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Context matters: Cortical rhythms in infants across baseline and play

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ABSTRACT

This study uses electroencephalography (EEG) to examine infants' cortical activity during baseline while they watched a dynamic audiovisual display and while engaged in play with an object and parent. Fifty-five 6- to 12-month-old infants participated in both baseline and play with their mother. We hypothesized that the baseline task recruits relatively more exogenous attention due to the dynamic audiovisual task, while the play task recruits relatively more endogenous attention when exploring the toy. We expected higher frontal theta and alpha power during play, reflecting higher endogenous control of attention compared to the baseline task. We expected the faster rhythms, beta and gamma, to have higher power during baseline at frontal locations, reflecting the salient attention-grabbing (exogenous) attributes of the baseline task in comparison to play. We also examined changes in parietal power between contexts. Our results were consistent with the expectations. Theta (3–6 Hz) and alpha (6–9 Hz) power were higher at frontal sites (Fp1/Fp2) during play relative to baseline. Beta (9–30 Hz) and gamma (30–50 Hz) power were higher at frontal (Fp1/Fp2) and frontal medial sites (F3/F4) during baseline relative to play. Alpha power was higher during baseline at frontal medial sites (F3/F4) relative to play. Beta and gamma power was higher during play at parietal sites (P3/P4). The results are discussed in terms of the potential role of different cortical rhythms over the scalp as they respond to relative endogenous and exogenous attentional demands.

1. Introduction

A growing body of evidence has shown individual differences in infants' cognitive and social-emotional development are related to the functional organization of their brain. Many neuroimaging studies have used electroencephalography (EEG) to investigate these relations during baseline (Bell, 2001; Benasich, Gou, Choudhury, & Harris, 2008; Tierney, Vogel-Farley, Tager-Flusberg, & Nelson, 2012). Baseline EEG is recorded while infants watch a dynamic stimulus that captures and maintains their attention to keep them calm and still. Baseline EEG has long been viewed as a window into trait-like patterns of cortical activity, but new perspectives are emerging that view baseline as a task that places unique attentional, cognitive, and self-regulatory demands on children relative to other contexts (Anderson & Perone, 2018; Camacho, Quiñones-Camacho, & Perlman, 2020). In this view, the dynamic stimulus meant to keep the infant calm should engage attentional and cognitive processes that are reflected in a specific pattern of cortical activity. Prior studies with infants have shown cortical activity changes from baseline to other task contexts, such as the Piagetian A-not-B task, shedding

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light on the functional role of cortical rhythms in attentional, cognitive, or social-emotional processes (Bell, 2001; Crost, Pauls, & Wacker, 2008; Meyer, Endedijk, Ede, Van, & Hunnius, 2019; Verona, Sadeh, & Curtin, 2009). Recent evidence suggests that even subtle changes in context, such as the difference between social engagement and joint attention, can influence the distribution of cortical activity over the scalp in infants (St. John et al., 2016). The current study examined cortical activity in multiple frequency bands in infants ranging in age from 6 to 12 months using EEG under two conditions: baseline and play with their mother where object exploration was the focal point of the interaction. The goal of this study was to examine the influence of these two contexts with different attentional and processing demands on cortical activity at sites over frontal and parietal regions.

1.1. *EEG measures*

EEG provides a continuous measure of the brain's electrocortical rhythms over the scalp. Power is a commonly reported measure of synchronized firing of neural ensembles in a given frequency at electrode sites placed over the scalp. The frequencies are grouped together to create different bands to describe the activity in distinct cortical rhythms. In adults, these bands are named theta (4–8 Hz), alpha (8–12 Hz), beta (12–30 Hz) and gamma (30–50 Hz). Theta and alpha are slower in infancy than in childhood and adulthood and are commonly measured as 3–6 Hz for theta and 6–9 Hz for alpha (Marshall, Bar-Haim, & Fox, 2002; Orekhova, Stroganova, Posikera, & Elam, 2006). Beta is less clearly delineated across the lifespan but is often defined as the frequencies in between alpha and gamma (Anderson & Perone, 2018). Gamma is defined as 30–50 Hz across the lifespan. Previous research has shown EEG power over frontal regions changes during early development (Gabard-Durnam et al., 2015, 2019; Tierney et al., 2012; see Anderson & Perone, 2018 for review). Within the second half of the first year of life, EEG power in theta, alpha, beta, and gamma increases over frontal regions (Gabard-Durnam et al., 2019; Tierney et al., 2012). In the current study we compared EEG during baseline and play with a social partner to better understand contextual influences on power in these bands in an infant sample.

