Impact of early childhood malnutrition on the adult brain function: an ERP study

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Abstract

According to the World Health Organization, 45% of deaths among children under 5 years of age are caused by childhood malnutrition, which affects 224 million children worldwide. The Barbados Nutrition Study (BNS) is a 50+year longitudinal study on a Barbadian cohort (*N*=258) with histories of moderate to severe protein-energy malnutrition (PEM) in the first year of life and healthy controls. Interestingly, a recent BNS publication used quantitative electroencephalography (EEG) to show differences in brain function (lower alpha1 activity and higher theta, alpha2 and beta activity) in children who suffered from early PEM compared to healthy controls. However, the adult brain function following early childhood PEM has not been reported in this cohort. In the current study, EEG recordings were undertaken during a Go-No-Go task on a subsample of the BNS cohort (*n*=55) at ages 45-51 years. Evoked-related potentials (ERP) analyses show that, compared to the control group (*n*=29), participants with histories of early PEM (*n*=24) presented with lower N2 amplitudes and a higher omission error rates, associated with conflict monitoring and attention deficits, respectively. These results may be linked to the attention and executive impairments that have been previously reported in this cohort.

Keywords

Early childhood malnutrition; Long-term outcomes; EEG; Go-No-Go; ERP; Inhibition; Attention

Introduction

Two-hundred million children under five are affected by malnutrition worldwide, which makes this condition a critical global health concern (UNICEF, 2019). Protein energy malnutrition (PEM) is a specific type of malnutrition defined as an acute energy deficit due to deficiency of all macronutrients, and micronutrients in some cases (Atassi, 2019; Grover and Ee, 2009; Morley, 2018). Determining the effects of such an important health problem at a young age is therefore a priority.

Malnutrition has deleterious effects on cognitive abilities (Agarwal et al., 1992; Berkman et al., 2002; Galler et al., 1990; Kar et al., 2008; Mendez and Adair, 1999; Upadhyay et al., 1989). Malnutrition has also been associated with various effects on motor skills, behavior, social abilities, and mental health (Galler et al., 1983b; Hoorweg and Stanfield, 1976; Upadhyay et al., 1989). Some of these effects have been shown to persist into adolescence and adulthood (Galler et al., 2012a, 2012b; Waber et al., 2014b, 2014a; Walker et al., 2007).

Using electroencephalography (EEG), brain function alterations have also been associated with early childhood malnutrition. Nelson and colleagues (1959) reported a general slowing of the EEG's dominant rhythm in undernourished children from 4 to 44 months, as compared to a control group, which only partly normalized with adequate food intake, which was replicated in several other studies (Baraitser and Evans, 1969; Griesel et al., 1990; Robinson et al., 1995; Stoch et al., 1963), but only a few assessed the children at later timepoints in childhood. Bartel and colleagues (Bartel et al., 1979) studied malnourished children five to ten years after their hospitalization and confirmed that their rest EEG still had a significantly diminished alpha and increased theta and delta frequencies compared to a control group. In a recent study, brain function alterations in the resting state activity of previously malnourished 5-11 year old children of the BNS cohort were reported, namely an excess of theta, alpha2 and beta frequencies and a decrease of alpha 1, which suggest a maturational lag in cortical development (Taboada-Crispi et al., 2018). It is clear from these behavioral and EEG findings that malnutrition at a young age has important acute deleterious effects on brain function, cognition and multiple other life fonctionning aspects. However, the effects of malnutrition on brain function in adulthood are still unknown.

The Barbados Nutrition Study (BNS) is a 50-year longitudinal study that has followed a Barbadian cohort hospitalized during the first year of life for a single episode of moderate to

severe protein-energy malnutrition (PEM; Galler et al., 1987, 1983a) based on the Gomez classification (Gomez et al., 1955) as well as matched healthy controls who were former classmates of the PEM participants. The objectives of this study were to characterize the medical, neuropsychological, behavioral and brain effects of early PEM over the lifespan. The cohort comprises participants that were originally recruited between 1967 and 1972 when they were hospitalized as infants and subsequently enrolled in a government program that provided health and nutrition monitoring until the children reached 12 years of age (PEM group). The malnutrition episode was restricted to the first year of life. Control participants were classmates of the PEM children and were matched by age, sex, and handedness. All children in the PEM group achieved complete catch-up in physical growth by adolescence (Galler et al., 1987). Neuropsychological and psychiatric assessments revealed many cognitive, behavioral and mental health impairments associated with early childhood PEM including lower IQ, conduct problems and higher prevalence of affective and depressive symptoms as well as attention deficits (Galler et al., 1983a, 2010; Galler et al., 2012a). Additionally, most participants in the PEM group exhibit persistent attentional and executive problems during childhood, adolescence and adulthood compared to the control group (Galler et al., 1983a; Galler et al., 2012b; Galler and Ramsey, 1989). However, little is known about the brain function effects of early childhood malnutrition on this cohort.

The present study is an international Canada-United States-Cuba-Barbados collaboration. Our aim was to study the persistence of brain function alterations in adults who experienced moderate to severe PEM during the first year of life by comparing the brain activity in adults from the PEM and the control groups of the BNS cohort using evoked related potentials (ERPs). Considering the attention and executive impairments previously reported in the PEM group (Galler et al., 1983a; Galler et al., 2012b; Galler and Ramsey, 1989), we administered a Go-No-Go attention task during EEG recordings to specifically isolate those altered processes. In a Go-No-Go task, two ERPs components are typically studied, namely the N2 and P3 components. N2 is defined as the largest fronto-central negative polarity deflection between 200 and 450ms and P3 is defined as the largest fronto-central positive polarity deflection between 350 and 600ms (Grane et al., 2016; McLoughlin et al., 2010; Schmüser et al., 2016; Woltering et al., 2013). N2 and P3 are respectively associated with conflict monitoring (i.e. conflict between the prepotent response and required response) and inhibition response (i.e. cancellation of a planned or

prepotent response) processes in an inhibition control task such as Go-No-Go, Stop signal, Stroop or Flanker task (Braver et al., 2001; Smith et al., 2008). Those components have been widely studied, notably in samples with ADHD (Grane et al., 2016; Johnstone et al., 2013; McLoughlin et al., 2010; Schmüser et al., 2016; Woltering et al., 2013) and are thought to be altered in individuals with attention and executive deficits. In the current study, we hypothesised that the PEM group will show smaller N2 and P3 component amplitudes compared to the healthy control group.

