Using fNIRS to Study Working Memory of Infants in Rural Africa

K. Begus[1], S. Lloyd-Fox[1,2], D. Halliday[2], M. Papademetriou[2], M. K. Darboe[3], A. M. Prentice[3,4], S. E. Moore[3,5] and C. E. Elwell[2]

[1] Centre for Brain and Cognitive Development, Birkbeck, University of London, UK
[2] Department of Medical Physics and Bioengineering, University College London, UK
[3] MRC International Nutrition Group, Keneba Field Station, The Gambia
[4] MRC International Nutrition Group, London school of Hygiene and Tropical Medicine, UK
[5] MRC Human Nutrition Research, Cambridge, UK

Abstract A pilot study was conducted to assess the feasibility of using fNIRS as an alternative to behavioral assessments of cognitive development with infants in rural Africa. We report preliminary results of a study looking at working memory in 12-16-month-olds and discuss the benefits and shortcomings for the potential future use of fNIRS to investigate the effects of nutritional insults and interventions in global health studies.

1 Introduction

Inappropriate nutrition during fetal and early postnatal life can cause detrimental and persistent central nervous system alterations and deficits in behavioral functioning into childhood and adulthood [1-3]. These deficiencies are generally only detected once the affected cognitive functions reach the point of observable behavior, usually during the second year of life or later, limiting the possibility of intervention at an earlier stage. Moreover, most assessments of cognitive development that can elucidate potential deficiencies are designed and validated for use in Western civilizations. Therefore these tests are often inappropriate for use in developing countries, where the majority of the population at risk for under nutrition live, without substantial cultural adaptations and lengthy validation processes [4].

In this pilot project, we aimed to assess the feasibility of using fNIRS as an alternative to behavioral assessments of cognitive development in a resource-poor setting in rural west Africa in infants in their second year of life. fNIRS is a non-invasive optical imaging technique, measuring absorption of near infrared light, as it travels from sources to detectors, placed on the surface of the head, through the underlying brain tissue [5], mapping the functional activation in the imaged brain. In recent decades, it has been used extensively to study infant cognitive development [6], has proven to be a sensitive tool for highlighting early biomarkers of

atypical brain development and function [7] and, in a previous phase of this project, we have provided evidence that fNIRS is a viable measurement tool in a resource-poor setting with young infants [8].

One of the most reported deficits attributed to poor nutrition in infancy is suboptimal memory functioning and deficiencies in executive functions [9,10]. By using fNIRS to directly map the cortical correlates of working memory in infants, we aimed to find a measure of cognitive development that would be less amenable to culture and that could be used to shed light on potential delays resulting from poor nutrition before these become apparent in behavior. We used an *object permanence* paradigm; a task testing the ability to create and hold a mental schema of an object in mind, when it is no longer visually accessible [11], tapping into both executive functions and working memory. A similar task has previously been used in a longitudinal study of infants, directly relating the emergence of the behavioral ability to track an occluded object to the underlying brain activation as measured by fNIRS [11].

2 Method

2.1 Participants

Participants were identified from the West Kiang Demographic Surveillance System. All infants were born full term, with normal birth weight, as well as head circumferences no less than minus 3 z-scores against World Health Organisation (WHO) standards. Ethical approval was given by the joint Gambia Government - MRC Unit Ethics Committee, and written informed consent was obtained from all parents/care-givers prior to participation. Twenty-four 12-16-month-old infants participated in this study (mean age = 435.2 days, SD = 36.3). A further 15 infants participated but were excluded from the study due to an insufficient number of valid trials according to looking time measures (6 infants), technical difficulties (no video recording, 4 infants), or due to tiredness/fussiness (5 infants). This attrition rate is within the standard range for infant fNIRS studies [6].

2.2 Equipment and procedure

Infants wore custom-built fNIRS headgear consisting of an array over the right hemisphere containing a total of 12 channels (source-detector separations at 2 cm, Figure 1a), and were tested with the UCL optical topography system [12]. This system uses near-infrared light of two different wavelengths (780 nm and 850 nm)

to make spectroscopic measurements of oxy (HbO_2) and deoxyhaemoglobin (HHb).

Once the fNIRS headgear was placed on an infant's head, they sat on their parent's lap in front of a screen. The parent was instructed to refrain from interacting with the infant during the stimuli presentation unless the infant became fussy or sought their attention.