1.2. *Baseline EEG*

Baseline EEG is almost always recorded from infants while they watch a dynamic visual display or an actor manipulating objects (Bell & Fox, 1992; Benasich et al., 2008; Brito et al., 2020; Diaz & Bell, 2012; Marshall et al., 2002; Perone & Gartstein, 2019). Infants' brain activity during baseline was shown to be associated with their behavior in many other contexts. For example, higher baseline alpha was related to performance in the Piagetian A-Not-B task (Bell & Fox, 1992; MacNeill, Ram, Bell, Fox, & Pérez-Edgar, 2018) and predicted cognitive abilities measured during childhood (Cuevas, Hubble, & Bell, 2012; Kraybill & Bell, 2012; Kühn-Popp, Kristen, Paulus, Meinhardt, & Sodian, 2016; Wolfe & Bell, 2007). Parent report of infants' emerging attentional abilities were related to lower frontal theta and higher frontal beta and gamma (Perone & Gartstein, 2019). Several studies have also demonstrated that higher baseline gamma in infancy reflects early neurodevelopmental processes that support infants' emerging cognitive abilities. For instance, higher frontal baseline gamma at 16 and 36 months was related to better cognitive abilities concurrently (Benasich, Gou, Choudhury, & Harris, 2008) and at 4 and 5 years of age (Gou, Choudhury, & Benasich, 2011; see also Brito, Fifer, Myers, Elliott, & Noble, 2016 and Tomalski et al., 2013).

Relations between baseline EEG activity and behavior in other contexts has been observed across the lifespan, which has made it an attractive platform to study individual and age-related differences (Anderson & Perone, 2018). Baseline EEG is generally thought of in two ways. One is as the resting, or default, activity of neural networks that become engaged in specific task contexts (Damoiseaux et al., 2006; for reviews, see Anderson & Perone, 2018; Raichle & Mintun, 2006). The second view of baseline is that it reflects the engagement of specific processes that are required to complete the task, which vary over the course of development because the demands of the task change. A recent review by Camacho and colleagues (2020) cautioned researchers not to view baseline as an "equalizer" across age groups because the contexts created by the baseline task vary in meaningful ways (Camacho et al., 2020). Baseline with adults typically involves the participants sitting quietly with eyes open attending to a simple fixation cross, or with their eyes closed. This task places minimal demands on the participants, but still requires them to exert control over their attention and behavior. Unlike older children and adults, infants cannot be asked to follow instructions to complete the baseline task. Instead, baseline tasks used with infants involve presenting them with dynamic stimuli. These stimuli are used to keep the infant engaged, producing a calm and alert state.

Over the course of the first year, infants acquire more endogenous control over attention (Colombo, 2001). However, the stimulus infants are presented with also influences attention. For example, during the second half of the first year – the age range studied herein – infants attend longer to dynamic than static stimuli (Courage, Reynolds, & Richards, 2006; Reynolds & Richards, 2014). Dynamic stimuli like those commonly used during baseline may be effective at keeping infants calm and engaged because they have attention-grabbing and attention-holding properties. Cohen's (1969) seminal theory of infant attention posited that there are two attentional processes – attention capture and attention holding (Cohen, 1972b, 1972a). Dynamic stimuli may capture infants' attention because they often have transient properties which are prioritized for information processing (Horst, Oakes, & Madole, 2005; Robinson & Sloutsky, 2004; Yantis & Jonides, 1990). Once attention is captured, dynamic stimuli may also hold infants' attention because stimuli extended over time take longer to learn about (Horst et al., 2005; Robinson & Sloutsky, 2007). We construe baseline EEG with infants as a task with strong exogenous (externally driven) influences on attention. This should be associated with a specific pattern of cortical activity relative to other contexts with relatively less exogenous influences on attention (see Anderson, Perone, Campagna, & Gartstein, 2021; Orekhova, Stroganova, & Posikera, 1999). We tested this possibility by comparing infants' cortical activity during baseline to play with their mother in which object exploration was the focal point of the interaction. We construe play as a task with relatively less exogenous influences on attention, as described in the next section.

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1.3. *Play with an object*

Play with an object involves manual, visual, and oral exploration of objects which has a foundational role in learning about object properties, object perception, and motor skill development (Bushnell & Boudreau, 1993; Gibson, 1988; Needham, 2001; Needham, Barrett, & Peterman, 2002; Perone Madole, Ross-Sheehy, Carey, & Oakes, 2008; Piaget, 1952; Ruff, McCarton, Kurtzberg, & Vaughan, 1984; Soska, Adolph, & Johnson, 2010). The play task we used as a comparison to baseline enables specific predictions about changes in cortical activity by considering known differences across the two contexts, building upon the extant infant EEG literature. For infants, we construe object exploration with a social partner as an activity that involves relatively more endogenously driven control of attention than baseline. Endogenous attention is internally driven attention, and/or internal maintenance of attention to a stimulus or object (Colombo, Richman, Shaddy, Follmer Greenhoot, & Maikranz, 2001; Posner, 1980). Between 6 and 15 months, the cortical connections that enable infants to voluntarily focus their attention are developing (Colombo & Cheatham, 2006). During this same period, infants' object exploration behaviors are becoming increasingly more advanced (Rochat, 1989; Ruff, 1984).