Materials and Methods

Participants

Fifty-five adults were recruited from the Barbados Nutrition Study (BNS) cohort, including 26 participants who experienced moderate to severe PEM during the first year of life (PEM group; male/female = 15/11) and 29 healthy controls, former classmates of the PEM group, who no histories of malnutrition (Control group; male/female = 14/15). The inclusion criteria for both groups were, as follows: (1) a normal birth weight (>2500g), (2) the absence of pre-or postnatal complications, (3) an Apgar score above or equal to 8, (4) no encephalopathic events during childhood and (5) no malnutrition or other serious childhood disease after the first year of life. Two participants of the PEM group had to be excluded, one due to heavy alcohol consumption the night before the testing and the other one did not complete the task. Groups did not differ in terms of age (t = 0.18, p = 0.67) and gender (Male: χ^2 = -0.58, p = 0.57; Female: χ^2 = -0.85, p = 0.40). The sample's demographic characteristics are reported in Table 1. Table 2 shows no difference in the child demographic characteristics between our subsample and the rest of the BNS cohort. The subsample is therefore representative of the BNS population.

Procedure

EEG recordings took place at the Barbados Nutrition Study Clinic, Bridgetown, Barbados. The room was air conditioned and the temperature was maintained at 24°C. Participants were seated in a comfortable chair and fitted with a 21-EEG Ag/AgCl electrodes active cap, one vertical and one horizontal electro-oculogram (EOG), and one electrocardiogram (ECG). The EEG signal was recorded on the scalp using the actiCHamps amplifier and Brain Vision Recorder Software (version 1.20, Brain Products, GMbH, Gilching, Germany). EEG channels were positioned according to the 10-20 system (Fz, Cz, Pz, Oz, Fp1/2, F3/4, C3/4, P3/4, O1/2, F7/8, T3/4, T5/6, plus ground and reference). The impedance was kept under 10kΩ. A near-infrared

spectroscopy (NIRS) recording was performed simultaneously with the EEG. However, the NIRS data are not included in the current article. A Go-No-Go task was performed during the EEG-NIRS recording.

Go-No-Go task

The Go-No-Go task was presented using Presentation (version 20.2, Neurobehavioral Systems; see figure 1). Participants were instructed to click a mouse with their dominant hand's index finger as fast as possible whenever a letter (Go trial) appeared on the screen, but to withhold from responding if the letter was an X (No-Go trial). Each letter was presented pseudorandomly for 500 ms and disappeared as soon as a motor response was made. The inter-stimulus interval varied randomly between 700 and 1000 ms. The task was built in a block design in which each block of 20 stimuli was delimited by a resting period that varied randomly between 15 and 21 sec. A block design was used rather than a single trial paradigm to accommodate both the EEG and NIRS signals. The task consisted of 14 No-Go blocks, and 14 Go blocks. The No-Go blocks included 30% of No-Go trials (6 X) and 70% of Go trials (14 letters) presented pseudorandomly. The Go blocks included Go trials only. Each participant went through a practice trial of one No-Go block that included feedback before the actual task. Overall, 28 blocks were presented to each participant, for a total of 476 Go and 84 No-Go trials (total of 560 letters). Additional blocks were presented so that at least 70 No-Go trials were correctly inhibited to ensure a good signal to noise ratio. Three behavioral variables were computed based on the 28 blocks of the task (without additional blocks): reaction time (RT), No-Go accuracy and Go accuracy.

EEG recording and data processing

The EEG signal was recorded from the scalp using at 500Hz sampling rate and referenced to electrode FCz. The data pre-processing was done using Brain Vision Analyzer (Brain Products, Munich, Germany). Data was first filtered offline between 0.5 and 35Hz using a Butterworth filter with a notch filter at 50 Hz to remove any electrical interference. Ocular artefacts were then removed by subtracting the corresponding components using Independent Component Analysis (ICA). The data was then re-sampled at 512 Hz and re-referenced to the average reference. Each trial was segmented from -500 to 1000 ms after stimulus onset. DC detrend was applied to the data to remove the signal drift.

An artifact correction was then performed to reject any segment with artifacts for each channel individually. Any segment with a voltage step > 50 µv/ms was removed. The maximum amplitude allowed was 100 µv and the minimum amplitude allowed was -100 µv. A trained Ph.D. candidate (K.R.) then performed a visual inspection of the signal to detect any remaining artifacts and validate the artifact correction. Every incorrect trial, namely every No-Go followed by a motor response or Go without a motor response, was also rejected. A baseline correction was further applied using 200 ms before stimulus onset. Trials were then averaged in Correct No-Go (M = 69.6 trials, SD = 10.5) and Correct Go trials (M = 471.3, SD = 67.3).

ERP analysis. For each participant, a semi-automatic peak detection for the N2 and P3 ERP components was first performed on Correct No-Go and Correct Go trials individually on Fz, Cz and FCz electrodes, where the components have previously been reported (Donkers and van Boxtel, 2004; Falkenstein et al., 1999). N2 was defined as the largest fronto-central negative polarity deflection between 200 and 450ms and P3 was defined as the largest fronto-central positive polarity deflection between 350 and 600ms (Grane et al., 2016; McLoughlin et al., 2010; Schmüser et al., 2016; Woltering et al., 2013). The peaks were reviewed by a trained Ph.D. candidate (K.R.) and an expert in EEG processing (P.V.). The mean amplitude ±10 ms around the peak and the latency of each peak was extracted and used for statistical analyses. A topographic T-test (without correction for multiple comparisons) was performed to compare amplitude topographies between groups (PEM vs Control). BrainVision assisted t-tests were computed on amplitude topographies during N2 and P3 components for No-Go and Go conditions individually when the differences between groups were maximal (see figures 2 and 3).

