when the image was seen for the first time, and '1' when the image was seen for the second time were considered as 'incorrect responses' (see

Figure 1). Children completed four blocks of 160 trials each (500ms stimulus duration; 900-1500ms inter-stimulus interval); half of which were initial presentations and half of these were simultaneously accompanied by semantically congruent or incongruent sounds. Children sat in a sound-attenuated chamber (MDL 102126E from Whisperroom Inc.) 80cm away from a 20" LCD computer monitor (i.e., images subtended ~4°). PsychoPy 3.0 (Peirce et al., 2019) controlled stimulus delivery and behavioural data collection.

Continuous EEG was acquired at 1024Hz through a 64-channel Biosemi ActiveTwo AD-box (http://www.biosemi.com) referenced to the common mode sense (CMS; active electrode) and grounded to the driven right leg (DRL; passive electrode). Pre-processing and analyses were performed using both homemade python scripts using Anaconda distribution (Python Software Foundation. Python Language Reference, version 3.5); Matlab (Mathworks, Natick, MA, USA Version 7.13); and the Cartool freeware (Brunet et al. 2011). Data were linearly filtered in both directions (2^{nd} order Butterworth filter; 12dB/octave roll-off; 1.0Hz high-pass; 60Hz low-pass; 50Hz notch). Then EEG epochs were time-locked to the motor response and spanned 200ms pre-response and 500ms post-response. Epochs with amplitude deviations over ±100μV at any channel, except for those labeled as 'bad' due to poor electrode-skin contact or damage, were considered artifacts and were excluded. Data from 'bad' channels (mean electrodes ±SD = 2.0 ±2.5 channels) were interpolated using 3D splines. Before group averaging, response-locked potentials were baseline-corrected (-200 to -100ms from the response). To extract the ERN and Pe components, a peak-to-peak analysis was performed between the pre-motor response periods (-100-0ms) and periods/electrodes of interest of each component (ERN: 0-100ms at FCZ and Pe: 250-450ms at Cz), based on previous literature (e.g., Aarts, De Houwer, & Pourtois, 2013; Grammer et al., 2014; Meyer, Weinberg, Klein, & Hajcak, 2012).

Statistical Analyses

Statistical analyses were conducted using R software. Throughout the manuscript, mean±SD is reported.

Demographics

Multiple independent t-tests with a 95% confidence interval (CI) for the mean difference were run, with a false-rate discovery (FDR) *p*-value correction at q=0.05.

Hypothesis 1: ACC maturation

Multiple analysis of covariance (MANCOVA) was run on cortical thickness measures of the three ROIs as dependent variables: rACC, cACC, and PCC, with age as a covariate and group (experiencing Montessori versus traditional pedagogy) as a factor (with $\alpha<0.05$). Given the effect of gender on the cortical thickness (Gennatas et al., 2017), we included gender as a factor and its interaction with the group.

Hypothesis 2: Effect of Age and Pedagogy on ERP markers of error processing

First, independent t-tests were computed on accuracy and error rates from Montessori and traditionally schooled children. Second, a repeated-measures analysis of covariance (rmANCOVA) with Response Type (correct, incorrect) as the within-subject factor, Pedagogy (Montessori, Traditional) as the between-subjects factor, and Age as a covariate, was run on reaction times (RTs) (with $\alpha<0.05$). Third, rmANOVAs were conducted on ERN and Pe with Response Type (correct, incorrect) as the within-subjects factor, Pedagogy (Montessori, traditional) as the between-subjects factor, and Age as a covariate (with $\alpha<0.05$). Post-hoc Tukey tests were performed when appropriate.

Hypothesis 3: Structure-Function relation between ACC cortical thickness and ERP markers of error processing

To investigate the structure-function relation between ERP markers and ACC maturation, we computed the difference between incorrect and correct peak-to-peak values for each error-related brain component (hereafter ΔERN and ΔPe). Multiple linear regression analyses were calculated to predict ΔERN and ΔPe based on the cortical thickness measures of the rACC, cACC, and PCC, age, and pedagogy.

Hypothesis 4: Pedagogy-dependent enhancement of error-monitoring biomarkers within cACC

We further investigated the anatomical sources of electrophysiological responses, to confirm the morphometrical observations and explore the effect of pedagogy. Accordingly, we applied the local auto-regressive average distributed linear inverse solution (LAURA; Grave de Peralta Menendez, Gonzalez Andino, Lantz, Michel, & Landis, 2001) to an average period around ±10ms around the ERN response-locked peaks. We visualize and statistically contrast the likely underlying sources with the use of the software brain template for 7.5-13.5-year-old children (provided by Cartool). Statistical analysis entailed the same mixed model design as above and was performed using STEN software (Knebel & Notter, 2012). A spatial-extent criterion of ≥5 contiguous significant nodes. F-maps thresholds by significant points were displayed, after separating distinguished blobs.