We hypothesize that the play context involves less exogenous attentional demands relative to the baseline task, and more opportunities for endogenous attention. Play with an object often occurs with a parent or caregiver present, with adults having some influence on an infant's play behaviors. For example, infants attend to the same object more when the parent is interacting with the infant than if the infant is playing with the toy alone (Wass et al., 2018a). Parental behaviors such as pointing and manipulating toys have been shown to influence object exploration in infant play (Belsky, Goode, & Most, 1980). These behaviors may increase the infant's attention to the object by making it more exogenously salient and bias the infant's attention to the toy. These attention directing parental behaviors have been shown to have long-term impacts on cognitive development (Landry, Smith, & Swank, 2006; Tomasello & Farrar, 1986). However, a recent study showed that infants' performance on an object search task is associated with their own engagement in the task, and not the parent's involvement in the activity (Clackson et al., 2019). This pattern of results suggests that while parental involvement in play impacts infant behaviors relative to solo play, endogenously driven attention toward the objects within the environment is also at work. Further, a parent's interaction with their infant is rhythmic, intermittent, and contingent on the infant's behaviors (Beebe et al., 2016; Feldman, 2012; Stern, 1974). This dynamic opens more space for infants to guide their own attention and parents to follow in on the infant's object of focus relative to the continuous dynamic stimulus present during baseline. Thus, while there are exogenous influences on attention during play, it differs from the exogenous demands on attention during baseline, which are thought to be stronger in terms of attracting and holding attention (Courage et al., 2006). Here we examine cortical activity during a naturalistic play task to see how brain activity during play differs relative to the more exogenously oriented baseline task.

1.4. *Links between EEG activity and object exploration*

Theta and alpha power have been linked to more endogenously driven attention to objects. For example, during solo play with an object, Wass et al. (2018a) found that infants' theta power measured at a central site increased prior to, and during sustained looking at an object, which was interpreted as endogenously driven shifts in attention. Previous studies have also shown theta and alpha power increase during tasks in which infants interact with objects relative to baseline. For example, infants show an increase in theta from baseline primarily over frontal and temporal regions while engaging in toy manipulation (Orekhova, Stroganova, Posikera, & Elam, 2006) or during periods of anticipatory attention, such as during a game of peek-a-boo (Orekhova et al., 1999, see also Orekhova, Stroganova, & Posikera, 2001). Bell (2002) found that power was higher while infants perform the A-not-B task relative to baseline in 3–5 Hz, 6–9 Hz, and 10–12 Hz (see also Bell, 2001). In the current study, infants participated in a typical baseline EEG task, watching an engaging video, and play with their mother centered on object exploration. We expected frontal theta and alpha to increase during play relative to baseline.

The faster beta and gamma rhythms have been studied less than theta and alpha during infancy. Prior studies have shown frontal gamma during baseline is associated with attentional and cognitive processes (Benasich et al., 2008; Gou et al., 2011; Perone & Gartstein, 2019). Gamma activity is thought to play a role in attention and information processing (for excellent reviews see Engel, Fries, & Singer, 2001; Fell Fernández, Klaver, Elger, & Fries, 2003 and Fries, 2009) and individual differences in gamma have been linked to deficits in attention (Barry et al., 2010). There are even fewer studies addressing beta in infants and children, but existing research has shown patterns of relations similar to gamma (e.g., Perone, Palanisamy, & Carlson 2018; Perone and Gartstein, 2019). We hypothesized that stimuli used during baseline have more salient exogenous attention-grabbing properties prioritized for information processing relative to play with an object. If our hypothesis is correct, we would expect that beta and gamma power would be higher over frontal regions during baseline relative to play. Very little is known about beta and gamma while engaged in a task other than baseline during infancy (but see Smith et al., 2021). The current study will inform our growing understanding of these cortical rhythms as typically studied during baseline in early development.

1.5. *The current study*

The goal of the current study was to test the influence of baseline and play contexts on theta, alpha, beta, and gamma power. The extant literature has largely focused on activity at frontal sites, and for this reason our expectations were strongest for frontal sites. We expected the attention and information processing demands associated with the dynamic stimuli used during baseline to be associated with higher frontal beta and gamma relative to play. We expected play which offers the opportunity to engage with an object in a more endogenous fashion to be associated with higher frontal theta and alpha relative to baseline.

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Some studies have examined parietal and occipital sites in infants and children (Perone et al., 2018; Stroganova, Orekhova, & Posikera, 1999; Tarullo et al., 2017) which may reflect activity in different brain regions and networks involved in processes at work during these tasks. As the extant literature has largely focused on frontal regions, our analyses of parietal sites were largely exploratory. That is, the limited existing studies do not permit a-priori band specific predictions. However, there is evidence to suggest that parietal regions may be involved in information processing in the current study contexts. For example, parietal regions are known to be involved in both in attentional and spatial processing (Behrmann, Geng, & Shomstein, 2004; Jordan et al., 2001, 2004) and examining cortical activity at sites over parietal regions is therefore relevant to the goals of the current study. Thus, we tested the influence of baseline and play tasks on cortical activity at parietal sites to better understand the influence of these task conditions on the topography of cortical activity.

