Auditory sensory memory and language abilities in former late talkers: A mismatch negativity study

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Abstract
The present study investigated whether (a) a reduced duration of auditory sensory memory is found in late talking children and (b) whether deficits of sensory memory are linked to persistent difficulties in language acquisition. Former late talkers and children without delayed language development were examined at the age of 4 years and 7 months using mismatch negativity (MMN) with interstimulus intervals (ISIs) of 500 ms and 2000 ms. Additionally, short-term memory, language skills, and nonverbal intelligence were assessed. MMN mean amplitude was reduced for the ISI of 2000 ms in former late talking children both with and without persistent language deficits. In summary, our findings suggest that late talkers are characterized by a reduced duration of auditory sensory memory. However, deficits in auditory sensory memory are not sufficient for persistent language difficulties and may be compensated for by some children.

Descriptors: Auditory sensory memory, Late talker, Mismatch negativity, MMN, Specific language impairment, SLI

Language delay in the absence of other medical conditions is found in approximately 10%–20% of 2-year-olds (Klee et al., 1998; Rescorla & Alley, 2001) who are referred to as “late talkers” (LTs; Horwitz et al., 2003; Rescorla, 1989). According to several studies (e.g., Miniscalco, Westerlund, & Lohmander, 2005; Rice, Taylor, & Zubrick, 2008), language delay is a risk factor for specific language impairment (SLI). For example, Dale, Price, Bishop, and Plomin (2003) examined 8,386 twins (LTs: n = 802; non-LTs: n = 7,584) and reported that 40.2% of LTs had language difficulties at the age of 4 years in contrast to 8.5% in normally developing children.

Children with SLI have a higher risk of developing socio-emotional problems. For example, they show lower achievements in school in a broad range of subjects including mathematics (Snowling, Adams, Bishop, & Stothard, 2001). Moreover, later in adulthood a twofold increase in the incidence of psychiatric disorders, such as disocial behavior and anxiety disorders was found (Beitchman et al., 2001). Therefore, it seems important to investigate the underlying neurophysiological mechanisms contributing to the development of SLI in order to enable and enhance possibilities for early intervention.

Deficiencies in auditory short-term memory are among the postulated causes of SLI. In a number of studies, auditory short-term memory deficits were reported in children with SLI (Montgomery, 2003) and dyslexia (Jeffries & Everatt, 2004; Smith-Spark & Fisk, 2007). These deficits are markers of SLI and are assumed to be predictive of language development in these children (Botting & Conti-Ramsden, 2001; Conti-Ramsden & Hesketh, 2003; Gathercole & Baddeley, 1990). In contrast, there is a lack of knowledge regarding the neurobiological basis of late talking.

The relationship between SLI and auditory short-term memory has been interpreted using Baddeley and Hitch’s (1974) working memory model (e.g., Montgomery, 2003). This model proposes a multicomponent capacity-limited system that comprises a “phonological loop” for verbal information processing and a “visuospatial sketch pad” for processing visual information. The “central executive” coordinates and integrates both subsystems. Deficiencies in auditory short-term memory found in SLI are explained by reductions in both the storage capacity of the phonological loop and the encoding speed of language input. Such deficits are assumed to lead to difficulties establishing phonological representations, consequently impacting vocabulary acquisition and the establishment of grammatical rules (Baddeley, Gathercole, & Papagno, 1998). A limitation of Baddeley’s model however, is that the initial steps of information processing are not well described.

In comparison, Cowan’s (1988, 1995) model specifies the reception and storage of sensory information in greater detail. According to this model, incoming sensory information is consecutively integrated within a sensory store for the purpose...
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of resolving component features. This first part of the sensory store is designed to briefly (200–400 ms) hold large amounts of data. From this system the sensory information is transferred to a second, longer-lasting division of the sensory memory store, where it is kept available for further processing in working memory. Information is suggested to decay from this second part after a period of about 10–20 s. Auditory sensory memory is presumed to operate automatically and preattentively. It is hypothesized that a reduced duration of sensory memory could be the neurophysiological background of disturbed language acquisition in children with SLI (Barry et al., 2008).