Statistical analyses

For the behavioral measures (performance at the Go-No-Go task), three separate independent sample t-tests with group as the between-subjects factor were conducted for the reaction time, Go accuracy and No-Go accuracy. For the ERP components, four mixed ANOVA [3 (Electrode: Fz, Cz, FCz) x 2 (Condition: No-Go, Go) x 2 (Group: Controls, PEM)] were conducted separately for N2 and P3 and for their amplitude and latency. The significant p-value was set to $p \leq 0.05$. The extreme outliers, defined as a value that is over 3 times the interquartile range, were winsorized as suggested by Wilcox and colleagues (2012). Greenhouse-Geisser adjustment was applied if the assumption of sphericity was violated (Mauchley's test statistic significant at $p<0.05$) and the Bonferroni correction was applied for multiple comparisons. Mann-

Withney U nonparametric test was used if the Shapiro-Wilk normality test was violated. If nonparametric and parametric tests provided similar results, parametric tests were reported. Statistical analyses were performed using SPSS (version 25).

Results

Behavioral results

Statistical analyses revealed a significant difference between groups on Go accuracy (U=462, p=0,041), with greater Go accuracy for the control group compared to the PEM group. Table 3 shows the means and standard deviations of the behavioral measures.

N2

Figure 4 and 5 show the waveform of the N2 and P3 components for each group during the No-Go and Go conditions, respectively.

Amplitude. A three-way ANOVA revealed a main effect of Electrodes (F (2,102) = 7.745, p=0.004, η_p^2=0.132) with pairwise comparisons indicating a smaller amplitude for Fz compared to FCz (p<0.001) and compared to Cz (p=0.060, statistical tendency). There was also a main effect of Condition (F (1,51) = 30.219, p<0.001, η_p^2=0.372) with the No-Go condition generating a larger N2 amplitude than the Go condition, according to pairwise comparisons. Significant interactions between Condition and Group (F (1,51) = 5.404, p=0.024, η_p^2=0.096) and between Electrode and Condition (F (2,102) = 5.061, p=0.020, η_p^2=0.090) were found. Appropriate t-tests and repeated measures ANOVA were conducted to further explore these interactions.

For the Condition x Group interaction, independent t-tests revealed a significant difference of the N2 amplitude between the two groups but only in the No-Go condition [No-Go: t(51) = 1.959, p=0.056; Go: (t(51) = 0.147, p=0.883]. During the No-Go condition, the amplitude of N2 was significantly larger for the control group compared to the PEM group.

For the Electrode x Condition interaction, the repeated measure ANOVA revealed a smaller amplitude for Fz compared to FCz (p<0,001) and Cz (p=0,035) during the No-Go condition (F(2,104)=9,103, p=0,002), but only a smaller amplitude for Fz compared to FCz (p=0,027) during the Go condition (F(2,104)=3,479, p=0,058).

Latency. The three-way ANOVA showed a main effect of Electrodes (F (2,102) = 13.943, p<0.001, η_p^2=0.215) with pairwise comparisons indicating a shorter latency for Cz compared to FCz (p=0.001) and compared to Fz (p<0.001). There was also a main effect of Condition (F (1,51) = 22.524, p<0.001, η_p^2=0.306) with the No-Go condition generating a longer N2 latency than the Go condition. No interaction was significant, and there was no significant nutrition group effect.

P3

Amplitude. The three-way ANOVA revealed a main effect of Electrodes (F (2,102) = 25.811, p<0.001, η_p^2=0.336) with pairwise comparisons indicating a smaller amplitude for Fz compared to FCz (p<0.001) and compared to Cz (p=0.001). There was also a main effect of Condition (F (1,51) = 195.127, p<0.001, η_p^2=0.793) with the No-Go condition generating a larger P3 amplitude than the Go condition, according to pairwise comparisons. There was also a significant interaction between Electrode and Condition (F (2,102) = 7.667, p=0.004, η_p^2=0.131). A repeated measures ANOVA was conducted as posthoc analysis to further explore this interaction. For the No-Go condition (F(2,104)=18.912, p<0.001, η_p^2=0.267), it showed that P3 amplitude was larger at FCz compared to Fz (p<0.001) and Cz (p=0.014), and that it was larger at Cz compared to Fz (p=0.027). For the Go condition (F(2,104)=26.076, p<0.001, η_p^2=0.334), it showed that P3 amplitude was smaller at Fz compared to FCz (p<0.001) and Cz (p<0.001).

Latency. No significant main effects or interactions were obtained for the P3 latency three-way ANOVA. Table 4, 5 and 6 show the means and standard deviations of the ERP measures for each condition for Fz, Cz and FCz, respectively.

Discussion

The main objective of this study was to compare the brain activity of adults who experienced moderate to severe PEM during the first year of life and healthy controls with no histories of malnutrition using a Go-No-Go inhibition task. We hypothesized that the PEM group

would show altered neural response associated with attention and inhibition (N2 and P3 components) during the task. The hypothesis was partially confirmed, since we observed a reduction of N2 amplitude during the No-Go condition in the PEM group compared to the control group, but no difference in P3. Overall, results of the Go-No-Go task revealed a main effect of Condition for both components (N2 and P3) in both groups (PEM and Control). This is typical result for a Go-No-Go task, indicating that the No-Go condition induces a genuine inhibition response process which is delaying the onset and amplifying the N2 and P3 components (Bokura et al., 2001; Eimer, 1993; Schmüser et al., 2016).

