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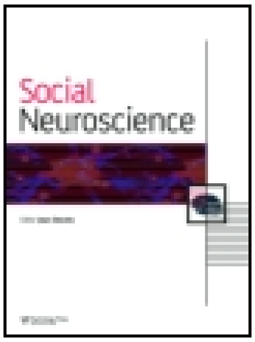

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Joint engagement modulates object discrimination in toddlers: a pilot electrophysiological investigation

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ABSTRACT
Joint engagement (JE) is a state in which two people attend to a common target. By supporting an infant's attention to the target, JE promotes encoding of information. This process has not been studied in toddlers despite the fact that language and social interaction develop rapidly in this period. We asked whether JE modulates object discrimination in typically developing toddlers. In a pilot evaluation of a novel, naturalistic paradigm, toddlers (n = 11) were introduced to toys by an examiner with or without JE. Toddlers then viewed images of the toys while high-density electroencephalography (EEG) was recorded. Analysis focused on the differential neural response to objects presented in the two conditions. EEG components of interest included frontal positive component (Pb), negative component (Nc), and positive slow wave. Toddlers discriminated between conditions with a larger Pb peak amplitude to stimuli presented with JE and a larger Nc mean amplitude to the stimuli presented without JE, reflecting greater familiarity with the toys presented socially. Our findings suggest that JE supports object learning in toddlers, and supports the potential utility of this novel paradigm in both the assessment and the potential to detect impairment in social learning among toddlers.

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Introduction

Joint engagement (JE), or the sharing of attention to a common target with a social partner, facilitates learning about one's environment and the achievement of referential communication (Bakeman & Adamson, 1984). However, the immediate effects of JE on information processing and learning are difficult to measure. The current study applied electrophysiological (EEG) methods to quantify attentional resources allocated toward information that is presented with JE relative to information presented without it. EEG offers a temporally precise measurement of cortical responses to information. Such methodology is particularly useful to quantify subtle cognitive functions such as attention or memory that precede or inform overt behavior (Bedford et al., 2012; Elsabbagh et al., 2012).

EEG studies of JE have manipulated gaze direction on images of faces toward (JE) and away from (non-JE) a target object (e.g., Reid, Striano, Kaufman, & Johnson, 2004). A more naturalistic test of JE involves a live examiner pointing to an object on a video monitor. In "high-magnitude" JE conditions, the examiner also comments about the target and/or adds an overlay of positive affect (Kopp & Lindenberger, 2011, 2012; Parise, Cleveland, Costabile, & Striano, 2007).

Several event-related potential (ERP) components have been robustly associated with object processing. For instance, 4-month olds' increased positive slow wave (PSW) amplitude to objects presented without JE (Hoehl, Wahl, Michel, & Striano, 2012; Reid et al., 2004) indicates less familiarity in the absence of social emphasis. In contrast, 5-month olds demonstrated a more negative component (Nc), suggesting greater attentional resources to objects presented with JE than without it (Parise et al., 2007). JE magnitude modulated object encoding according to positive component (Pb) and PSW amplitude differences by condition (Kopp & Lindenberger, 2011, 2012). Frequency of glances to the examiner, implying coordinated social engagement, was correlated with the PSW amplitude to learned objects.

While object processing in the context of JE has been well documented in infants, this domain has not been examined in toddlers. Given that language and social skills grow especially rapidly in toddlerhood (e.g.,

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Supplemental data for this article can be accessed here.

Goldfield & Reznick, 1990), we developed a novel, naturalistic paradigm in order to address unanswered questions regarding object processing in toddlers. Studying JE in a naturalistic interaction allowed us to capture individual differences in toddlers' social behavior and to determine whether they were associated with EEG markers of learning. We hypothesized that JE effects on object processing could be detected by enhanced frontal Pb, Nc, and PSW relative to objects presented without JE, suggesting that objects presented without JE will require more processing effort due to reduced salience during exposure. Furthermore, we expected that frequency of toddlers' glances to the examiner's eyes during exposure to objects would be associated with ERP responses.