2.3 Stimuli

Infants viewed videos in which an adult male actor (resident in The Gambia) picks up an object from the table in front of him, looks directly at the infant, vocalizes while holding the object (e.g. "Oooh!"), and then places the object into a box in front of him. While the object is occluded in the box (for 3 or 6 seconds, depending on condition) the actor is still and looking at the table. After the occlusion period, the actor retrieves the object from the box and again vocalizes, while holding the object and looking at the infant (Figure 1b). Each experimental trial was preceded and followed by a baseline, which contained a display of static images of animals, infant faces and landscapes, presented for random lengths of time.

2.4 Data processing and analysis

Changes in HbO_2 and HHb chromophore concentration (μmol) were calculated and used as hemodynamic indicators of neural activity [13]. Trials, channels or participant data were rejected from further analysis based on looking time measures and the quality of the signal, using artifact detection algorithms [6,14]. Grand averaged time response curves of the hemodynamic responses (across all infants) for each channel were compiled. Either a significant increase in HbO_2 concentration, or a significant decrease in HHb (but not concurrent increase or decrease in both measures), is commonly accepted as an indicator of cortical activation in infant work [6]. A time window was selected between 4 and 10 s post-stimulus onset for each trial. T-tests (two-way) were performed for each channel to analyze the activation during stimuli compared to baseline, and paired sample channel-by-channel t-tests (two-tailed) were performed to assess differences in activation between the two conditions.

3 Results

Figure 2a shows the time courses of the hemodynamic responses during the two trial types, in which the object was either occluded for 3 or for 6 seconds. Channels with significant increase in HbO_2 (black) or significant decrease in HHb (grey) compared to baseline are marked in Figure 2b. Comparisons between the two conditions as well as the results of t-test analyses for each condition separately are reported in Table 1.

By using a standardized scalp map of fNIRS channel locators to underlying anatomy [15], and the head measurements and photographs taken in the current study we estimated the location of activation in the condition with 3 second occlusion centered over the pSTS/TPJ region, and for the 6 second occlusion across a wider region of the cortex including the pSTS/TPJ, aSTG and IFG.

4 Conclusions

We have successfully obtained high quality fNIRS data in 12-16-month-old infants in resource-poor settings of rural west Africa. Our results show differential neural activity when infants observed objects being hidden for 3 compared to 6 seconds. This cortical activation presumably reflects the infants sustaining the mental schema of the occluded objects in mind, potentially providing a sensitive measure of two of the cognitive functions that are most likely to be affected by poor nutrition - working memory and executive functioning.

Further work is currently underway to validate this measure by relating it to behavioral outcomes. We are also exploring novel ways of analyzing this data by looking at duration of sustained activation as opposed to maximum change [16], and are in the process of collecting data in an age-matched UK sample.

Establishing if this measure could be used to elucidate potential cognitive delays therefore requires much further work, however we have provided the first evidence, that working memory can be measured in infants before they are able to express it behaviorally, even in a resource-poor setting such as rural Africa.

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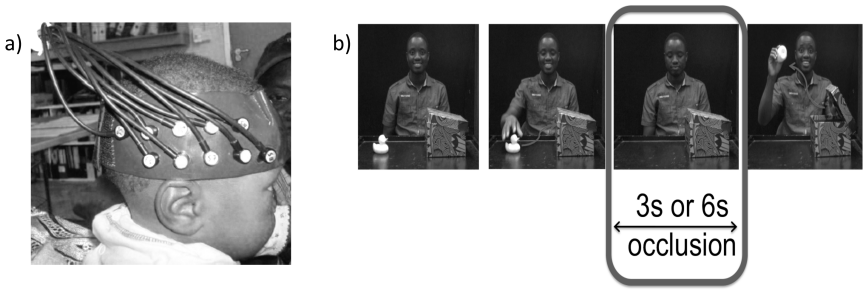

Fig 1. a) A Gambian infant wearing the custom-made headgear during the experiment. The headgear consists of an array of six sources (red) and four detectors (blue). b) A sequence of video frames taken from the stimuli videos that the infants observed.