The N2 amplitude was smaller in the PEM group compared to the control group during the No-Go condition. This result has also been found in adults and children with ADHD (Brandeis et al., 2002; Fallgatter et al., 2004; Gow et al., 2012; Woltering et al., 2013). There is debate amongst the scientific community on the cognitive process underlying the N2 component. Although some authors argue that N2 is related to the inhibition process (i.e. cancellation of a planned or prepotent response; Eimer, 1993; Falkenstein et al., 1999), more recent studies point to an association between N2 and conflict monitoring (i.e. conflict between the prepotent response and required response; Donkers and van Boxtel, 2004; Enriquez-Geppert et al., 2010; Groom and Cragg, 2015; Huster et al., 2013; Woltering et al., 2013). According to the conflict monitoring hypothesis, an inhibition task such as Go-No-Go should evoke a N2 component because of the unbalanced ratio between Go and No-Go trials, which would lead to the creation of a prepotent response (Go) that conflicts with the infrequent inhibition of this response (No-Go) and not because of the inhibition process *per se* (Braver et al., 2001). Conflict monitoring is however closely related to attention since it is responsible for triggering cognitive control changes by adjusting attention levels to optimize performance and prevent subsequent conflict (Botvinick et al., 2001). According to these models, our results can be interpreted as an impairment in conflict monitoring and/or attention following early childhood malnutrition.

Surprisingly, the ERP results showed no difference between the two nutrition groups in P3 amplitude or latency. P3 component is usually considered to be a marker of response inhibition processing and evaluation (Groom and Cragg, 2015; Huster et al., 2013). In studies of ADHD using a Go-no-Go task, both components, N2 and P3, are typically altered (Johnstone et al., 2013; Woltering et al., 2013). However, the reduced N2 amplitude in the PEM group and similar P3 amplitude between groups is in line with the behavioral results. Indeed, in the current study, Go

accuracy was significantly lower in the PEM group compared to the control group, revealing that adults who suffered from early childhood malnutrition committed more omission errors than controls. No difference in commission error rate was found. Omission errors are usually attributed to impairments in attention and vigilance whereas commission errors are associated with inhibition deficits. Therefore, early childhood malnutrition may be associated with diminished attention and vigilance rather than altered inhibition skills (Doehnert et al., 2013; Grane et al., 2016; McLoughlin et al., 2010; Valko et al., 2009). Furthermore, no differences in reaction times were found between our groups. Slower reaction times have been consistently reported in populations with attentional and inhibition difficulties and are associated with hyperactivity and impulsivity (Barkley et al., 2008; McLoughlin et al., 2010; Rubia et al., 2007; Schmüser et al., 2016; Tamm et al., 2012; Wiersema et al., 2006). Overall, the behavioral results suggest attention deficits with normal inhibition skills in adults who experienced early childhood malnutrition. Nevertheless, we cannot rule out that the PEM group developed compensatory mechanisms to overcome inhibition difficulties.

The ERP and behavioral results are in line with the persistent attention deficits previously reported in our cohort during childhood, adolescence and adulthood (Galler et al., 2012b, 1990, 1983a; Galler and Ramsey, 1989; Peter et al., 2016). Attention deficits have also been reported in other studies assessing the neurocognitive profile of malnourished population (Kar et al., 2008; Kesari et al., 2010; Richardson et al., 1972; Wang et al., 2016). Although the PEM group had persistent attention deficits in the prior BNS publications (e.g. 69% had at least one score falling within the clinical range for attention disorder at the Continuous Performance Test or CPT), only 8% achieved a clinical diagnosis of ADHD (Galler et al., 2012b). Attention deficits seem highly more prevalent in our cohort than hyperactive/impulsive ADHD symptoms. Interestingly, a recent study assessing neuropsychological functions in the BNS cohort showed that cognitive flexibility was more altered than inhibition (Waber et al., 2014a). This neuropsychological profile could explain why we did not find any electrophysiological marker of inhibition deficits (P3 or commission errors).

The altered electrophysiological marker found in this study is also coherent with literature on brain function effects following childhood malnutrition. Indeed, several studies show that childhood malnutrition is associated with slowing of the EEG's dominant rhythm in infancy (Baraitser and Evans, 1969; Griesel et al., 1990; Nelson, 1959; Robinson et al., 1995; Stoch et al.,

1963) and electrophysiological alterations that persist in childhood even with food rehabilitation (Bartel et al., 1979; Taboada-Crispi et al., 2018). ERP anormalities were also found following childhood malnutrition with a higher relative abnormality of their auditory evoked potentials compared to controls (Barnet et al., 1978; McDonald, Joffe, Barnet and Flinn, 2007). We expand knowledge in this field by showing brain function deficits still perceptible in adulthood.

This study has several limitations. First, the small sample size does not allow us to conclude with certainty that the results were not due to lack of statistical power. Nevertheless, the effect size is moderate for the N2 amplitude difference between the groups (d=0.55). Also, due to the small sample size, we could not adjust our statistical analyses for age, gender and handedness. Though we found no differences between the two groups on those variables, we cannot exclude that these variables might have had an effect on our results. The results reported here are specific to the N2 and P3 electrophysiological markers. Potential other electrophysiological differences between our groups might exist and would allow us to identify additional brain markers of early childhood malnutrition (e.g. time frequency, source level, connectivity). Indeed, using source localization analysis on our data would allow to explore more precisely at the source level the brain function temporal dynamics of the executive function. However, at least 64 electrodes would be needed to apply source analysis. Further analyses will be performed to better characterize and compare brain function in both groups.

