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Abstract

Several studies report that adults and adolescents with reading disabilities also experience difficulties with selective attention. In the present study, event-related brain potentials (ERPs) were used to examine the neural mechanisms of selective attention in kindergarten children at risk for reading disabilities (AR group, $n = 8$) or on track in early literacy skills (OT group, $n = 6$) across the first semester of kindergarten. The AR group also received supplemental instruction with the Early Reading Intervention (ERI). Following ERI, the AR group demonstrated improved skills on standardized early literacy measures such that there were no significant differences between the AR and OT groups at posttest or winter follow-up. Analysis of the ERP data revealed that at the start of kindergarten, the AR group displayed reduced effects of attention on sensorineural processing compared to the OT group. Following intervention, this difference between groups disappeared, with the AR group only showing improvements in the effect of attention on sensorineural processing. These data indicate that the neural mechanisms of selective attention are atypical in kindergarten children at risk for reading failure but can be improved by effective reading interventions.

Keywords

literacy, neurobiological, brain imaging

The fields of cognitive neuroscience and special education share a common interest in understanding the profile, origin, and remediation of learning disabilities. In the case of dyslexia, or specific reading disability, both fields consider the ways in which multiple factors work in concert to create the complex surface profile of labored, dysfluent reading (Shaywitz, Lyon, & Shaywitz, 2006). Within special education, this approach is illustrated by intervention efforts that address multiple component reading processes and that consider how individual student, teacher, and instructional characteristics interact to impact learning (Al Otaiba & Fuchs, 2006; Foorman & Torgesen, 2001; Simmons et al., 2007). Within cognitive neuroscience, this approach is illustrated by models of interactive specialization, in which dedicated neural circuitry, such as that used for efficient word reading, is established through the interaction of multiple domain-general systems including visual perception, object recognition, phonological processing, and selective attention (Karmiloff-Smith, 1998; McCandliss, Cohen, &

Dehaene, 2003). Deficits in any of these individual systems, or the ways in which these systems interact, could give rise to atypical reading circuits in the brain. Here, we present findings from a study that investigates the neural systems important for selective attention in a group of kindergarten children who are either on track or at risk in their early reading development. In addition, we studied the effects of an early reading intervention on early literacy skills and the neural systems important for selective attention in at-risk readers.

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Attention and Reading Disability

Impairments in selective attention, or the ability to focus on relevant information while ignoring distractors, have been repeatedly demonstrated in adolescents and adults with poor reading skills (Asbjørnsen & Bryden, 1998; Atkinson, 1991; Cherry, 1981; Klein & D'Entremont, 1999; Sperling, Lu, Manis, & Seidenberg, 2005; Ziegler, Pech-Georgel, George, Alario, & Lorenzi, 2005). However, the attention deficit does not occur only during reading- or language-related tasks. Instead, the selective attention deficit is both pan-sensory and domain-general as it is observed in linguistic and nonlinguistic contexts and in both the visual and auditory modalities. The implications of these findings for children with challenges in directing attention to relevant stimuli (e.g., to individual words and letters) within the context of a typical classroom of 20 to 30 students highlight a primary challenge for education in the 21st century.

Although deficits in aspects of attention have been documented in poor readers, it is unclear whether or how such a deficit is causally related to poor reading skills. One challenge is that most previous studies have examined older adolescents and adults, making it difficult to assess whether the attention difficulties contributed to or were a consequence of reading failure. However, there is some evidence that attention skills might be related to students' response to intervention (Al Otaiba & Fuchs, 2006). For example, one study reported that prior attention skills, as measured by parent or teacher report, are a stronger predictor of children's response to intervention than initial levels of phonological awareness, naming, or memory skills (Torgesen et al., 1999). Another study found that adolescents with dyslexia made greater gains from a writing intervention if it was preceded by an intervention focused on improving attention as opposed to reading fluency, suggesting a direct causal role between attention skills and response to intervention (Chenault, Thomson, Abbott, & Berninger, 2006). Furthermore, related research suggests that some effective language or reading interventions might work in part by training selective attention (Gillam, 1999; Gillam, Crofford, Gale, & Hoffman, 2001; Gillam, Loeb, & Friel-Patti, 2001; Hari & Renvall, 2001; Sundberg & Lacerda, 2003). For example, when intervention programs require children to focus on auditory or visual input for sustained periods, children's attention skills are also being engaged. Such practice using attention skills may enable children to benefit from the immediate intervention and/or also translate into domain-general improvements in attention that leverage skills across a range of tasks.

While attention deficits are unlikely to account for all reading difficulties, the aforementioned studies demonstrate the need for examining the role of attention in reading disability from a multidisciplinary perspective. Typical

intervention approaches focus on modifying instructional content and delivery variables and evaluating the efficacy of the intervention using behavioral measures of reading outcomes. However, these measures represent the final outcome of multiple stages of processing (e.g., sensory processing, memory, response selection), leaving the locus and underlying mechanisms of selective attention deficits unclear. The discipline and approaches of cognitive neuroscience focus on identifying the underlying brain circuitry and related mechanisms important in attention and learning. As such, a collaborative effort between cognitive neuroscience and education provides an opportunity to explore these issues.

Measuring Attention

Cognitive psychologists have long emphasized the role of attention in learning and the changes that take place within attention as children mature. For example, studies in developmental psychology indicate that both the abilities to selectively attend to relevant stimuli and to successfully ignore irrelevant stimuli improve progressively with increasing age across childhood (Doyle, 1973; Lane & Pearson, 1982; Zukier & Hagen, 1978). The ability to shift attention quickly and effectively also develops across childhood at least until adolescence (Hiscock & Kinsbourne, 1980; Pearson & Lane, 1991). Furthermore, there is some evidence that background noise creates greater interference for young children as compared to adolescents or adults (Cherry, 1981; Elliot, 1979). Investigators have noted in behavioral studies of children that it is difficult to separate attention from other cognitive processes (e.g., decision making, response selection), and therefore it is also difficult to identify where in the information processing stream developmental change occurs (Gomes, Molholm, Christodoulou, Ritter, & Cowan, 2000). Employing neurocognitive measures in conjunction with behavioral measures can help to clarify what sorts of attentional skills are developing as children mature.

