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Face-sensitive brain responses measured from a four year old child
with a custom-sized child MEG system

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Face-sensitive brain responses in a four year old child

Highlights

- A face-sensitive M170 brain response was obtained in a four-year-old child in both child custom-sized and conventional adult MEG systems.

- The child MEG system showed a larger, clearer and more accurately localized brain response in the child.

- The presence of the face-sensitive M170 in this child agrees with the early development of its electrical equivalent the N170 and supports an early maturation account of face processing.
1. Introduction

Magnetoencephalography (MEG) holds great promise for understanding the neurophysiological mechanisms underlying cognitive development, because it combines exquisite temporal resolution with reasonable spatial resolution. In principle, MEG should be well adapted for testing children since it measures brain activity in an entirely passive manner with no radiation, strong magnetic fields, loud system noises, or long experimental set-ups.

A major challenge in the use of MEG with children is that in most modern commercial MEG systems, MEG sensors are fixed in their spatial configurations within helmet dewars optimised for adult heads. The majority of children are poorly fitted in these adult-sized helmets in a way that their heads are neither well positioned within the effective distance of sensors nor well constrained for reducing head movements. These issues have recently been addressed by the development of child/paediatric MEG systems, which are designed to accommodate smaller child heads and are thus optimized for measuring children’s brain actions (Johnson et al., 2010; Kikuchi et al., 2011; Yoshimura et al., 2013).

In the current study, we used, for the first time, a custom-sized child MEG system to determine if the face-sensitive M170 response can be measured in a four year old child. In adults, faces elicit robust neuroelectric and neuromagnetic brain responses at a latency of 130-200 ms over bilateral occipital scalp areas. This response is termed “N170” when measured with EEG and “M170” when measured with MEG. The N170/M170 is earlier in latency and larger in amplitude than responses elicited by non-face objects (Botzel et al., 1995; Bentin et al., 1996).

In a developmental context, the N170/M170 responses will be valuable as objective neural markers of face-processing capabilities, and for adjudicating between theoretical
positions of early (McKone et al., 2012) versus late (Carey and Diamond, 1977) development of these capacities. Indeed, recent ERPs studies have provided strong evidence for an early development account of face perception by showing that the face-sensitive N170 can be elicited in children as young as four years old (Taylor et al., 2001; Itier and Taylor, 2004a, 2004b; Batty and Taylor, 2006), and exhibits relatively little variation through development into adulthood (Kuefner et al., 2010).

However, the developmental situation is much less clear for the M170. Kylliainen et al. (2006) provided the first report of the face responses using MEG in children aged between 8 and 11 years, and compared them with adult responses. Adults showed a robust face-sensitive M170 response; children showed a response at the same latency but with a different topographical and functional pattern: it was less prominent, not lateralized and was similar in amplitude and latency for faces and motorbikes. In a second large MEG study, Taylor et al. (2010) reported that there was no detectable M170 in children aged 6-16 years. Taken together with the N170 studies described above, these two MEG studies indicate that the neural generators of the M170 may be distinct from those of the N170 response and seem to also follow a distinctive developmental trajectory, i.e. the N170 develops early, while the M170 develops late.

An alternative explanation is that the lack of a M170 response and its face-sensitive functional characteristics in children could actually reflect the poorer fit of MEG sensors for children when using a system optimised for adults. We evaluated this possibility by comparing brain responses to faces in a four-year-old child, measured in both a conventional adult MEG system and a custom-sized child MEG system.
2. Material and methods

This study was approved by the Macquarie University Human Participants Ethics Committee, and written consent was obtained from the adult participant and from the child’s parent.

2.1 Participants

One male child aged four years and three months, and one male adult aged 22 years participated in this study. Both of them had normal vision and no history of neurological and psychiatric disorder (self-reported by the adult participant and parent-reported for the child).

2.2 Stimuli

Experimental stimuli were the same as those used in (Kuefner et al., 2010). Four sets of 43 colored photographs of faces, cars, and their Fourier phase-scrambled counterparts (remain low-level visual cues, such as color and amplitude spectrum unaltered) were used. These stimuli were viewed passively without requiring a response. To monitor vigilance and compliance with the experimental instructions we added catch trials including 41 colored pictures of faces of “space aliens” that required a button press response.