Conclusion

In sum, this study shows that adults who experienced early childhood malnutrition in the first year of life demonstrate different brain response patterns during a response inhibition task compared to healthy controls. This adds to the existent literature on cognitive and neural outcomes following early childhood malnutrition, suggesting that attention and conflict monitoring, two cognitive control processes, are still altered in adulthood. Malnutrition can have deleterious effects on cognition, physical and mental health, behavior and brain function even if restricted to the first year of life. Considering the impact of persisting cognitive alterations on the quality of life, more research is needed to better characterize the brain markers and clinical profile associated with early childhood malnutrition in order to develop a disease progression model applicable to various vulnerable populations.

Statement of Ethical Standards

This study has been performed in accordance with the ethical standards laid down in the 1964 Declaration of Helsinki and its later amendments. All study participants provided written informed consent and were compensated for their time and travel expenses. This study was approved by the Massachusetts General Hospital IRB (IRB Protocol 2015P000329/MGH), Hôpital Sainte-Justine and Centro de Neurosciencias de Cuba' (CNEURO) Ethics' committees.

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Table 1

Demographic Characteristics of NIRS Participants - BNS Summer Study 2018

Characteristic	PEM	Control	t-test / $\chi 2$	*p*
N	24	29		
Males [N (%)]	13 (54.17)	14 (48.28)	0.18	0.67
Age (years)				
Males (*SD*)	49.2 (1.76)	48.8 (1.99)	-0.58	0.57
Females (*SD*)	47.8 (1.74)	48.5 (1.97)	0.85	0.40
Handedness [N left (%)]	3 (12.50)	3 (10.30)	0.06	0.75
Hollingshead Index of Social Position (ISP)				
Education Index (*SD*)	5.13 (0.34)	3.79 (1.54)	-4.52	< 0.0001
Occupational Index (*SD*)	6.25 (1.03)	4.31 (1.58)	-5.36	< 0.0001
Total Index (*SD*)	64.3 (7.55)	45.3 (16.39)	-5.54	< 0.0001
ISP Category (*SD*)	4.7 (0.48)	3.4 (1.08)	-5.75	< 0.0001

Note. Handedness statistical tests were done using Fisher Exact Test (non-parametric). There are 5 social position categories : (1) Upper, (2) Upper-middle, (3) Middle, (4) Lower-middle, and (5) Lower.

Table 2

Demographic Characteristics of NIRS Participants vs. Non-Participants from Original Cohort

Characteristic	Participant	Non-participant	t-test / $\chi 2$	*p*
N	53	205		
Male (%)	27 (50.90)	126 (61.50)	1.93	0.165
History of Malnutrition (%)	24 (45.30)	105 (51.20)	0.59	0.441
Childhood Ecology (*SD*)	-0.683 (0.88)	-0.528 (1.00)	1.11	0.268
WISC Full-Scale IQ (*SD*)	98.6 (16.14)	96.9 (15.36)	-0.69	0.492

Note. The Childhood Ecology and the Full-Scale IQ measures are from the 1977-1978 data collection, when participants were children.

Table 3

Mean and standard deviation of the behavioral measures for PEM and control group

	PEM (*N*=24)		Control (*N*=29)			
Measure	*M*	*SD*	*M*	*SD*	Mann-Withney *U*	*p*
Reaction time (ms)	357.95	35.24	357.83	38.30	352.00	0.94
Go accuracy (%)	97.09	3.22	98.25	2.59	462.00	0.04
No-Go accuracy (%)	76.64	12.11	80.21	12.87	420.00	0.20

Table 4

Mean and standard deviation of the ERPs measures for Fz electrode

	PEM (*N*=24)		Control (*N*=29)	
Measure	*M*	*SD*	*M*	*SD*
No-Go Amplitude N2	-1.84	1.44	-2.20	1.38
Go Amplitude N2	-1.48	0.92	-1.36	1.04
No-Go Amplitude P3	2.72	2.21	3.02	1.57
Go Amplitude P3	0.83	1.06	0.98	0.88
No-Go Latency N2	313.88	36.03	313.24	35.65
Go Latency N2	291.75	36.40	294.85	35.20
No-Go Latency P3	417.24	26.30	415.75	40.10
Go Latency P3	416.34	36.34	414.80	39.23

Table 5

Mean and standard deviation of the ERPs measures for FCz electrode

	PEM (*N*=24)		Control (*N*=29)	
Measure	*M*	*SD*	*M*	*SD*
No-Go Amplitude N2	-2.04	1.78	-3.07	1.53
Go Amplitude N2	-1.53	0.97	-1.72	1.23
No-Go Amplitude P3	3.38	1.52	3.70	1.80
Go Amplitude P3	1.33	0.97	1.53	0.97
No-Go Latency N2	305.09	37.43	301.19	30.39
Go Latency N2	279.70	41.46	281.92	36.56
No-Go Latency P3	417.48	24.47	420.39	44.71
Go Latency P3	416.10	37.53	413.46	40.61

Table 6

Mean and standard deviation of the ERPs measures for Cz electrode

	PEM (*N*=24)		Control (*N*=29)	
Measure	*M*	*SD*	*M*	*SD*
No-Go Amplitude N2	-2.19	1.63	-3.06	1.52
Go Amplitude N2	-1.61	1.02	-1.66	1.23
No-Go Amplitude P3	3.74	2.19	4.24	1.76
Go Amplitude P3	1.21	0.91	1.55	1.02
No-Go Latency N2	307.94	36.42	310.01	23.93
Go Latency N2	287.60	37.51	291.49	33.66
No-Go Latency P3	426.76	34.67	416.15	39.51
Go Latency P3	415.93	37.06	412.85	38.25