Methods

Participants

Typically developing toddlers were recruited by means of public birth records. Letters of invitation were mailed. Interested parents were screened by telephone. Exclusion criteria included history of neurological, developmental, or psychiatric abnormalities, uncorrected vision, and family history of autism spectrum disorder (ASD). Seventeen children were initially recruited to the study.

Procedure

The JE Paradigm consisted of an exposure phase and an EEG test phase.

Exposure phase

The examiner and the participant sat at a table in a quiet testing room. One examiner administered both exposure phases to all participants. The exposure phase lasted 4 minutes. Four pairs of toys were matched based on type, function, size, and design. One set (half) of the toys was presented with JE and the other set without JE. The sequence of presentation was standardized across participants, but the order of the conditions (*JE/non-JE)* was counterbalanced. Each toy was presented for 30 sec (see Supplemental Figure 1).

In the *JE* condition, the examiner (1) attempted to engage the child in play with the toy; (2) directed attention to the toys using gestures; (3) promoted eye contact and JE with the child and toy; (4) promoted dyadic play; and (5) displayed positive affect. The examiner minimized her vocalizations; she did not ask questions or label toys, but used consistent prepositions and action words. In the *non-JE* condition, the examiner (1) did not initiate interaction with the child and toy; (2) did not use gestures; and (3) maintained a neutral facial expression.

Behavioral coding

The exposure phase was coded from video recordings by independent coders blind to study hypotheses. Development of a JE paradigm using live examiner–child interaction permitted us to code toddlers' glances to the examiner's eyes during the exposure phase. Glances to eyes were considered a proxy for social initiations and tested for relations with neural measures of attention and object discrimination. Coding also evaluated experimenter fidelity using a 5-point Likert scale to assess examiner's level of social engagement with the child during the two exposure conditions. Inter-rater reliability for 25% of cases using Cronbach's alpha confirmed high levels of agreement (glances at examiner's eyes: $\alpha = 0.93$; examiner social engagement—social condition: $\alpha = 0.79$; nonsocial condition: $\alpha = 0.94$). See Appendix for further details on behavioral coding.

EEG test phase

The EEG portion of the study followed the behavioral exposure phase, with no more than 15 minutes between phases. EEG was recorded while the child was seated approximately 65 cm in front of the monitor in a sound-attenuated dark room. Stimuli were presented on a 24-inch monitor with 1080 pixel resolution. Children viewed a continuous stream of photographs of the same toys presented during the exposure phase. One hundred twenty trials were presented, with each toy presented 15 times in a random order for 1000 msec. Interstimulus interval jitter was 500–750 msec. Trials in which participants were not watching the screen, marked in vivo and during review of the assessment video, were excluded from analysis.

Data provided by six participants were excluded from analyses. One child refused to wear the EEG cap; three were rejected during automatic artifact detection; two more were excluded based on manual artifact detection (eye blinks, saccades, electromyographic artifacts, and excessive movement). Eleven children (69%) provided analyzable EEG data (see Table 1 for participant characteristics).

Based on prior studies, the Pb, PSW, and Nc were targeted as components of interest. Visual inspection of the data provided no evidence of a PSW. Similar to Kopp and Lindenberger (2011), who also used a naturalistic JE paradigm, we observed a robust early frontal negativity, which we refer to as the N1. The N1 was interpreted as a marker of early visual discrimination of categories of stimuli (Kopp & Lindenberger, 2011). Our analysis focused on peak amplitude and latency of components (N1, Pb, and Nc) as well as mean amplitude for the Nc in keeping with previous studies (Hoehl, Reid, Mooney, & Striano, 2008; Kopp & Lindenberger, 2011, 2012; Striano, Reid, & Hoehl, 2006). Regions of interest were generated with clusters of electrodes in right, central, and left frontal regions (see Supplemental Figure 2) based on visual inspection of data and prior studies (Hoehl et al., 2012, 2012; Kopp & Lindenberger, 2011; Striano et al., 2006). Time windows for the components were based on prior studies and visual inspection of the data: N1 (150–300 msec), Pb (300–450 msec), and Nc (450–800 msec). Additional methodological details are presented in supplemental online materials.