2. Method

2.1. Participants

Fifty-five infants ranging in age from 6 to 12 months ($M = 9.02$ months, $SD = 1.49$ months, 31 females) contributed EEG to both baseline and play in the current study. Mothers were recruited through local birth centers/parent-infant programs, social media advertisements, and via pamphlets distributed to community members. Participants were mostly white (81.80%) and reported a family income above $30,000 (70.90%). The mothers in this study reported an average of 15.78 years of education. Twenty-four additional infants participated in a larger study of which baseline and play tasks were a part of but were not included in analyses because EEG was not acquired ($n = 8$), fussiness ($n = 1$), computer error ($n = 8$), experimenter error ($n = 4$), or procedural differences ($n = 3$). The dropped participants included 13 females and 11 males ($m_{age} = 9.22$ mos). Mothers of dropped participants completed a mean of 16.27 years of education, and the majority (70.83%) reported a family income above $30,000. Group differences were evaluated using independent samples *t*-tests for the continuous variables, and a chi-square test for binary variables (i.e., sex). There were no significant differences ($p > .05$) in infant age, infant sex, family income, or maternal education between dropped and retained sample. Only families with infants born full-term (>37 weeks) with no significant medical complications, birth complications, or developmental delays/disabilities were recruited. Families received a t-shirt in appreciation for their participation.

2.2. Design and procedure

2.2.1. Baseline EEG

The first task infants completed was baseline. Infants were seated in a high-chair and a 32 electrode EEG cap (Cortech Solutions, Inc.; Wilmington, NC) was placed on their head. After the cap's placement, electro-conductive gel and individual electrodes were placed into each site. The EEG was recorded via the BioSemi Active Two amplifier and screened via the BioSemi acquisition software at a sampling rate of 1024 Hz. The EEG was referenced to Cz during recording. After the EEG cap was applied, the infant was shown a short clip of Baby Einstein Baby Mozart for 60 s, consistent with previous baseline EEG studies with infants in which they watch a short (e.g., 1–2 min) dynamic display to keep them calm and still while the EEG is recorded (Bell, 2002; Gartstein, 2019; Marshall, Fox, & BEIP Core Group, 2004; Perone & Gartstein, 2019; Tomalski et al., 2013). Mothers were sitting next to the infant and were instructed to limit their interaction with infants to redirecting them to the video if needed.

2.2.2. Play

Following baseline, infants were given a ring with plastic fruits to explore and mothers were instructed to play naturally with their infant. The period of play was 90 s and was completed with the infant seated in a highchair. This duration has been shown to be sufficient to capture individual differences in infant play as well as parental influences on play (Baumgartner & Oakes, 2013; Gartstein, Hancock, & Iverson, 2018; Ruff & Lawson, 1992).

2.2.3. EEG processing

The EEG data was processed in MATLAB using custom scripts relying on functions from EEGLAB (Makeig & Delorme, 2004), ERPLAB (Lopez-Calderon & Luck, 2014), and FieldTrip (Oostenveld, Fries, Maris, & Schoffelen, 2011). EEG recorded during baseline and play were processed identically. A high-pass filter at 1 Hz and notch filter at 60 Hz was applied to the continuous EEG. Excessively noisy electrodes were removed and interpolated. The EEG was then re-referenced to the average. The continuous EEG was parsed into 3 s epochs with 50% overlap. Epochs were excluded from the analysis if any electrode had absolute voltage greater than 100 μV for more than 100 ms. Time-frequency decomposition was performed on the remaining epochs using Fast Fourier Transformation (FFT) with a 3 s Hanning window from 1 to 50 Hz. A mean of 27.53 (68.82%) epochs were processed for the baseline task, and a mean of 37.56 (62.60%) epochs were processed for the parent-infant play task. Absolute power was computed in theta (3–6 Hz), alpha (6–9 Hz), beta (9–30 Hz), and gamma (30–50 Hz). Power was natural log transformed to normalize the distribution. We report absolute power, rather than relative power, because it provides information about how amplitude within a given frequency band changes between contexts at the level of the individual. Data were transformed for plotting purposes only to aid in interpretation. The transformation was computed by adding 3 to each log transformed value for each frequency band.

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2.3. Analytical approach

We analyzed power across conditions averaged across homologous frontal pole sites Fp1and Fp2, frontal medial sites F3 and F4, and parietal sites P3 and P4 for each band (See Fig. 1). These sites were chosen because power at each site has been studied extensively across contexts or in relation to social-emotional and cognitive processes in infants and young children (Bell, 2001; Brito et al., 2016; Diaz & Bell, 2012; Tarullo et al., 2017). We examined the topography of cortical activity across sites and conditions using a two-way repeated measures analysis of variance (ANOVA) with site (Fp1/Fp2 vs F3/F4 vs P3/P4) and condition (baseline vs play) as within-subject factors. This analysis was repeated for each band separately. Huynh-Feldt corrections were applied because Mauchly's test indicated that sphericity assumption was not met for each band. We then explored how age and sex might be associated with changes in EEG power.