Results

Demographics and Behavior on the Continuous Recognition Task

Table 1 reports the comparability of the groups across all demographic metrics (all p>0.05). Using the Homogeneity of Variances Test (Levene's), we further confirmed that both groups had equal variances in age (F(1,25)=0.834, p=0.37). On the continuous recognition task, participants committed 17.3±11.4% errors, and the mean accuracy rate was 73.2±19.7%, which did not co-vary with age ($r_{(26)}$=-0.018, p=0.93). These rates were comparable between groups (errors: $t_{(24)}$=0.81, p=0.43, Cohen's d=0.32 and accuracy: $t_{(24)}$=0.25, p=0.80, Cohen's d=0.10). RTs were faster on incorrect than correct trials (915±357ms vs. 1050±442ms; $F_{(1,23)}$=6.37, p=0.019, η_p^2=0.22). Age significantly modulated RTs independently of accuracy ($F_{(1,23)}$=19.74,

$p<.001$, $\eta_p^2=0.46$), with older children being faster. There was no evidence of a significant effect of pedagogy ($p=0.84$) nor of interaction between pedagogy and RTs ($p=0.64$).

Hypothesis 1: ACC maturation

Corroborating our hypothesis, and beyond overall brain sizes (the total intracranial volume was not related to any of the ACC subregions' cortical thickness; *p*s>0.551), cACC thickness significantly decreased with age ($p=0.047$, Figure 2A). This was not observed for the rACC ($p=0.186$) or the PCC ($p=0.292$). However, the PCC was thinner in traditionally schooled (5.51±0.12mm) compared to the Montessori-schooled children (5.75±0.33mm; $p=0.018$). Gender did not significantly impact cortical thickness in any region ($p>0.208$).

Hypothesis 2: Effect of Age and Pedagogy on ERP markers of error processing

For both groups of children, ERN peak-to-peak amplitude significantly varied with Response Type. As expected, the ERN was more negative on incorrect than correct trials (-5.18±2.95µV vs. -4.16±3.12µV; $F_{(1,23)}=6.69$, $p=0.016$, $\eta_p^2=0.23$, Figure 2B). There was a main effect of Pedagogy as well ($F_{(1,23)}=5.34$, $p=0.030$, $\eta_p^2=0.19$). Montessori-schooled children had overall more negative brain responses than traditionally schooled children ($p_{tukey}=0.031$). There was a significant Response Type × Age interaction ($F_{(1,23)}=5.39$, $p=0.030$, $\eta_p^2=0.19$). Younger children exhibited increased negativity for incorrect responses and increased positivity for correct responses. The Pedagogy × Response Type interaction was not significant ($p>0.05$).

While the Pe did not show a main effect for Pedagogy, ($p>0.05$), we report the results for the other factor for completeness. There was a significant main effect of Response Type ($F_{(1,23)}=9.55$, $p=0.005$, $\eta_p^2=0.29$). There was also a significant Response Type × Age interaction ($F_{(1,23)}=5.74$, $p=0.025$, $\eta_p^2=0.20$), with increasing age related to higher positivity for correct responses, but not for incorrect responses.

Hypothesis 3: Structure-Function relation between ACC cortical thickness and ERP markers of error processing

Children's ΔERN was reliably predicted by Age ($F_{(1,20)}$=8.77, *p*=0.008), showing an increase across development. Furthermore, children's ΔERN was reliably predicted by cACC cortical thickness ($F_{(1,20)}$=5.05, *p*=0.036) (Figure 2C). Specifically, thinner and by extension more mature cACC was related to more negative ΔERN, which itself indicates more distinct processing of incorrect and correct response types. Neither pedagogy, PCC thickness, nor rACC thickness was a predictor of ΔERN (*p*=0.166).

Children's ΔPe was reliably predicted by Age only ($F_{(1,20)}$=4.36, *p*=0.050), with older children showing smaller ΔPe. No other factor was found to be a significant predictor of ΔPe (*p*>0.517).