Event-related brain potentials (ERPs) have been a useful methodology for studying the stages of processing affected by selective attention. ERPs are the measured change in electrical activity of the human brain in response to specific events, for example, the presentation of a sound or image. Using electrodes placed on the surface of the scalp, ERPs can be recorded completely noninvasively, making the technique well suited for studying infants and young children. ERPs are created by averaging the response to systematic presentations of stimuli in contrasting conditions, for example, comparing the time course of voltage fluctuations during the visual presentation of real words versus pseudowords. The difference in the amplitude or time course of neural activity across conditions in the measure of interest and can be monitored with millisecond precision.

ERPs have been very useful in identifying the effects of selective attention on neural processing in adults. In a classic experimental paradigm, competing streams of stimuli are presented (e.g., two different streams of auditory stimuli delivered to different ears), with participants alternating attention to one stream at a time in order to detect rare target events. By comparing neural activity to the same physical stimuli when attended versus ignored, the effects of selective attention can be ascertained. These studies reveal that in adults, selective attention amplifies neural activity in the first 100 ms after stimulus presentation by 50% to 100% (Hillyard, Hink, Schwent, & Picton, 1973; Woldorff & Hillyard, 1991). This ERP attention effect is associated with improved behavioral performance on selective attention tasks (Neville & Lawson, 1987; Roder et al., 1999; Squires, Hillyard, & Lindsay, 1973; Teder-Salejarvi & Hillyard, 1998; Teder-Salejarvi, Pierce, Courchesne, & Hillyard, 2005). Moreover, in between-group and change-over-time comparisons, ERPs can separately index processes of signal enhancement (ERP amplitude gains for attended stimuli) and distracter suppression (amplitude reductions for unattended stimuli). Thus, the ERP technique is useful for characterizing the time course and mechanisms (signal enhancement vs. distracter suppression) of selective attention.

In a review of both behavioral and ERP studies of the development of selective attention, Ridderinkhof and van der Stelt (2000) proposed that the abilities to select among competing stimuli and to preferentially process more relevant information are essentially available in very young children, but that the speed and efficiency of these behaviors and the systems contributing to these abilities improve as children develop. To examine the mechanisms of attention in young children, we have recently conducted studies using similar ERP paradigms with children as young as 3 years of age (Coch, Sanders, & Neville, 2005; Sanders, Stevens, Coch, & Neville, 2006). In these studies, children direct their attention to one of two children's stories presented in naturally spoken speech from separate speakers. The children are told to listen to just one story. Following each story, children are asked comprehension questions about the attended story in order to reinforce the goal of attending to a single story and ensure children are focusing on the task. ERPs are recorded to probe stimuli (e.g., *ba* and *buzz* sounds) superimposed on the attended and ignored story. Children show a broad positive deflection in response to probe stimuli approximately 100 ms after stimuli are presented, and the broad positivity is amplified (i.e., more positive) with attention in children as young as 3 years of age (Sanders et al., 2006). This finding indicates that the basic mechanisms of selective attention are available to very young children when sufficient cues—including content coming from distinct locations, in different voices, and reinforced with corresponding visual images—are available to direct their attention.

Plasticity of Selective Attention

The basic developmental research reviewed previously provides a baseline against which attention skills in special or at-risk populations can be compared. Specifically, we can ask whether the effects of attention on neural processing are impaired in special and at-risk populations and, if so, whether particular mechanisms are impaired and the extent to which any observed deficits could be remediated by intervention. A general principle guiding this research is that different neural systems show different profiles, or degrees, of neuroplasticity (Neville, 2006). Furthermore, the most plastic neural systems might show the potential both for vulnerability to deficit in some conditions and capability of enhancement under other conditions (e.g., see Stevens & Neville, 2006). We have observed these “two sides of plasticity,” namely, vulnerability to deficit and capability of enhancement, in research employing ERP paradigms to assess selective attention.

In studies of children at risk for school failure, we have observed atypical effects of attention on neural processing. For example, children age 6 to 8 years with specific language impairment (SLI) do not show evidence of early attentional modulation of neural processing (Stevens, Sanders, & Neville, 2006). For children with SLI, the deficit is specific to reduced amplification of the neural response to probes in the attended channel (i.e., signal enhancement) rather than difficulties in suppression of responses to probe stimuli in the ignored channel (i.e., distracter suppression). Interestingly, the attention deficits are seen even though the children with SLI are performing the task as directed as indicated by performance on comprehension questions about the attended story. Likewise, research in our laboratory (Stevens, Lauinger, & Neville, 2009) and others (D'Angiulli, Herdman, Stapells, & Hertzman, 2008) indicates that children at risk for school failure, namely, from lower socioeconomic backgrounds, also show reduced or absent attentional modulation of early neural processing. However, in contrast to children with SLI, children from lower socioeconomic backgrounds experience a deficit that is specific to greater difficulty suppressing neural activity to ignored information. Thus, both children with SLI and children from lower socioeconomic backgrounds, who are also at risk for school failure (Baydar, Brooks-Gunn, & Furstenberg, 1993; Liaw & Brooks-Gunn, 1994; Walker, Greenwood, Hart, & Carta, 1994), show atypical effects of attention on neural processing. One interpretation of these results is that many children at risk for school failure experience difficulty directing their attention and are unable to discriminate between relevant and irrelevant information, which could have profound implications for reading and academic development.