3. Results

The pattern of results is depicted in Fig. 2 which shows power for each band at frontal pole sites Fp1/Fp2, frontal medial sites F3/F4, and parietal sites P3/P4 during baseline (dark gray bars) and play (light gray bars). The general pattern of results revealed that power was higher at frontal sites during play than baseline but lower at frontal sites during play than baseline for faster rhythms; power at parietal sites was higher during play than baseline for faster rhythms. The formal results for each band are presented below.

3.1. Theta

The ANOVA for theta revealed a significant condition x site interaction, $F(1.74, 93.75) = 19.34$, $p < .001$, $\eta^2 = 0.26$, indicating that power varied across sites as a function of condition (Fig. 2A). To understand the interaction, post-hoc analyses were conducted using paired *t*-tests to compare power across condition at each pair of homologous sites. Bonferonni's correction was applied to control for multiple comparisons such that only tests with $p < .0167$ were considered significant. Power was higher during play relative to baseline at Fp1/Fp2, $t = -3.83$, $p < .001$, $d = 0.52$. There were no condition differences at F3/F4 or P3/P4.

3.2. Alpha

The ANOVA for alpha revealed a significant condition x site interaction, $F(2, 108) = 14.95$, $p < .001$, $\eta^2 = 0.28$ (Fig. 2B). Post-hoc analyses comparing power across condition at each pair of homologous sites with Bonferonni's correction applied showed that power was higher during play relative to baseline at Fp1/Fp2, $t = -2.47$, $p = .0166$ and power was higher at baseline than play at F3/F4, $t = 2.78$, $p = .007$, $d = 0.38$. There were no effects at P3/P4.

3.3. Beta

The ANOVA for beta revealed a significant condition x site interaction $F(1.64, 88.84) = 40.46$, $p < .001$, $\eta^2 = 0.43$ (Fig. 2C). Post-hoc analyses comparing power across condition at each pair of homologous sites with Bonferonni's correction applied showed that power was higher during baseline than play at Fp1/Fp2, $t = 6.83$, $p < .001$, $d = 0.92$ and F3/F4, beta, $t = 5.94$, $p < .001$, $d = 0.80$. Power was higher during play than baseline at P3/P4, $t = -3.64$, $p < .001$, $d = 0.49$.

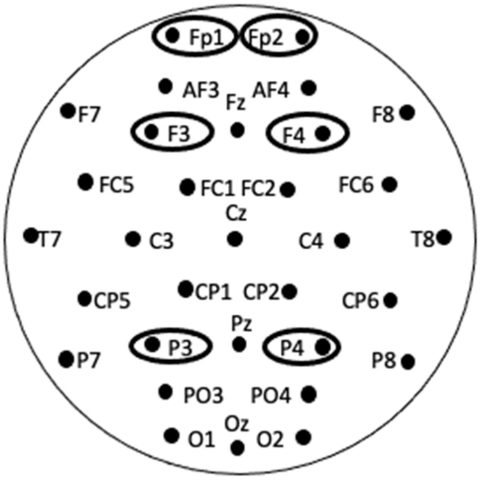

Fig. 1. Shows the 32-Electrode Cap with electrodes labeled. The 4 frontal electrodes, and 2 parietal electrodes used in analyses are circled. Averages of homologous right and left electrodes were used to compare power at baseline to power play.