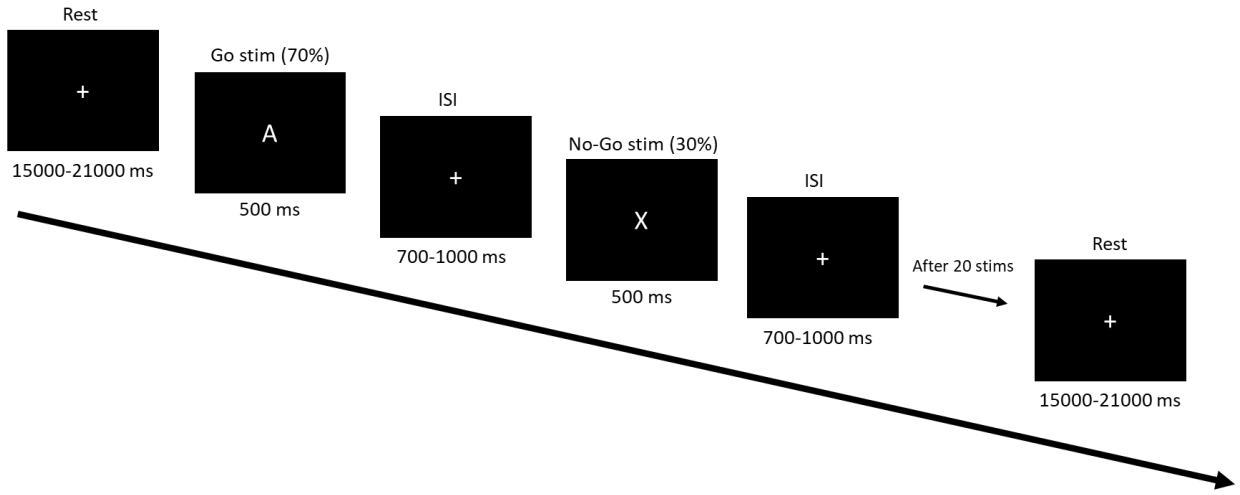

Figure 1

Go-No-Go task design

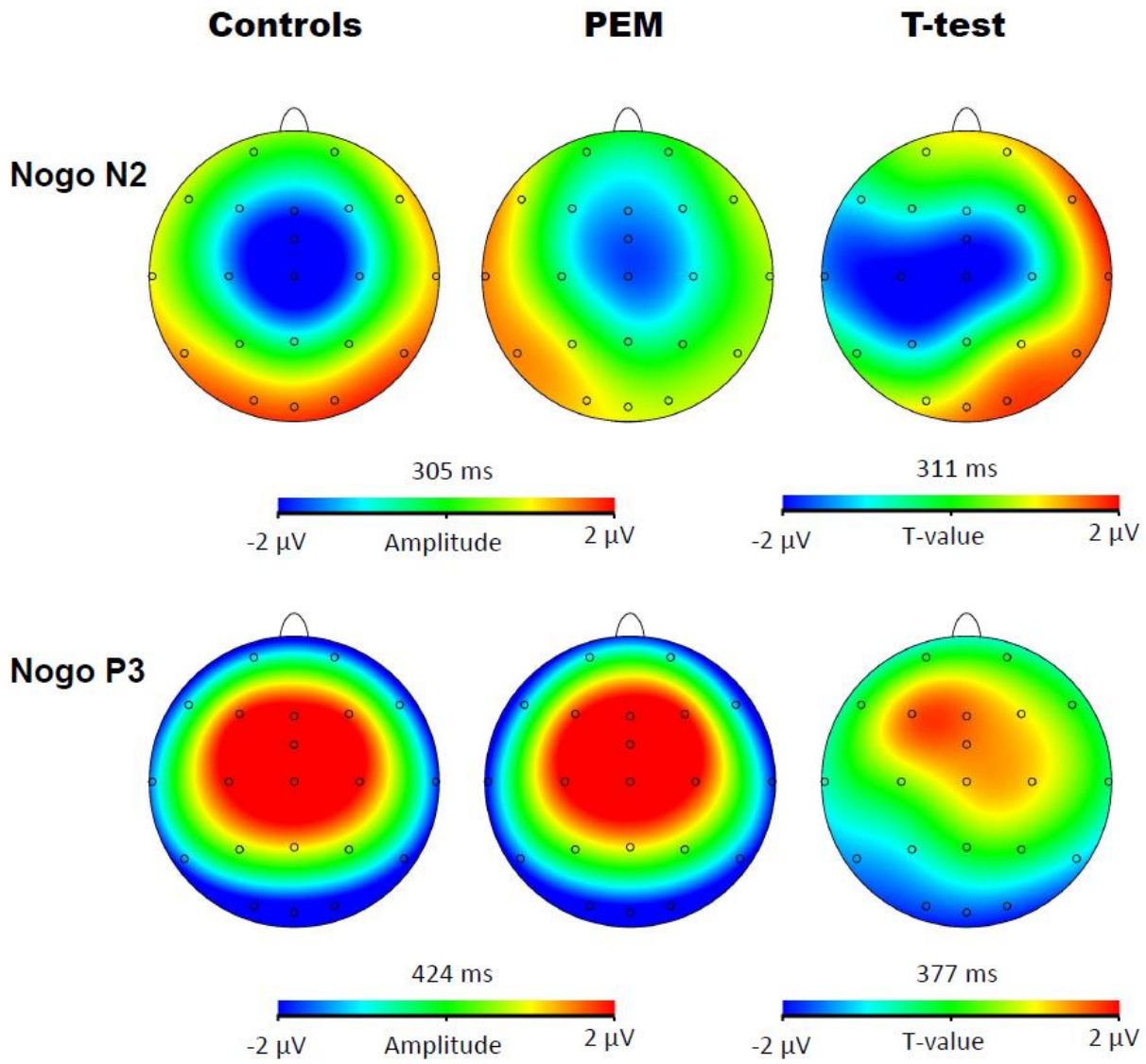

Figure 2

Topographic activation and topographic T-test (not corrected) of the difference of activation between PEM and control groups during No-Go condition