Auditory short-term memory is commonly assessed with behavioral tasks in which subjects are typically asked to verbally repeat sequences of tones, syllables, words, or numbers of increasing length. Difficulties successfully completing these tasks have been attributed not only to working memory deficits but also to language difficulties (Barry et al., 2008). Because repetition accuracy depends on lexical and sublexical properties, the repetition of nonwords is a powerful tool to identify children with language impairments (Coady & Evans, 2008), but less appropriate for the evaluation of short-term memory capacities in subjects with language deficits. Moreover, repetition tasks demand immediate responses from subjects, and thus results are affected by attention and motivation. For these reasons, behavioral tasks are not ideal for young children and subjects with language difficulties.

An objective method for assessing auditory sensory memory is the event-related potential (ERP) known as mismatch negativity (MMN; Näätänen, 2003). MMN is generally obtained in an acoustic oddball paradigm, in which rare deviant sounds are presented within a stream of reoccurring standard sounds. The MMN operates at the sensory memory level and reflects an automatic preattentive process of comparisons between acoustic stimuli. Thus, the MMN is observed regardless of attention to the stimuli (e.g., Näätänen, Paavilainen, Tiitinen, Jiang, & Alho, 1993). It is assumed that regular aspects of consistently presented standards form a memory trace in the sensory store and that violation of these regularities by deviants induces an MMN (Näätänen & Winkler, 1999).

MMN is used in basic and clinical research to determine auditory discrimination accuracy and the duration of sensory memory. Discrimination accuracy is generally investigated in oddball paradigms with constant and relatively short stimulus offset-to-onset intervals (interstimulus interval, ISI). In children with SLI, diminished MMN amplitudes have been repeatedly reported for speech-sound stimuli, but less consequently for tone stimuli. These results suggest that children with SLI have discrimination deficiencies specific to speech sounds (e.g., Bishop, 2007; Shafer, Morr, Datta, Kurtzberg, & Schwartz, 2005; Uwer, Albrecht, & von Suchodoletz, 2002).

To determine the duration of sensory memory, ISIs of different lengths are used. MMN is only found when the memory trace of the standard stimulus has not yet decayed from sensory memory. Therefore, sensory memory duration can be examined by varying the ISIs. It is thought that investigating the lifetime of the memory trace using MMN probes the second phase of sensory memory storage described by Cowan (Näätänen, Jacobsen, & Winkler, 2005).

Several studies have used MMN experiments with variable ISIs to probe the duration of auditory sensory memory in healthy children and adults. In newborns, a prominent MMN was found after a stimulus delay of 0.7 s, but not after 1.4 s (Cheour et al., 2002). Glass, Sachse, and von Suchodoletz (2008a, 2008b) found memory traces between 1 and 2 s in 2- and 3-year-olds, greater than 2 s in 4-year-olds, and between 3 and 5 s in 6-year-olds. Gomes et al. (1999) investigated the duration of auditory sensory memory in school-age children and adults (age groups: 6–7, 8–10, 11–12, and 22–38 years) and obtained a robust MMN at an ISI of 1 s in all age groups. An MMN for the ISI of 8 s was found only in the groups with subjects older than 10 years. In healthy adults an MMN was detected up to an ISI of approximately 10 s (Böttcher-Gandor & Ullsperger, 1992; Sams, Hari, Rif, & Knuttila, 1993). In summary, the duration of the auditory sensory memory trace demonstrates a maturational development from approximately 0.7 s in newborns to at least 10 s in adults.

Only a few studies have addressed the question of whether there is evidence for a diminished duration of auditory sensory memory in clinical samples. The lifetime of a memory trace in the sensory store has been reported to be reduced in patients with chronic alcoholism (Grau, Polo, Yago, Gual, & Escura, 2001; Zhang, Cohen, Porjesz, & Begleiter, 2001) and Alzheimer’s disease (Engeland, Mahoney, Mohr, Ilivitsky, & Knott, 2002; Pekkonen, Jousmaä, Kononen, Reinkainen, & Partanen, 1994). The findings suggest that MMN can objectively identify sensory memory deficits in patients with memory impairments.