Hypothesis 4: Pedagogy-dependent enhancement of error-monitoring biomarkers within cACC

To exploit the spatial information available more fully in high-density EEG analyzed within an electrical neuroimaging framework, we also conducted statistical analyses of distributed source estimations. For the ERN we observed a significant Response Type × Pedagogy interaction within the left cACC and mPFC, and the left inferior temporal cortex and cerebellum (Figure 2D). The x,y,z coordinates (Talairach & Tournoux, 1988) of the maximal F-value were -3,17,41, which is situated within the Brodmann area 32 (i.e., the cACC). Post-hoc t-tests revealed higher ERN amplitudes for incorrect responses for traditionally- than Montessori schooled children (for whom ERN amplitudes was higher for correct responses).

Discussion

The current study first investigated the extent to which cortical thinning within sub-regions of the ACC changed with age and schooling experience (i.e., Montessori versus traditional pedagogy). We further explored how these changes were related to the EEG components of error-monitoring. Finally, we explored whether schooling experience influences these markers. In light of the relatively limited sample size, we consider our results preliminary and discuss them in the framework of experience-dependent plasticity.

We observed brain maturation (i.e., cortical thinning) within the cACC, but not within other sub-regions of the ACC. This finding corroborates previous work showing functional changes in cACC connectivity from around 6 to 12 years of age (Kelly et al., 2009; Velanova et al., 2008). It may be that children at that age are more sensitive to error and correct-related information. The ACC maturation follows a caudal to rostral path, from birth to late adolescence, tightly related to the successive gain in self-monitoring abilities at the sensorimotor, cognitive, and social-affective levels (Margulies et al., 2007; Posner & Rothbart, 2007; Posner, Rothbart, Sheese, & Tang, 2007).

We also found thicker PCC in Montessori compared to traditionally schooled children, independently of age. PCC is a central hub of the default mode network, often reported to be involved in the internally directed cognition (Beaty et al., 2014; Immordino-Yang, Christodoulou, & Singh, 2012; Leech & Sharp, 2014; Raichle et al., 2001). Previous work has shown the effect of Montessori pedagogy on mindful thinking or increased self-correction (i.e., metacognition; Denervaud et al., 2019; Lillard & Else-Quest, 2006; Lillard, 2011; Rathunde, 2001). Our results thus raise the possible relationship between PCC thickness, default mode network activity, and error-monitoring abilities, a topic of our ongoing work.

Both ERN and Pe varied with age. Likewise, amplitudes for correct and incorrect responses may change across development. Correct versus incorrect responses seemed more differentiated in younger children than older children of our cohort (>9 yo.). It may be that correct responses (less frequent than errors) are first perceived as unexpected early in the learning curve, and not the other way around (see also Denervaud, Fornari, et al., 2020; van den Bos, Guroglu, van den Bulk, Rombouts, & Crone, 2009). This idea could explain why developmental studies vary in their outcomes (i.e., Tamnes et al., 2013). Children enrolled in

Montessori schools also exhibited generally larger ERPs for both correct and incorrect responses. This is consistent with self-monitoring and trial-and-error learning that is reinforced in Montessori curricula (Marshall, 2017; Montessori, 1936). Together these findings suggest a dynamic, likely non-linear, development of error-monitoring with a possible shift in the incorrect versus correct processing of responses across age and pedagogies. However, these observations require longitudinal investigations, and/or testing/replication with a larger sample to strengthen and better characterize the relationship between cortical and error-related neurophysiological responses across 6-12-year-old children.

Source estimations of the ERN differed across pedagogies within the cACC and the mPFC. This is in close agreement with previous work on error or conflict monitoring where the ACC is robustly activated (e.g., Carter et al., 1998; Kiehl, Liddle, & Hopfinger, 2000; van Veen & Carter, 2002), and linked to greater prefrontal activity (Botvinick, Cohen, & Carter, 2004). In the current study, Montessori-schooled children had stronger brain activity for correct rather than incorrect responses, while traditionally schooled children showed the reverse pattern. It may thus be that early error signals are dissimilar in Montessori and traditional schoolchildren or related to different affective responses (i.e., "being incorrect is aversive" versus "being correct is motivating") corroborating recent behavioral and neural findings (Denervaud, Hess, Sander, & Pourtois, 2020). Indeed, in traditional pedagogy, errors are usually related to negative outcomes (e.g., bad grades, punishment), while self-correction in Montessori pedagogy reduces any extrinsic value-based judgment related to errors. We would note that the children enrolled in this study were each experiencing these different pedagogies since the onset of their formal schooling, meaning that their experience with errors and self-correction at school differed from the onset of their schooling. Those from Montessori settings learn with self-corrective didactic materials from the age of 4, discovering concepts by and for themselves without time restriction or feedback in the form of grades, tests, or rewards. Furthermore, they were trained to ask for help and information from their peers, in a non-competitive manner. While more work is needed, our preliminary findings suggest that pedagogy may impact error monitoring physiological responses differently.