Although the neural mechanisms of selective attention are vulnerable in children at risk for academic failure, they are also capable of enhancement. For example, studies of adults

born deaf or blind indicate that the effects of attention on the remaining modality are enhanced relative to their hearing or sighted peers (Neville & Lawson, 1987; Roder et al., 1999). More recently, the effects of training on neural measures of attention have been examined (Rueda, Rothbart, McCandliss, Saccomanno, & Posner, 2005; Stevens, Fanning, Coch, Sanders, & Neville, 2008). In one recent study, enhancements in the effects of selective attention on neural processing were observed following 6 weeks of daily training with a computerized training program for children with language impairments (Stevens et al., 2008). These enhancements were observed in both children with SLI and typically developing children who received the program. Similar changes were not observed in a group of typically developing children tested and retested after a comparable period. The changes in the neural mechanisms of selective attention were accompanied by large improvements in standardized measures of receptive language in both groups of children. These results suggest that attention deficits in children with language disabilities can be traced to the earliest stages of processing influenced by selective attention, and also that effective training programs can habilitate these neural systems. In this case, the computer program's focus on encouraging children to attend for sustained periods of time to small details in acoustic input likely contributed to engaging and developing children's attention skills. However, to date no research has examined the integrity of the neural systems important to selective attention in children with reading difficulties or whether other types of intervention programs also influence the neural mechanisms of selective attention.

Overview of Present Study

The study reported here uses event-related brain potentials to examine the neural systems important for selective attention in 5-year-old children across the first semester of kindergarten. Two groups of children, either on track for reading (OT) or at risk for reading difficulties (AR), were studied. Children at risk for reading difficulties received supplemental reading instruction using an extended version of the Early Reading Intervention (ERI; Kame'enui & Simmons, 2003). The goal of the study was to examine differences in neural systems important for attention across groups and how those differences changed from the beginning to the middle of kindergarten. In addition, changes in early reading skills were monitored in both the AR and OT group through the winter of kindergarten with standardized early reading measures.

Method

Participants

In the fall of kindergarten, school personnel screened all children at three elementary schools using the *Dynamic*

Indicators of Basic Early Literacy Skills (DIBELS; Good & Kaminiski, 2003). Based on their scores on the *Letter Naming Fluency* (LNF) and *Initial Sound Fluency* (ISF) subtests, children were separated into two groups. Children scoring below the 35th percentile on either subtest were identified as at risk for reading difficulties (AR group) and received supplemental reading instruction using the Early Reading Intervention, described in detail in the following. This cutoff was based on two findings. First, students performing in this range on these measures are considered at risk for long-term reading difficulties (Good, Simmons, & Kame'enui, 2001; Kaminiski, Cummings, Powell-Smith, & Good, 2008). Second, the school district in which the study was conducted had years of experience using these measures to identify students needing additional support and used this criterion for identifying which students would receive additional support. Children scoring above the 35th percentile on both subtests did not receive additional services. Those scoring between the 50th and 75th percentile were identified as on track (OT group).

Children in the AR and OT group were invited to participate in the ERP study if they fulfilled the following criteria: (a) monolingual, native English speaker; (b) right-handed; (c) absence of attention-deficit/hyperactivity disorder (ADHD) diagnosis; (d) not taking psychoactive medications; and (e) no known neurological disorders.

In total, usable ERP data at both pre- and posttest sessions were available from 14 children, 6 in the OT group and 8 in the AR group. Two children completed pretest but failed to return for posttest (one child in each group). Data from an additional five children were discarded for poor data quality at either pre- or posttest (two in the OT group and three in the AR group). This rate of exclusion based on data quality (5 sessions out of 38 total sessions at pre or post, or 13%) is consistent with our previous larger scale studies of typically developing children in this age range (Sanders et al., 2006). The mean age of participants was 5.6 years ($SD = .25$ years). As shown in Table 1, there were no statistically detectable differences between the two groups in age, gender, socioeconomic status (Hollingshead, 1975), level of maternal education, or Stanford-Binet non-verbal fluid reasoning score (all $p > .05$).

Intervention

Children in the AR group received 45 min of time, 5 days per week, for 8 weeks in a small group outside the regular school day, with 30 min devoted to the Early Reading Intervention (Kame'enui & Simmons, 2003). ERI is a 30-min, highly scripted, and explicit intervention designed to be implemented in groups of five or fewer children. The content focus of ERI is to develop early reading skills in phonemic awareness, alphabetic understanding, letter writing, word reading, spelling, and sentence reading.

Table 1. Demographic Characteristics for the On-Track (OT) and At-Risk (AR) Groups

Characteristic	OT	AR
Gender	2 M: 4 F	1 M: 7 F
Age in years (<i>SD</i>)	5.7 (0.2)	5.5 (0.2)
^a Socioeconomic status (<i>SD</i>)	37.4 (6.2)	34.4 (12.2)
^b Maternal education (<i>SD</i>)	4.7 (0.5)	4.6 (0.7)
^c Nonverbal IQ, standardized score (<i>SD</i>)	12.8 (3.0)	10.5 (4.0)

^aFamilial socioeconomic status (SES) measured using the Hollingshead Index of Social Status (Hollingshead, 1975). Scores on the index represent one of five social strata corresponding to upper (55-66), upper-middle (40-54), middle (30-39), lower-middle (20-29), or lower (8-19) class.

^bLevel of maternal education measured using categories from the Hollingshead Index of Social Status (Hollingshead, 1975). Values range from 1 (*less than seventh grade*) to 7 (*graduate professional training*). A score of 4 indicates high school graduation, and a score of 5 represents partial college.

^cNonverbal IQ estimated using the nonverbal fluid reasoning scale from the Stanford-Binet test. One child in the OT group did not have complete data for calculating socioeconomic status.

The first 15 minutes of ERI develops and reinforces the phonologic skills of (a) first and last sound isolation, (b) sound blending, and (c) sound segmentation. Then these skills are integrated by teaching the alphabetic skills of (a) letter-name/sound identification, (b) blending to read consonant-vowel-consonant (CVC) words, (c) irregular word reading, and (d) sentence reading. The second 15 minutes reinforces previously taught phonological awareness and alphabetic skills and extends these skills through instruction in handwriting (e.g., letter dictation and formation), integrated phonologic and alphabetic tasks, and spelling. The efficacy of ERI has been previously demonstrated with kindergartners at risk for reading difficulties (Simmons et al., 2007; Simmons, Kame'enui, Stoolmiller, Coyne, & Harn, 2003). The nature of the ERI program demands children's focused attention on sounds and letters for short but sustained periods. Similar to previous computerized intervention programs, it was expected that this program both engages and influences children's attention skills. The final 15 minutes of time in a small group was devoted to nonliteracy activities, including puzzles and small-group activities. Students in the OT group did not receive additional instructional time beyond the typical research-based kindergarten instruction that occurred daily in the general education setting that the AR students also received.