To our knowledge, in children, auditory sensory memory duration has only been investigated in CATCH syndrome (Cheour et al., 1997) and oral clefts (Ceponienë et al., 1999). Both studies reported shorter auditory sensory memory duration in comparison to healthy peers and attributed this deficit causally to the children’s language impairments. Therefore, children with other language acquisition disturbances, such as SLI, might exhibit similar deficits.

To our knowledge, only one MMN study has investigated auditory sensory memory duration in SLI (Barry et al., 2008). In this study, parents of children with SLI were compared to parents with typically developing children using ISIs of 800 ms and 3000 ms. Reduced MMN was found for the 3000-ms ISI in parents of language-impaired children. This result was independent of the parents’ language abilities. The authors therefore postulated a shortened lifetime for auditory sensory memory traces in parents of children with SLI, providing evidence for persistent and heritable auditory sensory memory deficits.

Taken together, the results of previous MMN studies show that the duration of auditory traces in the sensory memory store is limited, that this limitation is age dependent, and that the duration is reduced in patients with memory or language impairments as well as in parents of children with SLI. Moreover, a deficient auditory sensory memory seems to be persistent because of its assumed heritability.

To our knowledge, no study has examined the auditory sensory memory of children at risk for SLI and its meaning for the persistence of language disabilities. For this reason the present study addresses the question of whether former LTs show a sensory memory deficit in the auditory modality. If a deficient auditory sensory memory is linked to persistent difficulties in language acquisition, this deficit should be found in LTs with persisting language disabilities but not in LTs with resolved language problems, so-called late bloomers. Additionally, we analyzed neuropsychological memory scores and correlations between MMN and neuropsychological memory data in an exploratory manner between groups.
In detail we used MMN to examine auditory sensory memory with two ISI durations (500 ms and 2000 ms) inserted between trains of four tones (Figure 1). We hypothesized a reduced MMN in LTs in comparison to control children for the longer ISI condition only. Additionally, if intact sensory memory is essential for normal language development, we should find no difference in mean MMN amplitude between late bloomers and control children.

Methods

Sample

Seventy-one German-speaking children participated in the study at the age of 4 years and 7 months (M = 55.04 ± 0.26 months). All children took part in a longitudinal study beginning at 2;1 years of age, with follow-ups at 3;1 and 4;7 years.

To recruit children with and without language delay, we used birth announcements to contact parents of 2-year-old children (for details, see Sachse & van Suchodoletz, 2008). Children were classified as LTs at 2 years of age via a parent questionnaire (Elternfragebogen fuer die Frueherkennung von Risikokindern, ELFRA; Grimm & Doil, 2002), a German version of the McArthur Communicative Development Inventories (CDI, Toddler Form; Fenson, Dale, & Reznick, 1993), and a standardized language test (Sprachentwicklungstest fuer 2-jaehrige Kinder, SETK-2; Grimm, 2000) composed of two receptive and two productive language subtests. Children with poor results in ELFRA–2 (vocabulary <50 words or vocabulary between 50 and 79 words and deficient morpho-syntactic abilities) as well as in SETK-2 (z-score [M = 0; SD = 1] ≤ –1.5 at least in one subtest) were classified as LTs (n = 60). Children with normal results in ELFRA-2 (vocabulary >80 words and normal morpho-syntactic abilities) and SETK-2 (z-score > –1 in all subtests) were defined as control children (n = 47). Children with results between these two classifications were not included in the analysis, with the aim to construct two clearly defined groups.

Information about developmental milestones, medical history (complications during pregnancy or birth, prematurity, chronic disorders, history of otitis media or other ear disorders), and socioeconomic characteristics were obtained by having the parents complete a questionnaire. There were no critical incidents reported for all of the participating children.