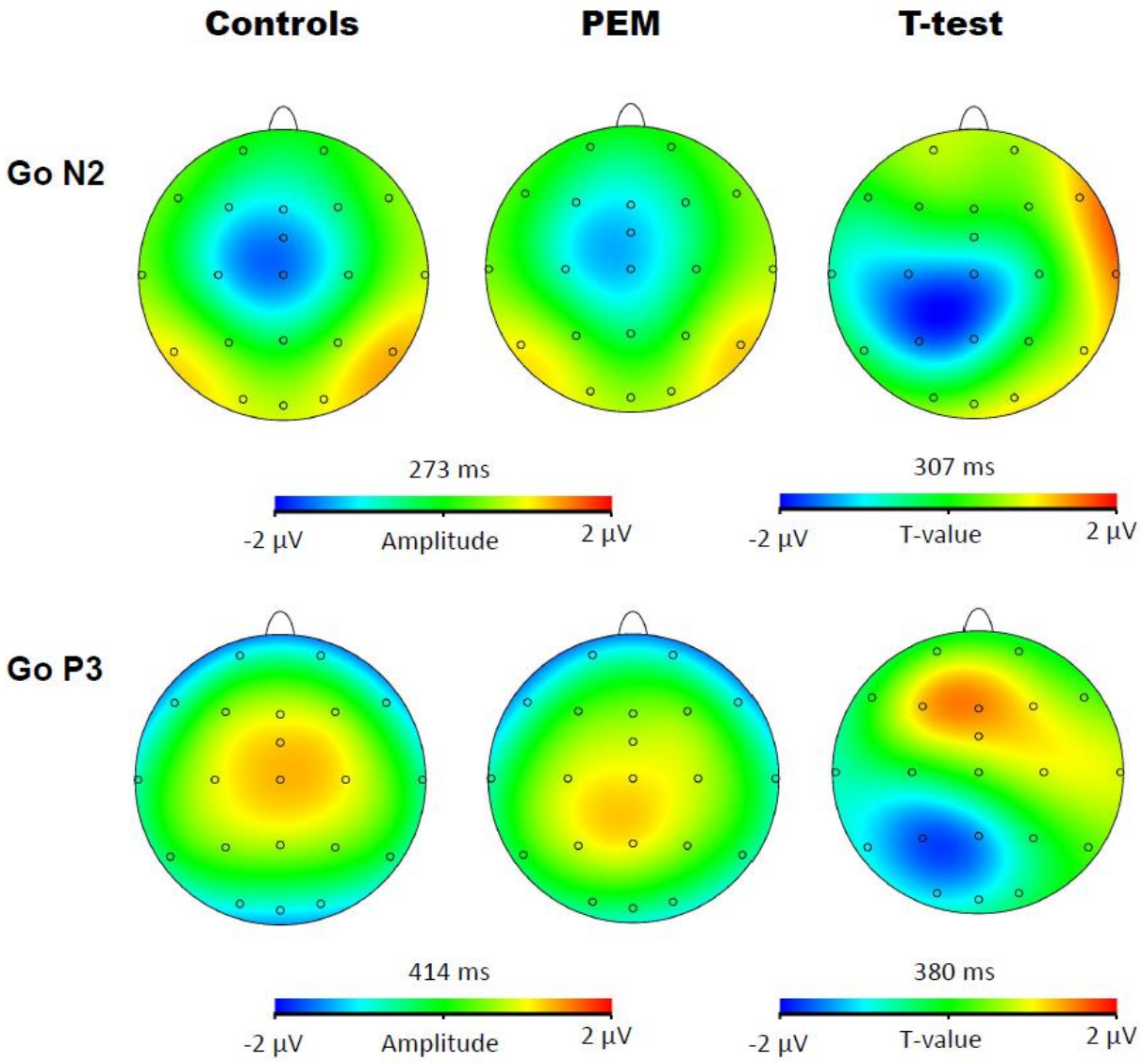

Figure 3

Topographic activation and topographic T-test (not corrected) of the difference of activation between PEM and control groups during Go condition