Assessment Protocol

All children completed the same behavioral and electrophysiological assessment battery. Behavioral and electrophysiological assessments took place on separate days.

Selected subtests from the DIBELS were administered at the children's schools the week before and after the reading intervention, with additional testing at the winter follow-up period in January. ERP testing occurred at the University of Oregon's Brain Development Laboratory. Pretesting occurred within 30 days of the start of the intervention. Posttesting occurred within 30 days of the end of the 8-week intervention. The intervention ran each day between the second week of October to the second week in December. All study procedures were approved by the University of Oregon Institutional Review Board. Informed consent was obtained from parents or legal guardians of participating children, and all children gave assent for participation.

Early Literacy Measures

The following subtests of the DIBELS assessment were administered at pretest and posttest, as well as at follow-up in the middle of kindergarten:

Letter Naming Fluency: This task measures a student's speed and accuracy for naming printed letters. Students are presented with a page of upper- and lowercase letters arranged in a random order and are asked to name as many letters as they can. The score is the total number of letters named correctly in 1 minute. In kindergarten, the alternate-form reliability of LNF is .88 and the median criterion-related validity with the *Woodcock-Johnson Psycho-Educational Battery-Revised Readiness Cluster* is .70 (Good, Gruba, & Kaminiski, 2002).

Phoneme Segmentation Fluency (PSF): This task assesses a student's ability in phonological awareness. It requires the student to verbally produce the sounds/phonemes of three or four phoneme words presented orally by an examiner. For example, the examiner says, "sat," and the student says, "/s/ /a/ /t/" to receive three possible points for the word. The number of correct phonemes produced in 1 minute determines the final score. PSF has an alternate-form reliability of .88 and predictive validity coefficient with other early reading measures ranging from .62 to .83 (Good et al., 2002).

Nonsense Word Fluency (NWF): This task assesses knowledge of the alphabetic principle. The student is presented a paper with randomly ordered VC and CVC nonsense words (e.g., sig, rav, ov) and asked to verbally produce, or read, the whole nonsense word. For example, if the stimulus word is "vaj" the student could say /v/ /a/ /j/ or say the word /vaj/ to obtain a total of three letter sounds correct. The final score is the number of letter-sounds produced correctly in 1 minute. The alternate form reliability

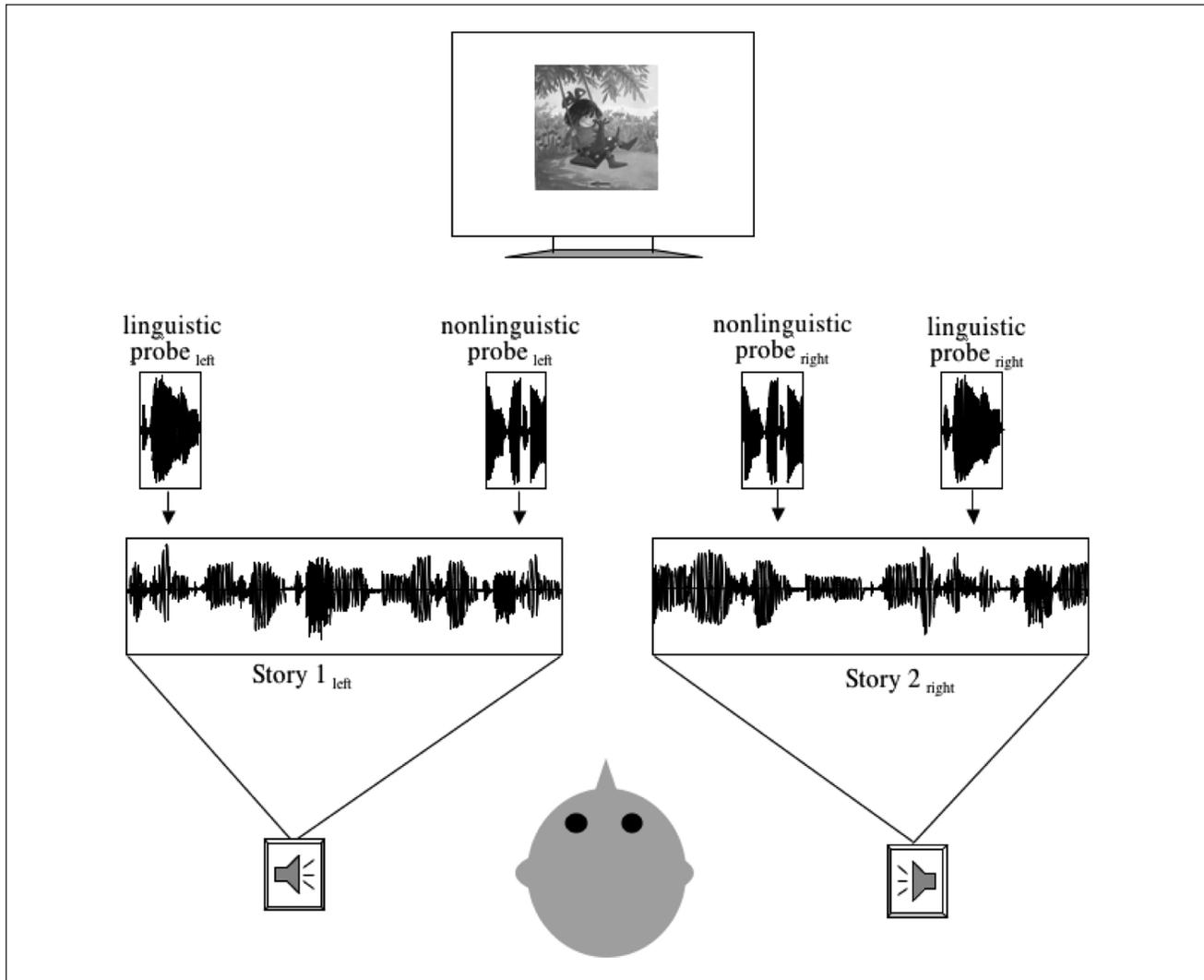


Figure 1. Schematic representation of the event-related brain potential (ERP) selective auditory attention paradigm

Note: In separate blocks, children were instructed to attend to the story from the right or left speaker. ERPs were recorded to probe stimuli superimposed on the attended and ignored auditory channel.

of NWF is .92 and predictive validity coefficient with other early reading measures ranging from .66 to .82 (Good et al., 2002).

