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Gamma power in rural Pakistani children: Links to executive function and verbal ability

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ABSTRACT

Children in low- and middle-income countries are at high risk of cognitive deficits due to environmental deprivation that compromises brain development. Despite the high prevalence of unrealized cognitive potential, very little is known about neural correlates of cognition in this population. We assessed resting EEG power and cognitive ability in 105 highly disadvantaged 48-month-old children in rural Pakistan. An increase in EEG power in gamma frequency bands (21–30 Hz and 31–45 Hz) was associated with better executive function. For girls, EEG gamma power also related to higher verbal IQ. This study identifies EEG gamma power as a neural marker of cognitive function in disadvantaged children in low- and middle-income countries. Elevated gamma power may be a particularly important protective factor for girls, who may experience greater deprivation due to gender inequality.

1. Introduction

Children in low- and middle-income countries (LMIC) experience numerous co-occurring forms of adversity that are detrimental to cognitive development, including absolute poverty, stunted growth, macro and micronutrient deficiencies, environmental toxins, and inadequate cognitive stimulation (Black et al., 2013; Walker et al., 2011). The global toll of these cumulative risks to cognitive development is staggering: More than 200 million children under age five in LMIC do not attain their cognitive potential (Grantham-McGregor et al., 2007). A third of three- and four-year-old children in LMIC fail to reach basic developmental milestones such as the ability to follow simple directions (McCoy et al., 2016). The early environment shapes brain development (Malter Cohen et al., 2013; Nelson et al., 2011). Since studies of children in high-income countries (HIC) show that early poverty-related adversity inflicts lasting damage on neurodevelopmental processes essential to higher-level cognition (Johnson et al., 2016), unrealized developmental potential in LMIC likely reflects compromised neural development. However, no study has examined neural markers of early childhood cognitive function in a LMIC population. Given that gamma power has well-established links to cognition among young children from HIC (Benasich et al., 2008), it represents a promising neural index to investigate early childhood brain-behavior associations in LMIC.

Gamma activity consists of high frequency oscillations, recorded from the scalp using electroencephalography (EEG), and is thought to underlie temporal integration of sensory input with higher-level cognitive processes (Kaiser and Lutzenberger, 2005). In adults in HIC, gamma increases during tasks that require executive function (EF; Lakatos et al., 2008) and semantic processing (Fitzgibbon et al., 2004).

Gamma activity increases as children develop, with a peak at 4–5 years of age, particularly in frontal regions (Takano and Ogawa, 1998); therefore, higher resting frontal gamma in early childhood may index neural maturity. Gamma reflects synchronization of neuronal firing, which facilitates development of efficient neural networks (Uhlhaas et al., 2010). Thus, increased gamma is also an indicator of ongoing neural processes that are likely to shape developing neural architecture in ways that promote efficient cognitive function (Gou et al., 2011).

In HIC, the gamma-cognition association is present in early childhood. Higher resting frontal and parietal gamma power in newborns

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predicted 15-month working memory and language comprehension, respectively (Brito et al., 2016). Resting frontal gamma in 16- to 36-month-olds related positively to language, cognition, and inhibitory control (Benasich et al., 2008) and predicted preschool language outcomes (Gou et al., 2011). Thus, gamma power in the frontal region appears particularly important to early childhood cognitive function.

The gamma-cognition association has not been studied among children in LMIC, whose brains are developing in the context of multiple risks. Limited access to prenatal care and to medically attended births increases perinatal complications and neonatal mortality (Katz et al., 2013). Other risks include food insecurity, infectious disease, nutritional deficiencies, inadequate water and sanitation, lack of cognitive stimulation, extreme poverty, maternal depression, exposure to violence, and limited access to education (see for review, Walker et al., 2011). Globally, as of 2011, 165 million children under age 5 showed stunting, as indexed by low height for age, and 52 million were wasting, as indexed by low weight for height (Black et al., 2013). These risks have cumulative effects on cognitive development across early childhood (Hamadani et al., 2014).

If gamma-cognition associations observed in HIC generalize to a severely disadvantaged LMIC, it would suggest a universal and context-independent role for gamma as an index of cognitive function. Because children in LMIC are at risk of cognitive deficits (Grantham-McGregor et al., 2007), it is critical to elucidate mechanisms underlying early cognitive development in LMIC.

In HIC, neural correlates of cognition often differ by gender. Preschool girls and boys had different EEG patterns during an inhibitory control task (Cuevas et al., 2016). Adolescents (Christakou et al., 2009) and adults (Bell et al., 2006) show gender differences in neural activation during EF despite equivalent performance. These gender differences partially reflect sexually dimorphic brain development due to prenatal and perinatal gonadal hormone exposures (Nugent et al., 2012).