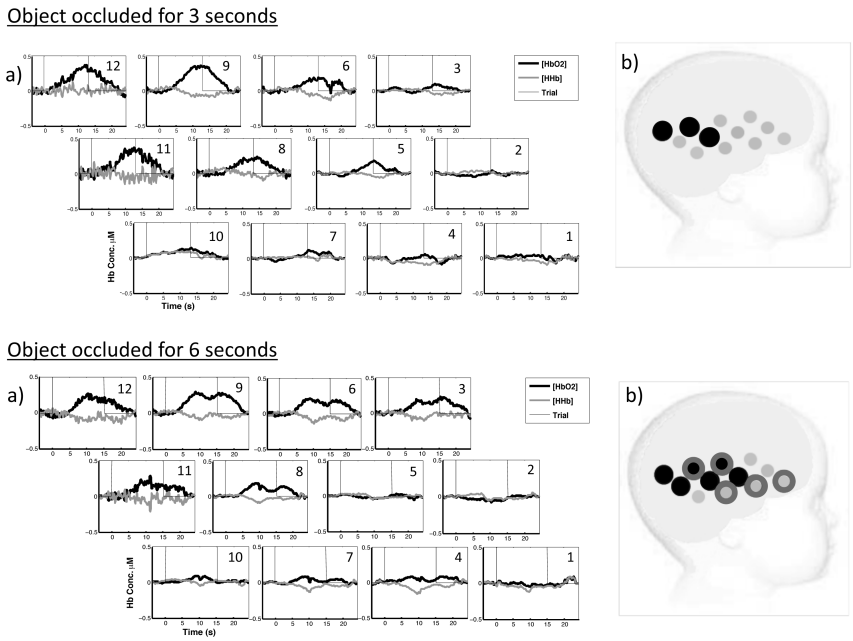

Fig 2. a) Time courses of the haemodynamic responses for each channel, separately for the two trial types (3 or 6s occlusion). b) Channels with significant increase in HbO_2 (black) or significant decrease in HHb (grey) compared to baseline, for each trial type.

Table 1. Summary of t-test analyses for each channel, reporting statistical significance of changes in HbO_2 and HHb for each condition separately and the difference between the conditions (significant changes are marked in bold).

	3 s occlusion				**6s occlusion**				**6s > 3s occlusion**			
	HbO_2		**HHb**		**HbO_2**		**HHb**		**HbO_2**		**HHb**	
Ch.	*t*	*p*	*t*	*p*	*t*	*p*	*t*	*p*	*t*	*p*	*t*	*p*
1	1.394	0.177	-0.353	0.727	0.042	0.967	**-1.942**	**0.064**	0.740	0.467	0.741	0.466
2	-1.160	0.258	1.124	0.272	-1.393	0.177	-0.160	0.874	0.238	0.814	1.164	0.256
3	0.022	0.983	0.347	0.731	-0.935	0.359	-0.527	0.604	0.638	0.530	0.736	0.469
4	-0.733	0.471	-1.551	0.135	0.486	0.632	**-3.483**	**0.002**	-1.185	0.248	1.118	0.275
5	1.014	0.321	0.317	0.754	**3.077**	**0.005**	-1.507	0.145	-1.633	0.116	1.709	0.101
6	1.427	0.167	-0.021	0.983	**3.489**	**0.001**	**-2.921**	**0.007**	-0.865	0.396	**1.763**	**0.091**
7	-0.105	0.916	0.179	0.859	0.495	0.625	**-1.919**	**0.067**	-0.609	0.548	**1.988**	**0.059**
8	**2.231**	**0.036**	1.628	0.118	**2.368**	**0.027**	-1.048	0.306	-0.166	0.870	**2.782**	**0.011**
9	**2.952**	**0.007**	-0.366	0.718	**3.447**	**0.002**	**-2.756**	**0.011**	0.255	0.801	1.233	0.231
10	1.512	0.144	2.509	0.019	0.063	0.950	-0.668	0.511	1.265	0.219	**2.455**	**0.022**
11	1.351	0.189	0.595	0.558	**1.860**	**0.076**	-0.137	0.891	0.099	0.922	1.073	0.294
12	**2.971**	**0.007**	1.172	0.253	**2.387**	**0.026**	**-1.830**	**0.080**	**1.826**	**0.081**	1.596	0.124