Overall, our findings provide preliminary evidence that the ability to discriminate and monitor errors is related to neuro-developmental changes but may also be modulated by educational experience in 6- to 12-year-old children. While the mean age of the participants was approximately 9 years old, they had on average 5 years of school experience in Montessori or traditional schools. Children enrolled in a schooling system emphasizing self-correction and descriptive feedback seem to have stronger discriminative neural responses compared with children enrolled in a schooling system emphasizing adult-directed correction and quantitative feedback (i.e., grades, reward). It may be that learning materials themselves convey important information to schoolchildren to reinforce built-in discriminative skills, more than adult wordings. Furthermore, the error monitoring system is tightly related to the reward system; intrinsic (i.e., self-direction and curiosity) versus extrinsic (i.e., grades, punishments) rewards may reinforce different neural responses to error and correct responses. However, more work is crucially needed in that direction to deepen that preliminary work and confirm this idea. Indeed, given the impact of error-monitoring on flexible adaptation later in life, such work is crucially needed to implement optimal learning means and adapt settings at a specific age range.

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Conflict of interest

The authors declare no conflict of interest.

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Independent Samples T-Test

	Mean (SD)				
	Montessori	**Traditional**	**Statistic**	***p***	**Cohen's d**
Age	8.82 (1.64)	8.74 (1.65)	0.04	*0.97*	0.02
PM-47	34.08 (2.35)	32.36 (3.27)	1.52	*0.14*	0.60
Anxiety	13.67 (6.39)	13.14 (4.88)	0.24	*0.82*	0.09
Mindset	13.46 (6.19)	15.62 (4.99)	-1.54	*0.14*	0.63
SES	7.18 (0.87)	7.50 (1.24)	-0.72	*0.48*	0.29
Parental Style (score)	26.82 (4.53)	26.86 (4.15)	-0.02	*0.98*	0.01