Results

Fidelity: The rating of the examiner's social engagement was greater in the JE (m = 4.95) than in the non-JE condition (m = 1.02; $t(1,10) = 111.67$; $p < .0001$), indicating adherence to the paradigm.

EEG data

N1

There was no main effect of condition or region and no condition-by-region interaction on N1 peak amplitude or N1 latency ($p \geq .35$).

Pb

There was no effect of condition or region on Pb peak amplitude ($p \geq .22$). There was a significant condition-by-region interaction ($F(2,20) = 4.33$; $p = .02$), with a more positive Pb peak amplitude in left electrodes toward stimuli presented with JE (m = 1.05) than without JE (m = −1.89; $t(10) = -2.64$; $p = .02$). No effects on latency were observed ($p \geq .46$).

Nc

No effects of condition or region were observed on Nc peak amplitude or latency ($p \geq .43$). There was no effect of condition on Nc mean amplitude ($p = .48$). There was a marginal region effect ($F(2,20) = 3.25$; $p = .06$) and a significant interaction between condition and region ($F(2,20) = 4.30$; $p = .02$). We observed more negative Nc mean amplitude toward stimuli presented without JE in central electrodes than in left frontal electrodes (left: −14.79; central: −16.47; right: −14.77; $t(10) = -2.40$; $p = .03$). Nc mean amplitude was more negative toward stimuli presented without JE in central than in right electrodes ($t(10) = 2.70$; $p = .02$; see Figure 1 and Supplemental Figure 3).

Age and behavior effects

Toddlers made more glances toward the examiner's eyes in the non-JE than the JE condition ($F(1,10) = 3.78$; $p = .07$), possibly indicating efforts to elicit social engagement.

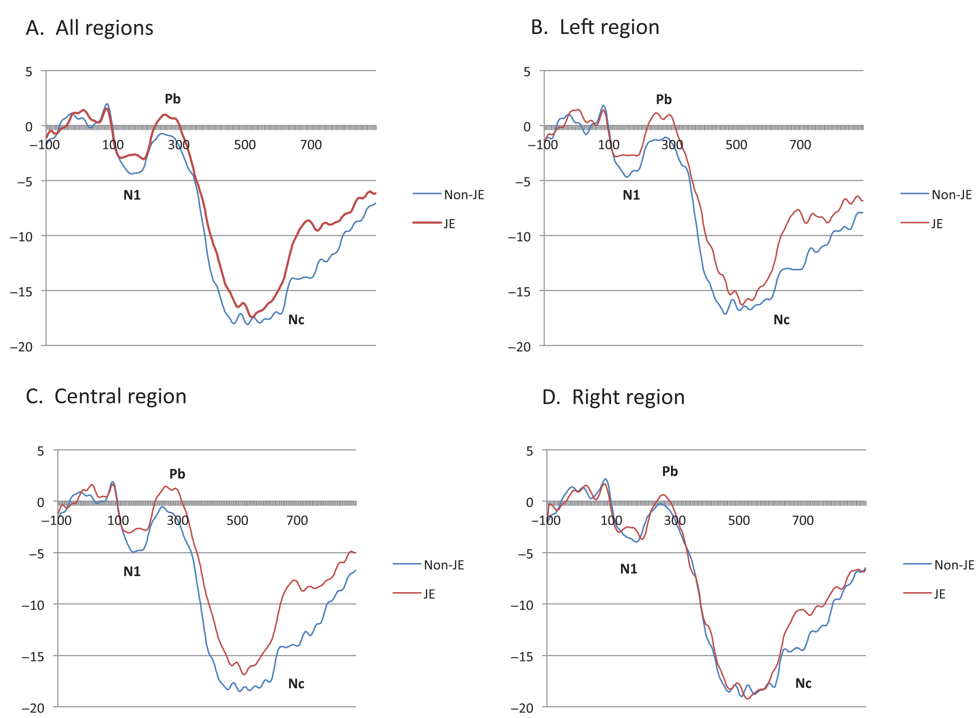

Figure 1. Electrophysiological response to toys introduced with and without JE by region.