2.3 Procedure

All stimuli were projected (InFocus Model IN5108, InFocus, Portland) onto a screen located 100 cm above the head of participants, using the software Experiment Builder (SR Research Ltd., Mississauga, Ontario, Canada) with a resolution of 1024 × 768, at a refresh rate of 100 Hz. The position of the right eye was monitored by an SR Research Eyelink 1000 eye tracking system with a sampling rate of 1000 Hz. The visual angle of all experimental stimuli in both systems was within the parafovea (adult system: 3.10° ×4.58°; child system: 2.64° × 3.90°). A photo-detector (i.e., optical-fibre feedback system) was used to measure the
delay between the physical onset of the visual stimulus and the trigger sent to the MEG acquisition computer. Measured delays were corrected in off-line analyses.

Before each trial, a fixation point (a small star) appeared at the centre of the screen for 200 ms. Each stimulus was presented only when eye fixations were in the proximity of the fixation point. After each trial, a drift correction was performed within 50 ms for a fixation point in the middle of the screen.

There were 385 trials in total, with six blocks of 86 experimental trials and 41 catch trials pseudo-randomized across the whole experiment. Each experimental trial had 500 ms duration. Catch trials were presented for 2000 ms in total regardless of the fixation point or the button press. Data from catch trials were not included in the final analyses. The total recording time was approximately 13 minutes for the child and 12 minutes for the adult.

For the child participant, child-friendly data acquisition techniques were employed to convey instructions, facilitate engagement in the experiment, and minimize movement artefacts during MEG recordings (Tesan et al., 2012).

### 2.4 MEG and EEG acquisition

Prior to MEG measurements, five head position indicators (HPI) were attached to a tightly fitting elastic cap for the child, and to an EEG electrode cap for the adult. Fiducial positions (preauricular points and nasion) and head shape were measured with a pen digitizer (Polhemus Fastrack, Colchester, VT). The position of the head inside the helmet was determined by the coregistration between the HPIs on the head and the MEG sensors inside the helmet. Head positions were recorded before and after each session, and the amount of head movement during the recording session was calculated by subtracting the pre-recording
position of each HPI from the post-recording positions with a movement tolerance of a maximum of 5 mm in any recording session.

MEG measurements were carried out with participants in a supine position in a magnetically-shielded room (MSR, Fujihara Co. Ltd., Tokyo, Japan). EEG was recorded with a BrainAmp MR plus MEG-compatible EEG system (BrainProducts Gmbh, Gilching, Germany). The EEG cap contained 64 Ag/AgCl electrodes including, 62 channels of EEG, one channel of EKG, and one channel of EOG, all referenced to Cz. MEG measurements were carried out with two KIT whole head MEG systems at Macquarie Brain Research Laboratory. The adult system (Model PQ1160R-N2, KIT, Kanazawa, Japan) consisted of 160 coaxial first-order gradiometers with a 50 mm baseline (Kado et al., 1999). The child system (Model PQ1064R-N2m, KIT, Kanazawa, Japan) had 64 first-order axial gradiometers with a 50 mm baseline. Both MEG and EEG data were acquired using a sampling rate of 1000 Hz and a filter bandpass of 0.03-200 Hz. A high-resolution anatomical MRI scan of the adult was acquired with a 3 Tesla Siemens Magnetom Verio 286 scanner at Macquarie University Hospital, Sydney, Australia.

2.5 Data Processing

2.5.1 Goodness of Fit

The fit of participant’s heads within the two MEG helmet dewars was calculated by measuring the distance between the primary (nearest) sensor of each gradiometer and the point closest to that sensor from the digitised head surface. We defined an overall goodness-of-fit index by calculating the average of the sensor to head surface distances in a given region, providing a reasonable guide of comparisons between different regions of interest, between different MEG measurements, and between different MEG systems:
GOF = \frac{\sum_{i=1}^{n}(S_i-HS)}{n},

n = number of MEG sensors; S_i = sensor position in Cartesian coordinates; HS = head surface position in Cartesian coordinates; S_i - HS = Euclidian distance (norm) between a given sensor and a given head surface point.