Electrophysiological Measures

The ERP stimuli, tasks, and procedures were similar to those used in our previous studies of selective auditory attention in typically developing children and children at risk for school failure (Sanders et al., 2006; Stevens et al., 2006, 2009).

Children sat in a comfortable chair in a sound-attenuated booth. They were instructed to attend selectively to one of two stories presented simultaneously from free-field audio speakers located to their left and right. The stories differed in location (left/right speaker), narration voice (male/female),

and content (story series). Small images from the attended story were presented on a central monitor (see Figure 1). Each participant attended to a total of four 2.5- to 3.5-minute stories (two from each speaker location). To encourage children to maintain focus on a single story, following each story set children were asked three comprehension questions about the attended story, as described in the following.

ERPs were recorded to linguistic and nonlinguistic probe stimuli (100 ms duration) embedded in the attended and unattended stories. The linguistic probe was the syllable /ba/, spoken by a female speaker (different from the female narrators) and then digitized and edited to 100-ms duration. The nonlinguistic probe was created by scrambling 4- to 6-ms segments of the /ba/ stimulus. This resulted in a broad-spectrum “buzz” that, while sounding nonlinguistic,

preserved many of the acoustic properties of the linguistic probe. The two stories were played at 60 dB SPL (A-weighted), and the probe stimuli were played at 70 dB. The interstimulus interval (ISI) between probes was 200, 500, or 1,000 ms, with an equal number of probes presented at each ISI. Across the stories, 228 trials of each of the four probe types (Linguistic/Nonlinguistic \times Attended/Unattended) were presented.

During ERP testing, an adult experimenter sat next to the child at all times to administer instructions and monitor the child's behavior. To encourage the child to pay attention, following each story the experimenter asked the child three basic two-alternative comprehension questions about the attended story (an answer of "I don't know" was counted as an incorrect response). These questions were not designed as a sensitive assay of children's language or attention abilities, but were instead included to reinforce to the child the goal of paying careful attention to a single story. After answering the three questions, the child heard another story concerning the same characters and read in the same voice. This procedure was repeated four times until the child had listened to four stories (attending twice to the left speaker and twice to the right speaker) and answered 12 comprehension questions. Responses to the attention questions were not used as an exclusionary criterion because children could miss the questions due to inattention or a number of other factors, including poor listening comprehension. However, as described earlier, children with poor data quality at either pretest or posttest were excluded from analysis.

Electrophysiological Recording Conventions

The electroencephalogram (EEG) was recorded from 29 tin electrodes mounted in an elastic cap (Electro-Cap International, Eaton, OH). Recording sites included: FP1/2, F7/8, FT7/8, F3/4, FC5/6, C3/4, C5/6, T3/4, CT5/6, P3/4, T5/6, TO1/2, O1/2, Fz, Cz, and Pz. Additional electrodes were placed at the outer canthus of each eye and on the cheek beneath the right eye to monitor eye movements and blinks, respectively. On-line, electrodes were referenced to the right mastoid. Off-line, electrodes were re-referenced to the average of the left and right mastoid. Electrode impedances were kept below 10K Ω for eye electrodes, 5K Ω for scalp electrodes, and 3K Ω for mastoid electrodes. The EEG was amplified 10,000 times using Grass 7P511 amplifiers (bandpass .01 to 100 Hz) and digitized online (250 Hz sampling rate). To reduce electrical noise in the data, a 60 Hz digital filter was applied off-line.

To remove artifacts due to blinks, muscle movement, or eye movement, individual artifact rejection parameters were selected for each participant. Parameters were selected based on inspection of the raw data to identify the smallest change in amplitude observed during a blink (based on shape of traces recorded from the eye electrodes and reversal

in polarity above and below the eye) or eye movement (based on shape and distribution). Muscle movement was assessed based on channel blocking. Trials thus determined to be contaminated by eye or muscle movements were not included in further analyses. Following artifact rejection, there was an average of 145 trials in each of the four conditions (Attend/Unattend \times Linguistic/Nonlinguistic Probe Types) at each time point. There were no differences between the AR and OT groups in the number of trials available for analysis. At pretest, the AR and OT groups had 133 and 131 trials per condition, respectively, $t(12) < 1$, $p = .89$. At posttest, the AR and OT groups had 170 and 148 trials per condition, respectively, $t(12) = 1.3$, $p = .20$.

Separate ERPs were averaged to the same physical probe stimuli when embedded in the attended and unattended channel. Mean amplitude measurements were taken from 100 to 200 ms poststimulus onset, using the 100 ms immediately prior to probe stimulus presentation as a baseline. Measurements were taken separately for probes when attended and unattended, as well as for the difference wave (attended – unattended), which more directly indexes the effect of attention on sensorineural processing. Analyses were conducted on these mean amplitude measurements averaged over 16 electrodes comprising the four most anterior rows of the electrode montage (F7/8, FT7/8, F3/4, FC5/6, C3/4, C5/6, CT5/6, T3/4). Analyses with the 100– to 200-ms window over this set of electrodes have been used in our previous research with this paradigm (Sanders et al., 2006; Stevens et al., 2006, 2008, 2009).

Results

Early Literacy Measures

DIBELS scores for the LNF, PSF, and NWF subtests are presented in Table 2 and Figure 2, separately for the at-risk and on-track groups. Data from three time points are presented: pretest, posttest, and winter follow-up.