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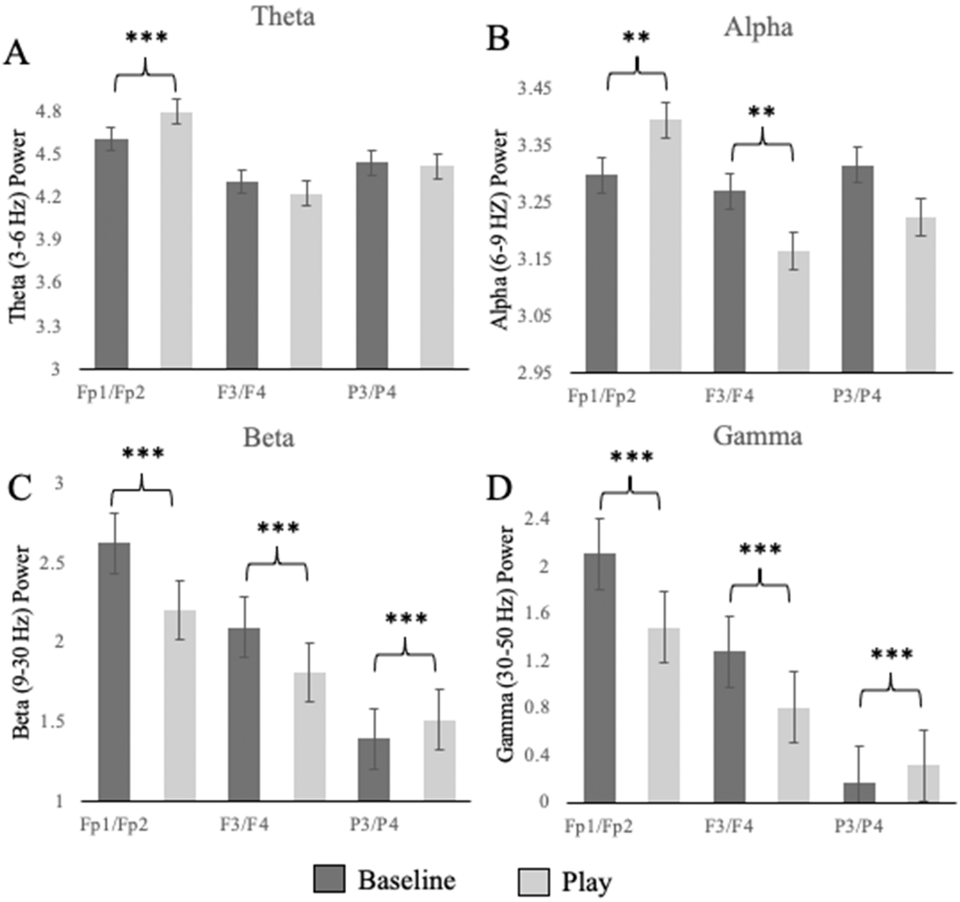

Fig. 2. Shows changes in power over Fp1/Fp2, F3/F4, and P3/P4 for baseline and play. 2 A shows changes in power in theta. 2B shows changes in power in alpha. 2 C shows changes in power in beta. 2D shows changes in power in gamma. Data were transformed by adding 3 to all log transformed power values for each site for data visualization purposes. * **p $< .001$; * *$p < .01$.

3.4. Gamma

The ANOVA for gamma revealed significant condition x site interaction, $F(1.71, 92.12) = 54.16, p < .001, \eta^2 = 0.50$ (Fig. 2D). Post-hoc analyses comparing power across condition at each pair of homologous sites with Bonferonni's correction applied showed that power was higher during play than baseline at Fp1/Fp2, $t = 7.56$, $p < .001$, $d = 0.62$ and F3/F4, $t = 7.04$, $p < .001$, $d = 0.50$. At P3/P4, power was higher during play than baseline, $t = -3.92$, $p < .001$, $d = 0.27$.

3.5. Age effects, sex effects and EEG

The goal of the current study was to test contextual influences on patterns of EEG activity during infancy. Change in EEG power across contexts relate to age during infancy (Bell, 2001, 2002) and sex differences have been observed in EEG power across contexts with different attentional demands (Cuevas, Calkins, & Bell, 2016). To explore relations between age and sex with change in EEG power across contexts, we computed change in power from baseline to play at each pair of homologous sites and then correlated change with age in months and again with sex. Age was inversely related to change in theta at F3/F4, $r = -0.44$, $p = .001$ and P3/P4, $r = -0.32$, $p = .02$. This indicates that power from baseline to play changed more for younger infants than older infants. No other correlations between change in power and age were found (all $ps > 0.05$). No correlations between infant sex and change in EEG power were observed ($p > .05$).

4. General discussion

This study examined shifts in infants' cortical activity in multiple rhythms from baseline to play. We hypothesized that baseline and play may engage endogenous and exogenous attention to differing degrees which is then reflected in differences in power across bands. For infants, baseline EEG is recorded while they watch a dynamic audio and visual display, which are known to have attention-

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grabbing and holding properties prioritized for information processing by infants (Courage et al., 2006; Horst et al., 2005; Robinson & Sloutsky, 2004). Gamma power has been linked to attentional and cognitive processes in previous literature (Benasich et al., 2008; Gou et al., 2011; Perone & Gartstein, 2019). We therefore expected higher beta and gamma power during baseline relative to play, which we hypothesized reflects the higher relative exogenous attentional demands of the task. Play, involving manual, visual and oral exploration of objects, is associated with differences in cortical activity and perceptual and motor development (Needham, 2001; Perone et al., 2008; Soska et al., 2010; Wass et al., 2018a). Theta and alpha power modulation has been observed in periods of anticipatory attention and during toy manipulation (Orekhova et al., 2006; Wass et al., 2018b). Because play so often involves exploration, which we hypothesized requires more endogenous attention relative to baseline, we expected to see higher frontal theta and alpha during play, reflecting this object manipulation and exploration. Our results were generally consistent with our expectations at the most anterior sites. We observed higher frontal theta and alpha and lower frontal beta and gamma relative to baseline. We also examined change in power at parietal sites and found that parietal beta and gamma increased during play relative to baseline at parietal sites.