Regional GOF indices were also calculated for five sensor regions corresponding to Frontal, Central, Right/Left Temporal, and Occipital cortical areas.

2.5.2 ERP/ERF waveforms

Neurophysiological data were processed and analysed off-line using BESA research version 5.3.7 (BESA GMbH, Grafelfing, Germany), and MEG/EEG-MRI co-registration for the adult participant was carried out with BESA MRI 1.0 (BESA GMbH, Grafelfing, Germany).

All data were segmented into 500 ms epochs with a 100 ms pre-stimulus interval as baseline and digitally filtered with a bandpass of 1.6 to 30 Hz. MEG data with head movements of more than 5 mm during acquisition were rejected automatically during pre-processing, and other EEG and MEG artefacts, including blinks and eye-movements, were rejected on each trial and channel before averaging. Rejections were based on amplitudes (4000 fT/120 µV), gradients (2500 fT/75 µV) and low signal (64 fT/0.01 µV) criteria. For each participant and condition, at least 90% of trials survived artefact rejection. EEG data were re-referenced to the average reference (Kuefner et al., 2010).

ERPs were collected from the adult participant to facilitate comparison with the N170 literature, but were not subjected to any further source analysis.

2.5.3 Source analysis
Regional sources were fitted over the peak M170 interval with locations and orientations varied according to different conditions and individual data.

Two symmetric, bilateral regional sources, with two orthogonal tangential components inside, were randomly seeded and freely fitted in individual data. A single shell head model with an outer radius of 83.9 (child)/90.1 mm (adult) was used for MEG source analysis.

3. Results

3.1 Goodness of Fit

Table 1 shows the fit of participant’s heads in the two MEG systems. The mean sensor to head surface distance was about 35 mm for the adult in the adult MEG system, and about the same for the child in the child MEG system. The child’s fit in the adult MEG was substantially worse: on average sensors were about 20 mm more distant from the head surface. There were larger regional variations in the fit of the adult helmet dewar on the child’s head, with quite a good fit in the occipital region (due to the supine positioning), poorer fits over temporal regions (about 50 mm from the head surface) and worst fits over frontal and central regions where sensors were about 60 mm from the head surface.

3.2 Face-sensitive brain responses

Figure 1 A & B left column compare the child’s face-sensitive event-related fields (ERFs) measured in the two MEG systems. Broadly similar responses were obtained in both systems: A M100 component peaking at about 130 ms after stimulus onset; followed by a face-sensitive M170 response peaking at about 200 ms latency. The ERFs from the child MEG system are larger in amplitude and have a visibly sharper morphology than the ERFs from the same child in the adult MEG system.
Figure 1 B & D left column compare the face-sensitive ERFs between the child in the child MEG and the adult in the adult MEG. The M100 and M170 were clearly observed in both participants, with a visibly delayed M100 in the child. Similar response patterns were elicited in the child and adult across the four types of visual stimuli. Notably, the M170 showed an earlier and larger response to faces than to the nonface stimuli in both participants.

3.3 Source Localisation

Figure 1 middle column panel shows source locations obtained with the dipole modelling procedure. The regional source analysis was based on the difference ERF/ERP waveforms (the ERF/ERP elicited by intact faces minus ERF/ERP elicited by scrambled faces), which removed the M100 peak that is larger and longer lasting in the child and enhanced the M170 component (Kuefner et al., 2010).

The adult data were well-modelled with regional sources centred in bilateral fusiform gyri (Talarach coordinates x = 30.3 mm, y = +/-60.0, z = -12.6), as were the child data measured with the child MEG (20.9, +/-63.5,-13.2). The child data measured in the adult MEG were mis-localised 15 mm laterally from the fusiform gyri (24.3, +/-57.1, 0.3).

Figure 1 right column shows M170 source waveforms that appeared similar in face sensitivity in adult and child, with a delayed peak onset latency and longer duration in the child.
4. Discussion

Our aim was to determine if conventional MEG systems are suboptimal for measuring M170 responses in children, due to the relatively poor fit of the adult helmet dewar. However, our results show that an M170 response was obtained in the child in both child and adult MEG systems. The present finding of a face-sensitive M170 in a child is consistent with previous ERP studies, which reported that the N170 is present at least from four years of age (Taylor et al., 2001; Itier and Taylor, 2004a, 2004b; Batty and Taylor, 2006; Kuefner et al., 2010). However, this observation contradicts the findings from several previous MEG studies that reported no M170 in groups of children aged 6-16 (Taylor et al., 2010) and no face-sensitive M170 in children aged between 8 and 11 years (Kylliainen et al., 2006).