As seen in Table 2, the at-risk group had significantly lower scores than the on-track group on all three DIBELS subtests at the pretest. At posttest, this group difference was no longer statistically detectable. As seen in Table 2 and Figure 2, the at-risk group caught up to the on-track children on early literacy measures by the middle of kindergarten. In addition to examining mean scores across groups, a supplemental analysis examined the percentage of at-risk children achieving critical winter benchmarks on both the PSF and NWF subtest. The DIBELS benchmark scores were empirically derived from a large longitudinal data set identifying scores predictive of end-of-year literacy performance (Good et al., 2001). Research demonstrates that students who achieve these critical benchmark scores on time (i.e., beginning, middle, or end of year) have more than an 80% chance of meeting the subsequent benchmark (Kame'enui, Good, &

Table 2. Dynamic Indicators of Basic Early Literacy Skills (DIBELS) Early Literacy Outcomes

Test	On track (<i>n</i> = 6)	At risk (<i>n</i> = 8)	<i>p</i>	Cohen's <i>d</i>
<i>Letter Naming Fluency</i>				
Pretest	17.3	3.0	<.001	-3.46
Posttest	23.3	16.5	.219	-0.70
Winter follow-up	30.5	20.6	.139	-0.86
Change score (post – pre)	+6.0	+13.5	.207	+0.43
<i>Phonemic Segmentation Fluency</i>				
Pretest	15.8	2.1	<.05	-1.11
Posttest	42.0	25.6	.323	-0.79
Winter follow-up	39.2	35.4	.295	-0.21
Change score (post – pre)	+26.2	+23.5	.789	-0.19
<i>Nonsense Word Fluency</i>				
Pretest	8.0	0.0	<.05	-1.49
Posttest	21.7	19.5	.599	-0.29
Winter follow-up	20.2	20.4	.976	+0.02
Change score (post – pre)	+13.7	+19.5	.185	+0.55

Note: One child in the at-risk group did not complete the *Phonemic Segmentation Fluency* winter benchmark. Mean scores for each group are presented. *p* values represent results of independent samples *t* tests between groups. Cohen's *d* based on the formula $((M_{AR} - M_{OT})/SD_{pooled})$.

Harn, 2004). These percentages are useful in comparing outcomes or growth in student performance across other interventions as well as with previous studies using the ERI program. In winter, five of the seven at-risk children (71%) who completed the winter PSF test exceeded the benchmark criterion score of 18. Six of the eight at-risk children (75%) who completed the winter NWF test exceeded the benchmark criterion score of 13. These results demonstrate a similar response to intervention observed in previous, randomized controlled studies of ERI implemented across a full year of kindergarten (Simmons et al., 2007).

ERP Measure of Selective Auditory Attention

Grand average waveforms for the AR and OT groups are presented in Figure 3, for both pretest and posttest. Voltage maps display the distribution of the attention effect (computed as the difference in mean amplitude of the ERP for stimuli in the attended versus unattended channel from 100- to 200-ms poststimulus onset) for each group at the two time points. These figures and the following analyses collapse across the two probe types (linguistic and nonlinguistic) as preliminary analyses indicated that none of the results were influenced by this factor.

Visual analysis of the waveforms indicated that both groups of children showed a broad positivity in response to probe stimuli. At pretest, attentional modulation of this positivity appeared larger in the OT than AR group in the 100- to 200-ms window. At posttest, attentional modulation appeared to be present in both groups during this time window. Quantitative analyses, described in the following, supported these observations.

At pretest, the OT group tended to have a larger effect of attention on neural processing (i.e., a greater difference in the amplitude of the ERP response to attended vs. unattended stimuli) than the AR group, $t(12) = 2.03, p = .06$. Attempts to localize the group difference at pretest to AR deficits in signal enhancement versus distractor suppression were inconclusive. Specifically, the patterns of means indicated that relative to the OT group, the AR group showed a smaller amplitude response to attended probes (i.e., poorer signal enhancement) and a larger amplitude response to ignored probes (i.e., poorer distractor suppression), but neither difference reached statistical significance, largest $t(12) < 1, p = .252$. At posttest, there were no statistically detectable differences between groups (see Table 2), $t(12) = -1.46, p = .17$.

Changes in the effects of attention from pretest to posttest differed in the AR and OT groups, $t(12) = -2.2, p < .05$. To examine the pattern of change across session in the AR and OT groups separately, additional paired *t* tests were conducted. Children in the AR group showed a significant increase in the attention effect from pretest to posttest, $t(7) = -3.78, p < .01$. In contrast, children in the OT group showed no significant change from pretest to posttest, $t(5) < 1, p = .92$.

Although correct responses to the 12 comprehension questions about the attended story were not used as an exclusionary criterion in this study, both groups performed at above chance levels at both pretest and posttest (one-sample *t* test against chance performance, all $p < .05$). The mean number of questions answered correctly for each group at pretest and posttest is presented in Table 3. At pretest, children in the at-risk group answered fewer questions