Table 1. Participant characteristics.

	Mean	SD
Chronological age (months)	19.7	4.6
Male:female	4:7	-
IQ	117.9	18.5
Nonverbal IQ	117.6	12.7
Verbal IQ	111.2	17.9

Analyses linking behavior with ERP measures should be considered exploratory. Frequency of child gaze to the examiner's eyes was not related to either ERP component in either condition ($p > .1$). Child's age was not related to either ERP component in either condition ($p > .09$).

Discussion

This is the first study of the effects of JE on object discrimination in toddlers using a novel, naturalistic EEG paradigm. The findings reported here suggest that JE facilitates object discrimination in typically developing toddlers. Toddlers demonstrated a larger Pb peak amplitude to the stimuli presented with JE and a larger Nc mean amplitude to the stimuli presented without JE, both suggesting that toddlers were more familiar with objects presented *with* social cues. Toddlers glanced more frequently at the examiner's eyes in the non-JE condition than in the JE condition, indicating sensitivity to the social context and a tendency to elicit social interaction when it waned. These findings are consistent with research involving infants, and we did not find evidence that the effects of JE on object processing decline during toddlerhood. We did not observe relations between children's efforts to engage the examiner and neural markers of object discrimination, suggesting that learning may be dissociated from a child's overt behavior during social interaction.

The Pb component in memory paradigms reflects stimulus expectancy, or certainty about the occurrence of an event, usually in the context of previously learned information (Karrer & Monti, 1995; Karrer, Wojtascek, & Davis, 1995; Webb, Long, & Nelson, 2005). Our observation of a larger Pb response to objects presented with JE suggests that toddlers were more familiar with those toys. Infant studies report larger Nc amplitudes to unfamiliar stimuli. For instance, infants demonstrated a larger Nc amplitude to new objects compared to old objects regardless of exposure type (Kopp & Lindenberger, 2011, 2012). Elsewhere, infants showed a larger Nc to objects presented without social emphasis (averted gaze; Hoehl et al., 2008). In the current study, the larger Nc to objects presented without JE suggests that the toddlers were more familiar with the toys presented with JE, as they allocated more neural resources to attend to the objects that were less well learned. The results suggest that JE enhances attentiveness and promotes learning.

Larger Pb amplitude in the left frontal region in response to toys presented in the JE condition likely reflects the role of the left frontal cortex in processing socially relevant information. Relatedly, left frontal EEG coherence (measured in the theta band) has been associated with joint attention skills during infancy (Caplan et al., 1993; Mundy, Card, & Fox, 2000). Lateralization of effects reported in ERP studies has been inconsistent (Kopp & Lindenberger, 2011; Striano et al., 2006; Wahl, Michel, Pauen, & Hoehl, 2013). Longitudinal research may determine that lateralization increases in the second year as frontal cortical networks become specialized, in this case for processing and encoding of socially salient information.

The hypothesis that toddlers' efforts to engage the examiner would be related to ERP measures of attentiveness was not supported. This null result merits further investigation with a larger sample because analogous effects have been observed in infants (Kopp & Lindenberger, 2012) and the strength of the correlation observed here was in the moderate range ($r = -0.5$). If further research confirms that the relation is nonsignificant, it would indicate that neural processing is independent of toddlers' eliciting behaviors and it would highlight the importance of exploring neural markers of learning. If the correlation between gazes to face and mean Nc clears the threshold of statistical significance, it would suggest that social interest moderates object learning at the neural level. Either result emphasizes the importance of evaluating the effects of child behavior on learning. Our future work will evaluate duration of attention to toys and to the examiner as well as toddler vocalizations. The modest sample size in this pilot investigation increases the likelihood of type I and type II errors. Still, few studies have explored the effects of JE on object processing during toddler development (Hirotani, Stets, Striano, & Friederici, 2009; Theuring, Gredebäck, & Hauf, 2007) and little is known about the association between toddler behavior and social learning.

