Developmental Cognitive Neuroscience 30 (2018) 178–190

Contents lists available at ScienceDirect

Developmental Cognitive Neuroscience

journal homepage: www.elsevier.com/locate/dcn

Anterior and posterior erp rhyming effects in 3- to 5-year-old children[☆]

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ARTICLE INFO

Keywords:
Rhyming effect
Event-related potentials
Phonological awareness
Preschoolers
Nonword processing

ABSTRACT

During early literacy skills development, rhyming is an important indicator of the phonological precursors required for reading. To determine if neural signatures of rhyming are apparent in early childhood, we recorded event-related potentials (ERPs) from 3- to 5-year-old, preliterate children (N = 62) in an auditory prime-target nonword rhyming paradigm (e.g., *bly-gry*, *blane-vox*). Overall, nonrhyming targets elicited a larger negativity (N450) than rhyming targets over posterior regions. In contrast, rhyming targets elicited a larger negativity than nonrhyming targets over fronto-lateral sites. The amplitude of the two rhyming effects was correlated, such that a larger posterior effect occurred with a smaller anterior effect. To determine whether these neural signatures of rhyming related to phonological awareness, we divided the children into two groups based on phonological awareness scores while controlling for age and socioeconomic status. The posterior rhyming effect was stronger and more widely distributed in the group with better phonological awareness, whereas differences between groups for the anterior effect were small and not significant. This pattern of results suggests that the rhyme processes indexed by the anterior effect are developmental precursors to those indexed by the posterior effect. Overall, these findings demonstrate early establishment of distributed neurocognitive networks for rhyme processing.

1. Introduction

The term ‘phonological awareness’ encompasses skills involved in recognizing and manipulating the sounds of language, from basic rhyme recognition to complex phoneme deletion (e.g., Adams, 1990). Behavioral studies have shown that early phonological awareness skills like rhyming ability develop during the pre-school years (e.g., Wood and Terrell, 1998). However, few studies have explored pre-school development of rhyming abilities from a neurocognitive perspective. Event-related potentials (ERPs) provide an on-line index of real-time neural processing, and allow for measurement of rhyme processing without the potential confounds of a behavioral response. To our knowledge, the present study is the first ERP investigation of rhyming in preschoolers.

1.1. Rhyming and reading: behavioral measures

The development of phonological awareness is typically divided into three stages: syllable awareness, onset-rime awareness, and phonemic awareness (Cisero and Royer, 1995). The awareness of rhyme, as tested by asking children to produce or judge rhyming syllables, typically first appears around 3 or 4 years of age (Hayes et al., 2000; Hayes et al., 2009; Wood and Terrell, 1998). Recent studies have reported a relationship between speech decoding skills and rhyming skill in preliterate 4-year olds (Janssen et al., 2016; van Goch et al., 2014), and rhyming ability predicts later word understanding and word production (Tsao et al., 2004). Remarkably, rhyming ability is also directly predictive of reading ability (e.g., Bradley and Bryant, 1983). This causal link may be because rhyming words often share spelling patterns (e.g., *beak* and *peak*) that children who are able to rhyme can take advantage of (Goswami, 1988, 1994; Wood and Farrington-Flint, 2001). There is also an indirect link in that rhyming ability is strongly related to the

☆ Financial support for data collection was provided by the National Institutes of Health [NIDC RO1 DC000481]; for the preparation of this manuscript was given by the Knut & Alice Wallenberg Foundation [grant KAW 2010.0178 ‘Culture, brain, learning’].
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https://doi.org/10.1016/j.dcn.2018.02.011
Received 18 June 2017; Received in revised form 16 February 2018; Accepted 27 February 2018
Available online 06 March 2018

development of phoneme-level awareness, which in turn is critical for decoding grapheme-phoneme associations (Bryant et al., 1990). Overall, through these links, behavioral studies have indicated that the ability of preliterate children to detect rhyme is one of the best predictors of initial reading development (Ellis and Large, 1987; Gathercole et al., 1991; Maclean et al., 1987; Wood and Terrell, 1998).

1.2. Rhyming: electrophysiological measures

ERPs index neural processing as it unfolds millisecond by millisecond, and can therefore index rhyme processing not captured by behavioral tasks − tasks that young children might be unwilling or unable to perform. Yet few studies have capitalized on the sensitivity of ERPs to investigate the neural basis of early rhyming abilities, particularly within the preschool age range when rhyming skills are beginning to develop.

In one of the first developmental ERP studies of rhyming, Coch et al. compared auditory rhyme processing in adults, adolescents, and children as young as age 7 (Coch et al., 2002). Both reaction times (RTs) for rhyme judgments (via button press) and ERPs were recorded to word pairs presented as primes and nonrhyming or rhyming targets. RTs were significantly longer in children than adults. In contrast, there were no differences in a posterior ERP rhyming effect between groups: in each age group, the negativity peaking around 450 ms was larger (more negative) for nonrhyming compared to rhyming targets, particularly over occipitoparietal regions. Given the similarities in the electrophysiological index of rhyme processing across groups, the longer RTs observed in children may have been due to immature motor skills or slower overt judgments, rather than slower processing of phonological information. Regardless, this study did not address the development of neural rhyme processing before first grade.