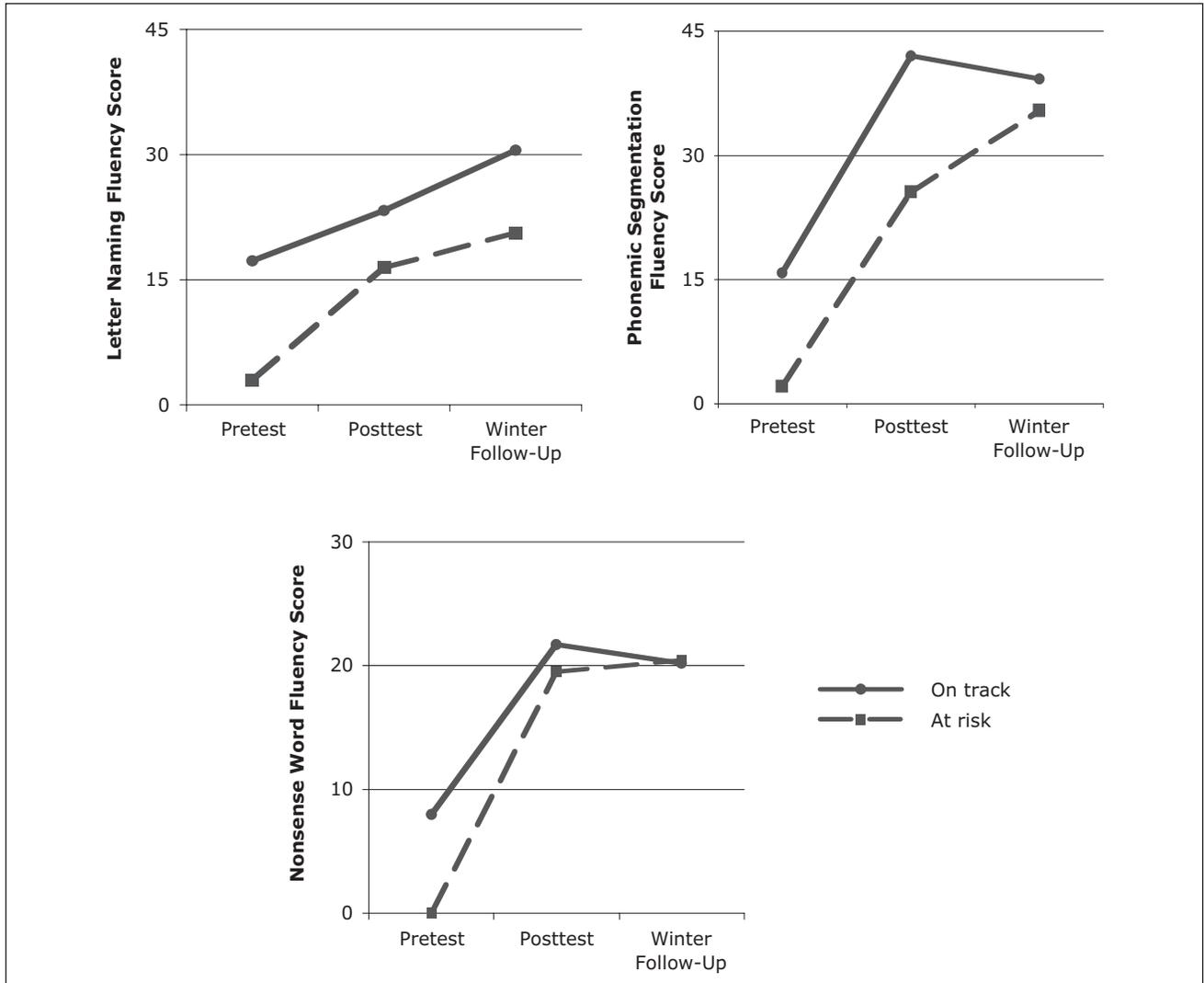


Figure 2. Mean scores on three *Dynamic Indicators of Basic Early Literacy Skills* (DIBELS) preliteracy measures at pretest, posttest, and winter follow-up, separately for the on-track and at-risk groups

correct than the on-track group, $t(12) = 3.9, p < .01$. At posttest, the difference between groups was no longer statistically significant, $t(12) < 1, p = .62$.

Discussion

The present study used event-related brain potentials to examine the earliest effects of selective attention on neural processing in 5-year-old children across the first semester of kindergarten. At the start of kindergarten, children with early literacy skills that put them at risk for reading difficulties tended to show reduced effects of selective attention on sensorineural processing relative to their peers who began kindergarten with typically developing early literacy skills. However, after a semester of kindergarten and intervention with the Early Reading Intervention, children at risk for

reading difficulties showed increased effects of attention on neural processing that exceeded changes in the on-track group. These data are consistent with the hypothesis that aspects of selective attention are impaired in children at risk for reading difficulties but can be improved through interventions.

Group Differences in Attention

A number of recent studies report deficits in behavioral measures of selective attention in children at risk for school failure, including those with low language or literacy skills (e.g., Atkinson, 1991; Cherry, 1981; Sperling et al., 2005) or from lower socioeconomic backgrounds (e.g., Farah et al., 2006; Mezzacappa, 2004; Noble, Norman, & Farah, 2005). Event-related brain potentials have been useful in

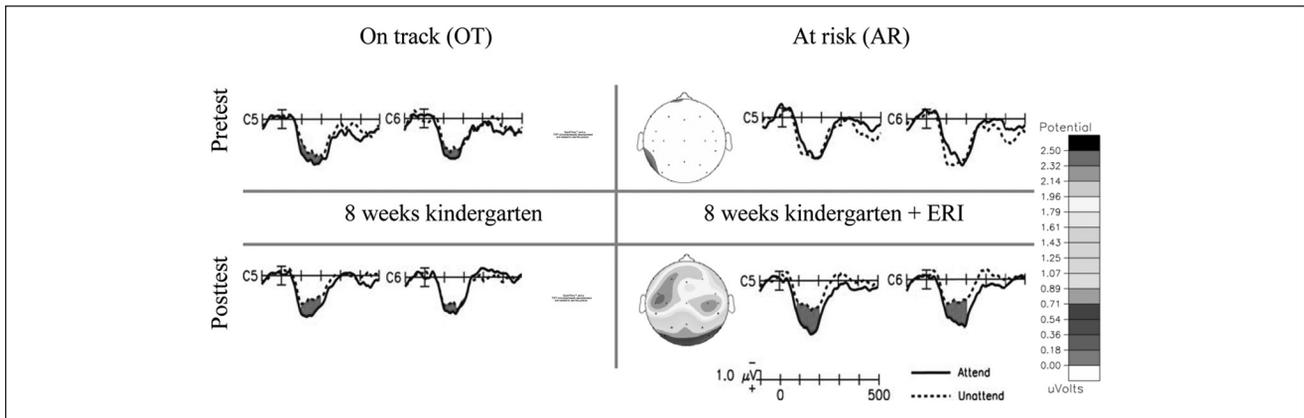


Figure 3. Grand average event-related brain potential (ERP) waveforms from the selective auditory attention paradigm show the effects of attention on sensorineural processing

Note: Top row shows data from pretest, and bottom row shows data from posttest for the on-track and at-risk groups. ERPs to probes in the attended channel are shown in solid lines and ERPs to probes in the unattended channel are shown in dashed lines. Shading indicates the attention effect. Negative is plotted up. Voltage map, showing a top-down view of the scalp, indicates the magnitude and distribution of the attention effect (attended – unattended).