The increase in theta power at Fp1/Fp2 during play relative to baseline may reflect active learning about an object. Higher levels of theta power have been observed during visual exploration (Wass et al., 2018b) and increases in theta relative to baseline have been observed in prior studies involving attention to and manipulation of objects (Orekhova et al., 2006). Theta has also been proposed to play a central role in learning (Braithwaite, Jones, Johnson, & Holmboe, 2020) and theta modulation is predictive of performance on components of intelligence tests (Jones et al., 2020 see also, Begus & Bonawitz, 2020). Given that object exploration has a foundational role in learning about object properties and perceptual development (Bushnell & Boudreau, 1993; Needham, 2001; Ross-Sheehy, Perone, Macek, & Eschman, 2017), it is possible higher levels of theta during play relative to baseline reflect the active learning process. Also consistent with the extant literature was our observation that alpha at Fp1/Fp2 was higher during play relative to baseline. Previous literature has found similar results showing that higher levels of frontal alpha reflect ongoing cognitive processes in the A-not-B task (Bell, 2001, 2002). Other observations differed from the extant literature. For instance, alpha decreased from baseline to play at frontal medial (F3/F4) sites. Previous studies have shown increases in alpha power during the A-not-B task at frontal sites, relative to baseline, were linked to better performance in the task (Bell, 2001). These cross-study differences might be due to differences in task demands. For example, A-not-B is a more structured task than naturalistic play and is designed to place spatial memory and motor demands on infants.

Higher levels of gamma power have been linked to engagement of attention networks in adults (Gruber, Müller, Keil, & Elbert, 1999; Müller et al., 2000) as well as cognitive and language abilities in toddlerhood and early childhood (Benasich et al., 2008; Gou et al., 2011; Tarullo et al., 2017). Most studies using infant EEG have focused on examining relations between beta and gamma during baseline and tasks or measures completed separately. By studying these rhythms in tasks with known properties and demands, we can gain insight into the role of these rhythms in the processes at work. We found higher gamma power at frontal sites Fp1/Fp2 during baseline, a task which has properties known to capture and hold infants' attention in an exogenous fashion (Courage et al., 2006; Horst et al., 2005; Reynolds, Zhang, & Guy, 2013). Previous literature has outlined different neural substrates recruited for endogenous relative to exogenous attention in adults. While both exogenous and endogenous attention engage the frontoparietal network (Corbetta & Shulman, 2002; Coull, Frith, Bu, & Nobre, 2000), endogenous attention appears to recruit more activity frontal regions, while exogenous attention recruits more activity in parietal regions (Buschman & Miller, 2007; Meyer, Du, Parks, & Hopfinger, 2018). The higher parietal gamma power during play relative to baseline might reflect differences in neural networks involved in control of attention across these two tasks. The two tasks may place different demands on spatial attention, for instance, leading to differences in where over the scalp more gamma power is observed. More research explicitly manipulating task demands is needed to understand the specific aspects of a task that elicit higher levels of gamma over frontal or parietal regions.

Given that the gamma literature has been built on baseline activity as it relates to cognitive measures (e.g., preschool language assessments, Bayley Scales of Infant Development), the present findings enhance our understanding of the baseline task by giving us a sense of what different levels of gamma might reflect. One question our findings raise is if we would observe similar relations between gamma and cognitive tasks if gamma was measured during play (or a standard cognitive task) instead of baseline. Future research should address this question to add to our understanding of the processes at work during baseline EEG. Very little work has been done on beta power in infant EEG research. Our beta findings very much resembled our gamma results. Many studies have focused on frontal gamma, yet parietal gamma has been associated with executive control in childhood (Tarullo et al., 2017). Our findings raise the possibility that individual differences in parietal gamma reflect the endogenous attentional processes at work to a higher degree during object exploration in infancy. This possibility is supported by literature in adults showing that parietal gamma power is associated with endogenous attention shifts, but not exogenous attention (Landau, Esterman, Robertson, Bentin, & Prinzmetal, 2007), and that stimulation of parietal regions using transcranial magnetic stimulation (TMS) enhances performance in endogenous, but not exogenous attention tasks (Hopfinger, Parsons, & Fröhlich, 2017).

The nature of our play task differs from previous efforts to understand the function of cortical rhythms by examining their levels across contexts. Prior studies have used more rigidly controlled contexts, such as in the A-not-B (Bell, 2001, 2002), or examined cortical activity time-locked to specific behaviors (Jones, Venema, Lowy, Earl, & Webb, 2015; Orekhova et al., 2006; Wass et al., 2018a). Previous studies have also found associations between baseline EEG and parent-infant interactions (Perone, Gartstein, & Anderson, 2020; Swingler, Perry, Calkins, & Bell, 2014), which often take place with objects as a focal point. By examining EEG *during* this type of play, we can better understand what types of processes might be occurring in the brain. Naturalistic contextual manipulations, such as object play considered in this study, have the advantage of greater ecological validity, because these exchanges occur in infants' daily routine. Object exploration often takes place in this type of social setting, especially with a parent as a social partner. This type of parent-infant interaction is common in research studies as well as interventions because it is known to influence social and

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cognitive development (Bagner et al., 2016; Landry, Smith, Swank, & Guttentag, 2006, 2008). Therefore, it is important to understand infants' brain activity within this environment to better understand how this context is influencing brain development. One limitation of this study is that we do not have a comparison of infant play without the parent present. Previous research has shown that infants engage in greater endogenous object exploration without a parent present (Wass et al., 2018b). A task in which the infant plays on their own would shed light on the influence the parent has in the infant's brain activity during play.