This classic posterior ERP rhyming effect – a larger N450 for nonrhyming than rhyming targets – has been replicated across a number of studies with auditory and visual stimuli, in adults (e.g., Coch et al., 2008a; Coch et al., 2008b; Davids et al., 2011) and children as young as age 6 (Ackerman et al., 1994; Coch et al., 2002; Coch et al., 2005; Coch et al., 2011; Grossi et al., 2001; Lovrich et al., 1996, 2003; Perre et al., 2009; Wagensveld et al., 2012a; Weber-Fox et al., 2003; Weber-Fox et al., 2008). Moreover, some studies with children, using both auditory nonword (Coch et al., 2005) and printed letter (Coch et al., 2008a) stimuli, have reported relationships between the posterior rhyming effect and behavioral measures of phonological awareness.

In addition, a subset of these studies has reported a polarity reversal of the posterior effect within the same time window over frontal regions (e.g., Coch et al., 2002; Coch et al., 2005; Grossi et al., 2001). The amplitude of this anterior effect (rhyming targets elicit a larger negativity than nonrhyming targets) was not correlated with the amplitude of the posterior rhyming effect (e.g., Coch et al., 2002), suggesting that the two ERP effects index unrelated aspects of rhyme processing (see Khateb et al., 2007; Mohan and Weber, 2015, for a similar account).

Studies with children as young as age 6 have identified ERP rhyming effects using real word (e.g., Coch et al., 2002), nonword (e.g., Coch et al., 2005), and single letter (e.g., Coch et al., 2008a) stimuli. Importantly, the use of nonwords as stimuli avoids confounding phonological awareness with vocabulary size, since nonwords are not lexical items and thus are equally unfamiliar to all participants (Wagensveld et al., 2012b). Using nonword stimuli, in comparison to words, results in longer RTs in rhyme judgment tasks and smaller, later ERP rhyming effects, presumably because nonwords are more difficult to process (Dumay et al., 2001; Praamstra and Stegeman, 1993; Rugg, 1984; Wagensveld et al., 2012c).

Whereas these studies have investigated phonological processing in young children and adults in terms of rhyming (at the onset-rime level), other developmental ERP studies have explored phonological processing at the phonemic level in terms of the phonological mismatch negativity (MMN) (e.g., Lovio et al., 2009; Pihko et al., 2008). As with the ERP rhyming effect, the MMN effect is reduced for pseudowords, as compared to words (e.g., Pulvermüller et al., 2001; Pulvermüller et al., 2004). However, the MMN is greatest under conditions of rare deviance within a stream of common standards, and most rhyming studies have been designed with equal frequency of a rhyming or nonrhyming stimulus pair; therefore, it is unlikely that MMN effects intermingle with ERP rhyming effects in standardly designed rhyming studies.

1.3. The present study

The reliable ERP rhyming effects observed in primary-school children raise the possibility that electrophysiological measures might provide an index of rhyme processing in even younger children. Here, we modified the nonword rhyming paradigm employed by Coch et al. (2005) for use with preschoolers: children watched an animated movie rather than a crosshair and an explicit judgment was requested on only 18% of the trials. This resulted in a short and interesting paradigm that maintained the engagement of 3- to 5-year-olds. We predicted both posterior and anterior ERP rhyming effects in preschoolers who could demonstrate the ability to rhyme behaviorally. Further, we expected significant correlations between the size of the posterior ERP rhyming effect and scores on standardized measures of phonological awareness (cf. Coch et al., 2005; Coch et al., 2008a).

2. Materials and methods

2.1. Participants

Children in the current study were part of a larger study involving 117 3- to 5-year-olds recruited from Head Start schools (early childhood education centers for low income children). The study was conducted in accordance with the Declaration of Helsinki. Parents gave informed consent (approved by the Institutional Review Board of the University of Oregon) prior to the child's participation. The overall study included multiple ERP paradigms composing a recording session lasting about one hour. From this larger group, children were excluded according to our screening criteria: insufficient ERP data in the rhyming paradigm (fewer than 10 trials/condition, $n = 15$), language impairment (i.e., lower than 17th percentile on the receptive language test while still within one standard deviation of the mean on the nonverbal IQ measure, $n = 3$), low language proficiency (i.e., lower than 25th percentile on the receptive language test, $n = 15$), handedness (left-handed, $n = 1$), missing behavioral data ($n = 5$), and not possible to match into the two phonological awareness groups ($n = 16$). Thus, the final sample of participants was composed of 62 3- to 5-year-old children (see Table 1). All participants who contributed data to analyses were native English speakers, were right-handed according to parental report on a questionnaire (Oldfield, 1971), had normal or corrected-to-normal vision and normal hearing, were screened for childhood behavioral and

Table 1
Group demographics.

	3- to 5-year-olds	LPA	HPA
N (Females)	62 (38)	31 (21)	31 (17)
Age (SD)	4;8 (0;6)	4;8 (0;6)	4;8 (0;5)
Range	3;7 – 5;5	3;8 – 5;4	3;7 – 5;5
SES[a] (SD)	4.5 (0.9)	4.5 (0.8)	4.5 (1.0)
Range	2–7	2–5	2–7

Note. Age shown in years; months. LPA = Lower Phonological Awareness; HPA = Higher Phonological Awareness.

[a] The seven-point socioeconomic scale (SES) taken from (Hollingshead, 1975) included (1) less than 7 years of education, (2) between 7 and 9 years of education, (3) 10–11 years of education (part of high school), (4) high school graduate, (5) 1–3 years at college (also business school), (6) four-year college graduate (BA, BS, BM), and (7) a professional degree (e.g., MA, MS, ME, MD, PhD).