There are several possible reasons for these previous failures to measure a face-sensitive M170 in children. First, the M100/P100 is rather larger in amplitude and later in latency in children, and so tends to overlap with and obscure the M170/N170. In contrast, in adults these two components are well separated in time (Figure 1). The recent ERP study by Kuefner et al. (2011) showed that when the P100 is controlled for (by subtracting responses to scrambled faces from those to intact faces), the N170 is present in children as young as four years of age and is quite stable over development through to adulthood. Our results, using the identical stimuli and subtraction procedure, are consistent with the result of Kuefner et al. (2010)

Our goodness of fit measurements indicates that the position of the child during the experiment may also be a factor. In our study and that of Taylor et al. (2010), participants were tested in a supine position that is optimal for the occipital sensors where the M170 is maximal. In Kylliainen et al. (2006)’s study, participants were seated upright. The sitting position could result in larger distance between child heads and occipital MEG sensors.
One further salient difference between our methods and those of the previous MEG studies is our use of an eye-tracker to ensure eye fixation during experiments. Since the presentation of experimental stimuli was contingent upon central fixation, we can be certain that children were actually looking at all of the stimuli presented. Young children are much less capable than older children or adults in controlling eye movements, understanding experimental instructions, and maintaining attention and vigilance throughout experiments. This problem may be a significant confound in child neuroimaging studies that rely on consistent and accurate visual fixations.

While we obtained a comparable M170 response from the child in the adult system, the child MEG system was relatively superior for measuring the face-sensitive M170 response. The maximal M170 was visibly larger in amplitude (on the order of 50 fT) and the overall waveform had a clearer morphology when being measured in the child system, indicating that the even a few millimetres better fit to the occipital region of the child in the child MEG system (about 3 mm closer to the head on average) had a measureable influence on the recorded response. The better fit of the child MEG system may also have indirectly improved the morphology of the response by better restricting the amount of lateral head movements that can occur in the helmet dewar.

The finding that M170 responses can be measured from a child in an adult system is not surprising given the reason we mentioned above: the M170 response is maximal at occipital sensors, which have the best fit with respect to the occipital surface of the head in both systems because of supine positioning of participants. However aside from these sensors, it is evident that the adult MEG helmet dewar was quite a poor fit for this child’s head. Temporal sensors were about 5 cm from the head surface and frontal-central sensors were about 6 cm away.
Taken together, our results suggest that the improved signal to noise ratio of occipital responses, and the more accurate measurement of the overall topography of the child M170 at extra-occipital sites can offer a better sampling of neuromagnetic fields and contribute to better source modelling of the face-sensitive response, a result that is not surprising given evidence for an extended network under the face processing (Haxby et al., 2000).

5. Conclusions

Our results demonstrate that while the face-sensitive M170 can in principle be measured from a healthy four-year-old child using a conventional adult MEG, a custom-sized child system may be required for analyses that depend on accurate spatial sampling of neuromagnetic fields, including source localisation and functional connectivity analyses. Both our data and those of Kuefner et al. (2010) support an early maturation account of the development of face processing (McKone et al., 2012). This study demonstrates the feasibility of further investigations at the group level to clarify the neural mechanisms underpinning the development of face processing in typically developing children as well as in certain clinical groups such as autistic spectrum disorder.
Legends

**Figure 1.** Left panel: M100/P100 and M170/N170 from right temporal-occipital site where these components were maximal in amplitude; Middle and right panels: Brain images and source waveforms of M170/N170 generated from difference waveforms (ERP/ERF elicited by faces minus ERP/ERF elicited by scrambled faces) (A) child in adult MEG. (B) child in child MEG. (C) adult in adult MEG. (D) adult ERP waveform.

**Table 1.** Regional GOFs and mean overall GOFs for the adult measured in the adult MEG system and the child measured in both adult and child MEG systems.
Acknowledgements

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References


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