The weakness of these more naturalistic observations includes limits on measuring fast-acting attentional and cognitive processes or the influence of a parent's intervention on an infant's brain activity. Specifically, there are few repetitions of trials (e.g., parenting pointing to an object) to average, and we may not observe the same behavior from parents across trials or between participants. Further, there may be other confounding factors that are driving the effects seen in this study. For example, the play task used in this study is inherently a social activity which has been shown to have an influence on cortical activity (St. John et al., 2016). As parent-infant play is often construed as a positively valanced emotional context (Landry et al., 2006; Stern, 1974), the current study's findings might also be confounded by differences in emotional processes at work in the different contexts. The current study sets the stage for examination of a more structured play task which could help identify additional brain-behavior relations within this parent-infant play context. For example, linking infants' cortical activity to specific endogenously (e.g., voluntary exploration of a toy) or exogenously driven (e.g., looks based on a parent's redirection; see Wass et al., 2018b for example) behaviors during play would allow us to further test the hypotheses guiding the current study (see Smith et al., 2021 for discussion).

An important direction for future research will be to test the assumptions upon which our expectations for the results of this study were based. We observed a shift in the distribution of power across rhythms and sites as a function of condition. Power in slower rhythms were higher at frontal sites during baseline than play, whereas power was higher at parietal sites for faster rhythms during play than baseline. We attribute these observations to the relatively higher degree to which the baseline task recruits attention in exogenous fashion by providing a continuous audio-visual dynamic display relative to play, a context in which attention is assumed to be relatively more endogenously driven by providing less frequent exogenous stimulation and more opportunity to explore independently. If these assumptions are true, we should observe the same pattern across different task conditions specifically designed to vary in the degree to which they place exogenous relative to endogenous attentional demands on infants.

The current study offers an initial investigation into the contextual influences on infants' cortical activity. The study findings should be interpreted with limitations on our task selection and sample in mind. The contexts tested in this study were limited to two different contexts with timing and task demands dictated by the larger study from which the data were drawn. While tasks ranging from 1 to 2 min are typical for infant EEG studies, longer recording times provide the opportunity to explore fluctuations in brain activity as it relates to changing task demands, behavior, or social interactions evolving over time. Another limitation is the relatively small sample size that limits our ability to detect small effects, for example age effects. Our sample of 6–12-month-olds is broad based on the age-related changes in attention and brain development that occur during that time. Preliminary age-related analyses indicated that age was associated with change in theta at F3/F4 and P3/P4 such that younger infants exhibited a greater change in power between baseline and play. The age effect appears to be driven by increasing baseline theta power with age at F3/F4 and P3/P4. This finding is consistent with prior studies during this same period of development (Cuevas & Bell, 2011; Orekhova et al., 1999) and may indicate more neuronal resources are being recruited with age while processing information contained in typical dynamic audio-visual baseline tasks. A larger sample is required to tease apart any small but potentially informative age x condition effects, or potential sex effects. Additionally, there was limited diversity of our sample of participants both in racial identity as well as mother's educational level. Future studies should seek to replicate these findings with a larger and more diverse sample to ensure that the results are generalizable.

In conclusion, we examined change in cortical activity from baseline to play which are two tasks that place different demands on infants. This work builds on the vast infant baseline literature which largely relies on identifying associations between cortical activity with behavior in other contexts (e.g., cognitive tasks, parent-report). Investigation of contextual influences on activity in multiple rhythms enabled us to identify the emergence of unique topographical patterns of activity across tasks with different demands. Some of our observations were consistent with our expectations, including increases in frontal theta and alpha from baseline to play. Other patterns were novel. For example, we found decreases in parietal beta and gamma between baseline and play. Our study underscores the importance of investigating cortical activity in multiple rhythms over the scalp across contexts, including those typical of daily life, to build our knowledgebase of the function of cortical rhythms during infancy. The current study sets the stage for further inquiry into brain-behavior relations in the context of engagement with a social partner using play paradigms that balance the structure of laboratory tasks with natural contexts typical of daily life.

CRediT authorship contribution statement

Alana J. Anderson: Conceptualization, Methodology, Software, Formal analysis, Investigation, Project administration, Writing – original draft, Writing – review & editing. **Sammy Perone:** Conceptualization, Methodology, Software, Formal analysis, Investigation, Resources, Project administration, Writing – original draft, Writing – review & editing. **Maria A. Gartstein:** Conceptualization, Methodology, Investigation, Resources, Project administration, Resources, Supervision, Writing – review & editing.

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