Table 1 Demographic variables

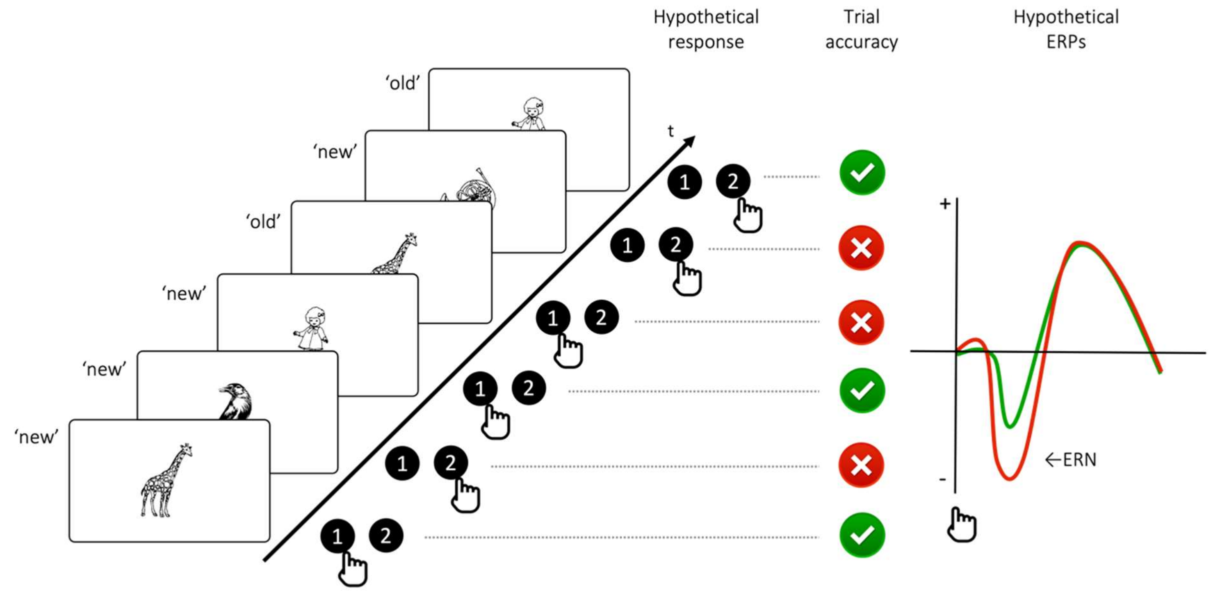

Figure 1 Speeded Continuous Recognition Task. Children were asked to discriminate whether each image was seen for the first (button '1') or second time (button '2') via button-press on a serial response box as fast and accurately as possible. Trials where children responded accordingly were considered as "correct responses", otherwise as "incorrect responses". Children completed four blocks of 160 trials each (500ms stimulus duration; 900-1500ms inter-stimulus interval); half of which were initial presentations and half of these were simultaneously accompanied by semantically congruent or incongruent sounds.

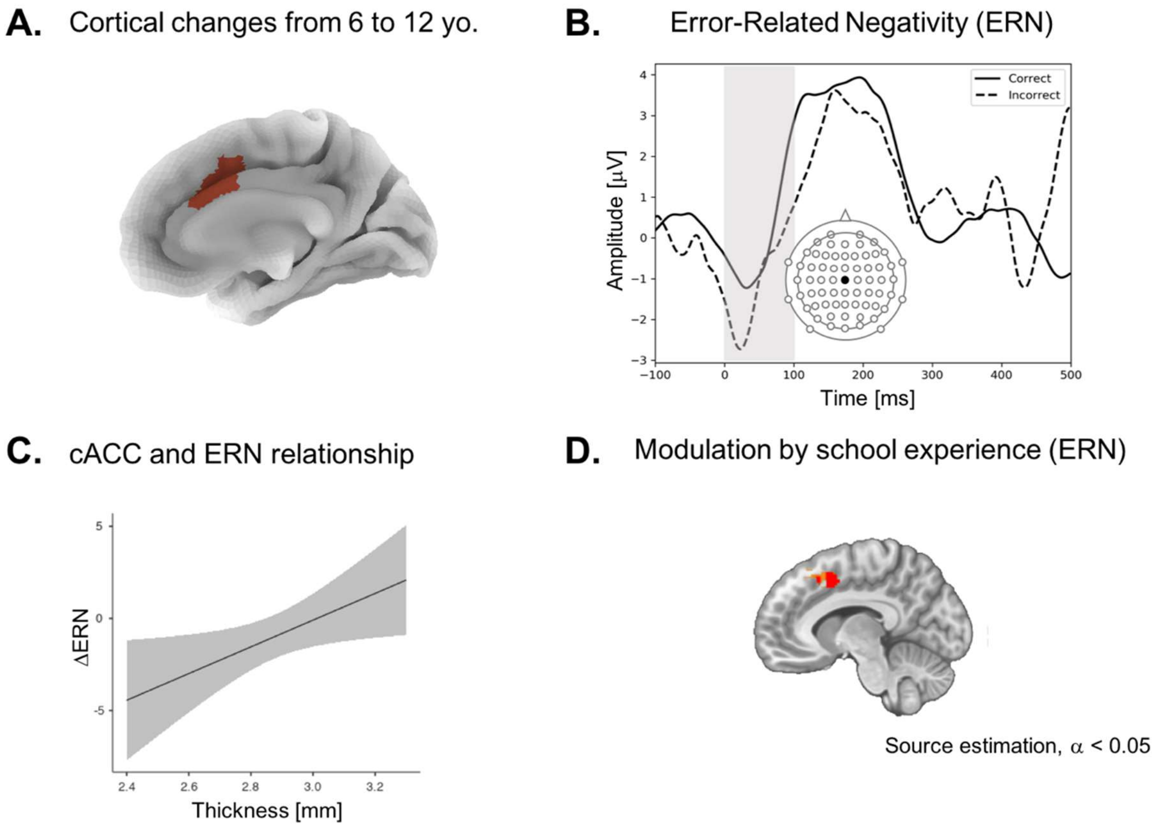

Figure 2 Effects of Age and Pedagogy on the cACC maturation and the ERN. A. Cortical Thickness within the ACC: effect of age on the caudal sub-region of the anterior cingulate cortex that is significantly thinner across 6 to 12 years of age ($p<0.047$). **B. ERN (incorrect-correct)** component as measured at FCz through Peak-to-Peak analyses **C. ERN was found to be a significant predictor of cACC thickness** ($p<0.036$). **D. ERN source estimation across the Montessori and traditionally-schooled children**, interactions found within the cACC ($\alpha<0.05$), among others (mPFC, left inferior temporal gyrus, and cerebellum)**.**