This study supports the use of an interactive JE paradigm to evaluate risk for social learning impairments during the time frame when behavioral markers of atypical development are both subtle and emergent. Quantifying the cognitive effects of JE may support identification of children likely to benefit from interventions targeting social learning and social communication and may provide a useful predictor of treatment effects.

Disclosure statement

No potential conflict of interest was reported by the authors.

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Appendix

Micro- and global-coding descriptions
Micro-coded variables

Time Looking at Toy: Time the subject spends looking at the toy in each presentation.

Time Playing with Toy: Time the subject spends interacting with the toy in each presentation.

Time Looking at Examiner: Time the subject spends looking at the examiner during each toy presentation.

Number of Glances to Examiner: Number of glances the subject makes to the examiner during each toy presentation. This is a frequency count of the glances to the examiner's eyes regardless of the length of time.

Global Likert Scale—Child

Likert scale for subject's social engagement with the examiner during toy play. This is scored as a combination of eye contact, turn-taking, and active social engagement with the examiner. Affect can also be considered, but higher ratings can be scored in the absence of positive affect.

(1) Does not acknowledge the examiner, focuses on toy or surroundings only; any vocalizations are clearly not directed at examiner.

(2) Occasionally watches examiner or "checks in," but most of the time is focused only on toy or surroundings; any vocalizations are clearly not directed at examiner.
(3) Acknowledges examiner by looking up more than once and/or following movements; interacts with examiner less than half of the time or interaction is of low quality; any vocalizations are directed ambiguously. In the nonsocial condition, the subject may glance to the examiner on more than one occasion but plays with the toy independently. The subject may also attempt to engage the examiner in play once, but continues playing independently when this is not reciprocated.
(4) Frequently acknowledges examiner by looking up and/or following movements, may take turns with toy or imitate once or twice; interaction (including any vocalizations directed at examiner) is not always of high quality. In the nonsocial condition, the subject frequently tries to engage the examiner in play but does play independently with the toy when attempts are not reciprocated. The subject may attempt to make eye contact/jointly attend to toys with the examiner for a prolonged period in anticipation of dyadic play.
(5) Actively interacts with or seeks engagement with examiner; may look up several times, follow the examiner's movements, take turns with toy, and/or imitate; any vocalizations are clearly directed at examiner. In the nonsocial condition, the subject will actively seek engagement with the examiner through vocalization, eye contact, and/or toy play.

Global Likert Scale—Examiner

Likert scale describing the degree of social engagement exhibited by the examiner toward the subject during each toy trial. Social engagement is defined as a combination of attempts to engage the subject in play (either through turn-taking or demonstration), attempts to facilitate eye contact, and positive affect.

(1) Watches the subject play or looks down during the entire trial. Maintains neutral facial expression and does not use gestures (such as pointing).
(2) Occasionally attempts to engage with the subject. For example, may acknowledge some of the child's attempts to initiate. Maintains neutral facial expression throughout most of the trial.
(3) Regularly attempts to engage with the subject. For example, examiner may not use overt gestures or affect may be subdued relative to a four or five rating. Examiner may not actively seek engagement with the subject consistently throughout the trial.
(4) Attempts to engage with the subject most of the time. For example, there may be a few seconds where the examiner's affect is more neutral or they are focused elsewhere (such as checking the stopwatch or changing toys).
(5) Prompts subject to engage during the entire trial. Examiner displays positive affect throughout. Regularly uses prompts to initiate turn-taking and demonstrates the toy to the subject.