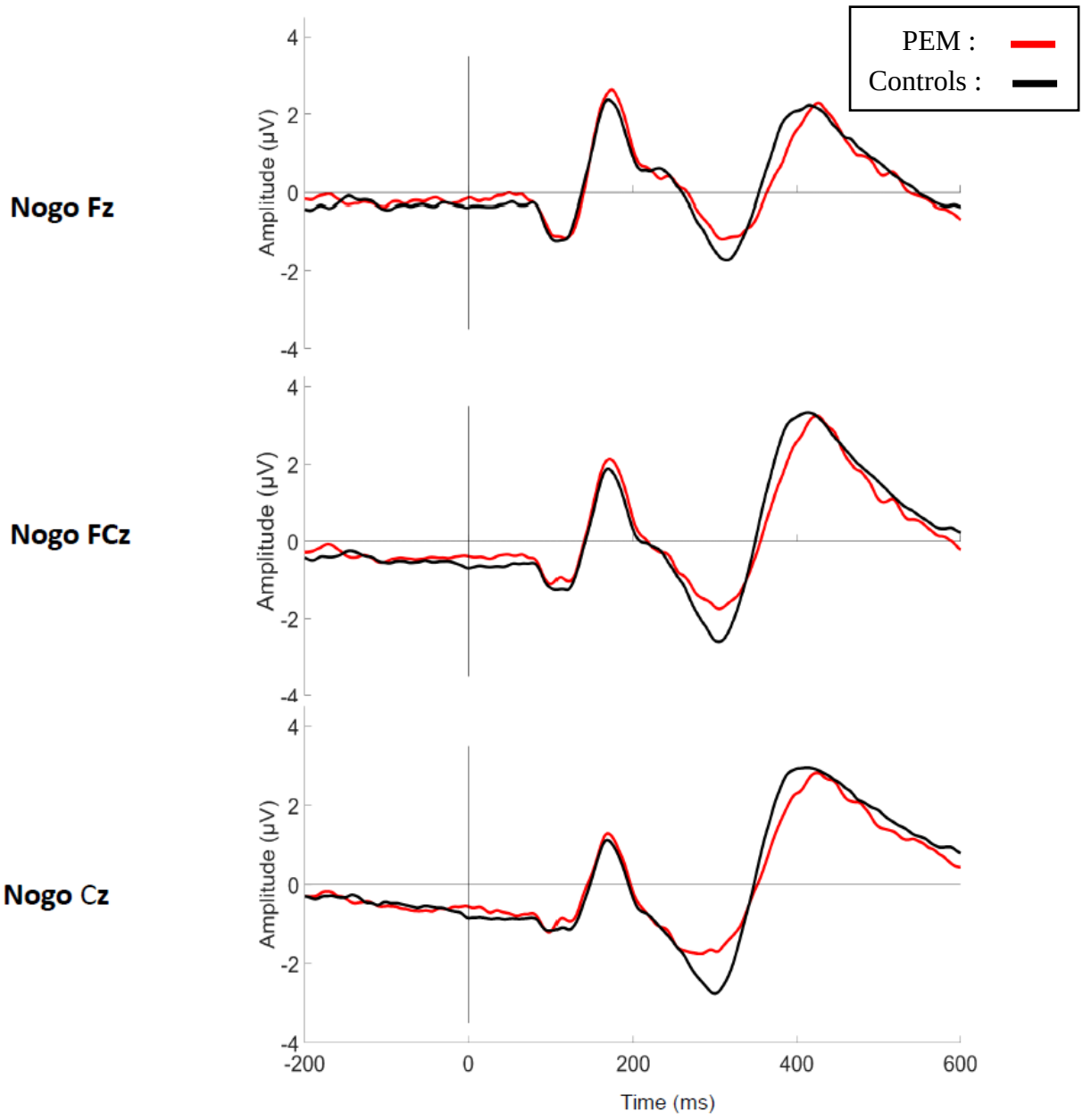

Figure 4

Grand average waveform of the N2 and P3 components during No-Go condition for each group

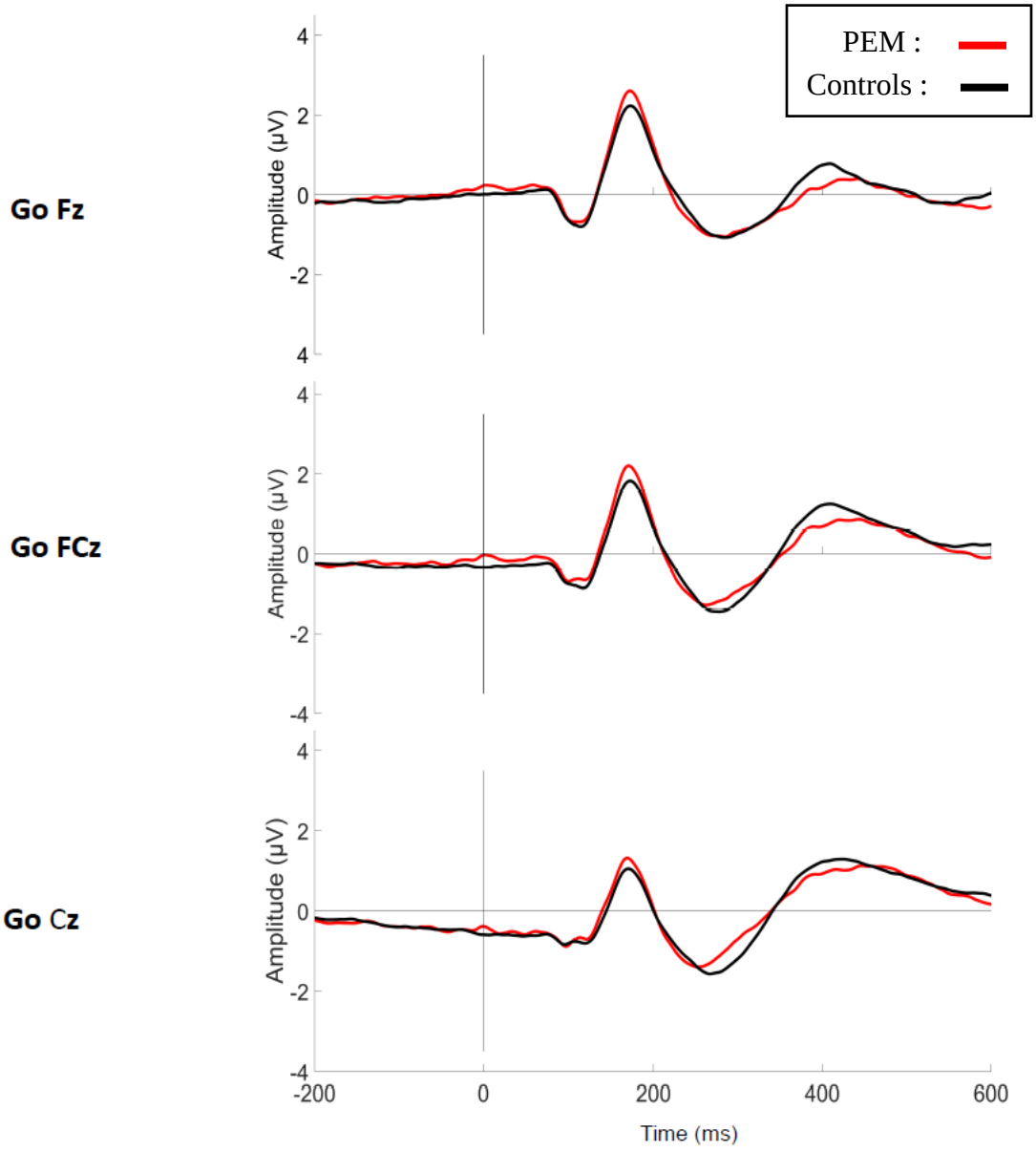

Figure 5

Grand average waveform of the N2 and P3 components during Go condition for each group