Table 3. Event-Related Brain Potential (ERP) Outcomes

Measure	On track ($n = 6$)	At risk ($n = 8$)	p	Cohen's d
Attention effect, in μV (attended – unattended)				
Pretest	0.8	-0.5	<.1	-1.10
Posttest	0.9	1.8	.17	+0.79
Change score	+0.1	+2.4	<.05	+1.19
Correct responses comprehension questions				
Pretest	10.3	7.5	<.01	-2.12
Posttest	10.2	9.5	.62	-0.27
Change score	-0.2	+2.0	.13	+0.86

Note: Mean amplitude of the attention effect and performance on the comprehension questions at pre- and posttest sessions. p values represent results of independent samples t tests between groups. Cohen's d based on the formula $((M_{AR} - M_{OT})/SD_{pooled})$.

tracing the nature of this deficit to the earliest stages of neural processing that are typically modulated by selective attention, both in children with specific language impairment (Stevens et al., 2006) and children from lower socioeconomic backgrounds (D'Angiulli et al., 2008; Stevens et al., 2009). The present study extended this research to examine kindergarten children at risk for reading difficulties. Consistent with the previous literature, the at-risk group also tended to show reduced effects of attention on sensorineural processing.

A deficit in the effects of selective attention on early neural processing could have cascading consequences on the development of other brain systems, as well as a child's ability to respond to instruction. Within neuroscience and cognitive neuroscience, it is accepted that the development and specialization of many cortical areas is influenced by the effects of experience. Considerable animal research has shown the central role of attention in facilitating neuroplasticity, that is, experience-dependent changes in cortical networks. For example, when monkeys are provided extensive

exposure to auditory and tactile stimuli, experience-dependent expansions in associated cortical areas occur, but *only* when attention is directed toward those stimuli in order to make behaviorally relevant discriminations (Recanzone, Merzenich, Jenkins, Graiski, & Dinse, 1992; Recanzone, Schreiner, & Merzenich, 1993). Mere exposure is not enough. Thus, it is reasonable to hypothesize that deficits in aspects of selective attention could impede the establishment of experience-dependent, specialized neural circuitry for reading since learning to read is dependent on attention to relevant stimuli during instruction (Dally, 2006).

Effect of Intervention

Related research suggests that some effective language or reading interventions might work in part by training selective attention (Gillam, 1999; Gillam, Crofford, et al., 2001; Gillam, Loeb, et al., 2001; Hari & Renvall, 2001; Sundberg & Lacerda, 2003). When children spend sustained amounts of intervention time attending to auditory and/or visual

information, it is likely that attention skills are being engaged and developed. Furthermore, there is some evidence that attention training can improve the effectiveness of domain-specific training in, for example, writing skills (Chenault et al., 2006). In the present study, children at risk for reading difficulties who received the Early Reading Intervention made larger gains in the effects of attention on sensorineural processing following the first semester of kindergarten than did on-track children receiving a typical kindergarten curriculum and instruction. These effects were observed even though the attention task involved attending to stories that were not part of children's intervention program. However, the time in small groups where attention is focused on individual letters and letter sounds may have both demanded and, by virtue of use, trained selective attention.

Measures of early literacy skills also showed that children receiving the ERI intervention caught up to their on-track peers by the middle of the year. Furthermore, three quarters of the at-risk children exceeded benchmark criteria on winter follow-up tests, indicating that they were no longer at risk for reading difficulties. These percentages were equal to or exceeded gains made by students in previous larger scale studies of kindergarten children at risk for school failure that included contrasting interventions for children at risk for reading difficulties (Simmons et al., 2003), suggesting that such results are unlikely to be accounted for by regression to the mean alone. Taken together, the effectiveness of the ERI program on both early literacy measures and the ERP measure of selective auditory attention is consistent with the hypothesis that effective reading or language interventions may also improve, or work in part by training, selective attention.

Limitations and Future Directions

The present study was the first in an extended program of research and included a small sample of students. In light of the promising results with these small samples, we are planning further studies with larger samples of children to allow replication of the current results. Such studies will also allow for different reading interventions to be contrasted against one another, as well as the study of how different programs may interact with students with varying skills (e.g., attention, language, etc.). Including contrasting interventions will also provide an important control for possible differential test-retest effects in children with on-track versus poor early literacy skills on the behavioral or ERP measures, as well as the effects of spending time in a small group setting. Finally, with larger groups of students, it will be important to collect standardized measures of language alongside early literacy measures, as reading and language difficulties are highly comorbid (Catts, 1993; Eisenmajer, Ross, & Pratt, 2005; McArthur & Hogben, 2001). This will

allow the contribution of attention deficits to language and reading difficulties to be assessed separately.

Although the results of the ERP study generalized across both linguistic and nonlinguistic probe types, the overarching context of the paradigm—listening to an auditory story—may be closely tied to early literacy development. Thus, it is unclear from the present study whether the early neural mechanisms of selective attention would also be impaired (and improvable) in a completely nonlinguistic context. Given the results from behavioral studies showing deficits in nonlinguistic measures of selective attention among adolescents with reading difficulties (e.g., Sperling et al., 2005), we predict that such deficits would be observed and that attention gains would translate to the nonlinguistic domain. We are currently developing a nonlinguistic selective auditory attention ERP paradigm that would be useful in testing this hypothesis directly.

Conclusion

The present data are suggestive of a relationship between the neural mechanisms of selective attention and both the profile and development of early reading skills. Continued multidisciplinary and collaborative study into the nature of this relationship and the complex interplay of student characteristics, as determined by both traditional standardized behavioral and neuropsychological measures, and intervention development and delivery is needed. As Varma, McCandliss, and Schwartz (2008) discuss, our fields are interdependent. The goal of either discipline should not be simply to identify or document typical and atypical performance, but to understand why and how interventions work, and also why interventions that work for most children do not work for *each* child. Further multidisciplinary collaboration will support the design, implementation, and fine-tuning of instructional methods that are more effective and efficient to the needs of each student.

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