Gender disparities in health, knowledge, and standard of living are greater in countries with low to middle human development indices (UNDP, 2014). In LMIC, being female has been associated with lower cognitive performance (Escueta et al., 2014). To the extent that girls have less access to education and receive a smaller share of scant resources, boys and girls in LMIC differ in experiences that shape brain development. Given the complex interplay of hormones and experience, neural organization and gamma-cognition associations may be gender-specific.

1.1. Current study

Our goals were (1) to determine if early childhood gamma-cognition associations extend to disadvantaged children in LMIC and (2) to examine whether gamma-cognition relations differ by gender. We were particularly interested in frontal gamma power because gamma – cognition associations reported for this age in HIC are specific to the frontal region (e.g. Gou et al., 2011) and because frontal gamma activity at this age is thought to indicate neural maturity (Benasich et al., 2008; Takano and Ogawa, 1998). We examined EEG, EF, and cognition measures collected from 48-month-old children in rural Pakistan during a follow-up assessment for the Pakistan Early Child Development Scale-Up (PEDS) Trial, a community-based, cluster-randomized controlled trial of early responsive stimulation (RS) and enhanced nutrition (EN) interventions from birth to two years (Yousafzai et al., 2014). Because the RS intervention was linked to better 48-month cognition (Yousafzai et al., 2016), we examined intervention exposure in relation to gamma. We also tested 24-month height-for-age (HAZ; an indicator of stunting); hemoglobin levels (a proxy indicator for anemia); and family wealth as possible covariates.

Participants lived in the Naushero Feroze District in Sindh Province, Pakistan, which is mainly agricultural and highly impoverished. Within Pakistan, the rural poor face disparities in health (Di Cesare et al., 2015) and education (UNICEF, 2014) compared to wealthier urban counterparts. Gender compounds these inequalities, and gender disparities are often more pronounced in rural areas. For example, in Sindh Province, only 31% of rural girls aged 10–12 years attend school, as compared to 62% of rural boys and 81% of urban boys and girls (UNICEF, 2013).

We hypothesized that higher frontal gamma in rural Pakistani children would index better EF, verbal IQ, and performance IQ. Based on gender disparities in early experience in this population, we expected gamma-cognition associations to differ by gender.

2. Methods

2.1. Participants

The final sample consisted of 105 children (52 girls) who were enrolled in the original PEDS trial from birth to 24 months, participated in the longitudinal follow-up at 48 months (M = 48.24, SD = .24), and had usable EEG. From the re-enrolled sample of 1302, we randomly selected 219 for EEG data collection, stratified by intervention group. Children selected for EEG did not differ from the rest of the re-enrolled sample on 48-month demographic variables or EF. They had slightly higher 48-month verbal IQ ($t(1238) = 2.17$, $p = .03$, mean difference = 1.62) and performance IQ ($t(1263) = 2.38$, $p = .02$, mean difference = 1.66) compared to the rest of the sample. Of these 219 children, 114 did not have sufficient EEG data (see below for inclusion criteria), resulting in a final sample of 105. Children with usable EEG did not differ from children with insufficient EEG on 48-month demographic variables or cognition.

In the final sample of 105 children, 59.0% of mothers and 22.9% of fathers were illiterate, and mothers had minimal formal education (M = 2.42 years, SD = 4.04, range 0–16). Mothers were predominantly housewives (72.4%) and fathers mainly were daily-wage laborers (41.3%) or in agriculture (21.2%). At 48 months, 28.4% of households reported food insecurity.

2.2. Procedures

A birth-cohort was enrolled in the PEDS trial from birth to 24 months (Yousafzai et al., 2014). This study uses data collected at 48 months (Yousafzai et al., 2016) by a community-based assessment team. All experimenters were extensively trained in standardized testing protocols as well as in how to build rapport with the children, create a comfortable testing environment, and introduce the EEG and apply the net in a manner that set the children at ease. Each day, three to four children and their families were transported in one vehicle to the testing center for EEG assessment. All children were tested between approximately 10:00 am and 3:00 p.m. Before each child was assessed, the assessor would check if they needed a snack, drink or rest. Once all children were assessed, the families would be transported home in the same vehicle. Assessments were administered in the local language, Sindhi.

2.3. Measures

Table 1 reports descriptive statistics.

2.3.1. Electrophysiological recording and analysis

EEG was recorded using a 64-channel high-density Geodesic sensor net (Electrical Geodesics, Inc.; Eugene, OR) and a NetAmps 300 high-input amplifier. To decrease attrition, ocular (EOG) electrodes were not used. The net was soaked in electrolyte solution (6cc KCl/liter distilled water) to facilitate electrical contact. Impedances were accepted if lower than 50 KOhm. Data were sampled at 500 Hz and referenced to the vertex (Cz). Eyes-open continuous EEG was recorded for four blocks of one minute each. A central fixation was presented on a gray