Forty-six LTs (77%) and 40 (85%) control children were reassessed at the age of 4 years and 7 months. Children with abnormal otoacoustic emission results due to common colds or other unspecified reasons at the time of measurement were excluded from analysis (n = 8). Other children were excluded because they refused to participate in the auditory screening (n = 3) or the ERP recording (n = 3) and because of emigration into a country with a foreign language (n = 1). This resulted in a total inclusion of 37 LTs (62%) and 34 (72%) control children.

All children had a normal nonverbal intelligence score (Snijders-Oomen nonverbal intelligence test: IQ ≥ 80), normal hearing abilities (measured by otoacoustic emission screening or audiometry), and normal results on otoacoustic emission screening at least for one ear at the time of electroencephalogram (EEG) recording.

We additionally classified the LTs at the age of 4;7 years into late bloomers and non-late bloomers (z-score > –1 in all language tests vs. ≤ –1 in at least one language score including subtests sentence comprehension, sentence repetition, plural creation, and expressive vocabulary). Twenty-one of 37 (57%) LTs met the late bloomer criteria and 30 of 34 (88%) control children had language abilities within or beyond the normal range (z-score > –1) in all language tests (“language category”; see Table 1).

The characteristics of the sample are shown in Table 1. The groups (LTs vs. control children) differed in their frequencies for language category (normal vs. impaired: χ² = 8.68, p < .01). Significant differences were also found for nonverbal intelligence (T = 3.46, p < .01) and language abilities (sentence comprehension: T = 2.32, p < .05; plural creation: T = 3.83, p < .01; sentence repetition: T = 3.94, p < .01; expressive vocabulary: T = 3.93, p < .01). No differences were observed for gender (χ² = 1.03, p > .1) and handedness (χ² = 5.69, p > .05) frequencies.

All parents gave their written informed consent for their children to participate in the study. The study was approved by the

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Figure 1. Oddball paradigm for probing the duration of auditory sensory memory with 500-ms (A) and 2000-ms (B) interstimulus interval condition.
Characteristics of Late Talkers (LTs) Divided into Late Bloomers (LBs) versus Non-LBs and Control Children at the Age of 4.7 Years

<table>
<thead>
<tr>
<th></th>
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<td>Boys/girls</td>
<td>25/12</td>
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<td>19/15</td>
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<tr>
<td>Handedness (right/left/ambidextrous)</td>
<td>27/2/8</td>
<td>16/2/3</td>
<td>11/0/5</td>
<td>30/3/1</td>
<td>6.09 .06</td>
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<td>Language category (SD &gt; –1/SD)</td>
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IQ (M, SD)

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<td>Sentence comprehension</td>
<td>10.05 ± 2.74</td>
<td>11.1 ± 1.92</td>
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<td>Plural creation</td>
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<td>Sentence repetition</td>
<td>76.22 ± 16.19</td>
<td>86.48 ± 9.36</td>
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Note: LTs vs. Controls

- Four subtests of the Snijders-Oomen nonverbal intelligence test (Tellegen et al., 1998).
- SETK 3-5 (Grimm, 2001).

Neuropsychological and EEG data were assessed on two consecutive days at the age of 4.7 years.

Follow-up procedures

For the follow-up procedures, we administered standardized language tests comprising expressive vocabulary (Kaufman Assessment Battery for Children, K-ABC; Melchers & Preuss, 1991), grammar production, and comprehension (Sprachentwicklungstest fuer 3- bis 5-jaehrige Kinder, SETK 3-5; Grimm, 2001). Grammar production was quantified by sentence repetition and plural creation. The latter ability is more complex in German than in English because there is a larger range of plural forms in German. Grammar comprehension was assessed by means of sentence comprehension. Here, the children were required to carry out verbal instructions.

Expressive vocabulary was measured using a nonword repetition task (NRT; subtest of SETK 3-5) and the subtest “word order” of the K-ABC. For the latter subtest, children listened to word sequences of increasing length; after each sequence children pointed to the corresponding pictures in the same order.

Handedness was evaluated using a preference inventory based on the Edinburgh Handedness Inventory (Oldfield, 1971). The children were asked to demonstrate how they would carry out everyday activities: to bring someone a book, to comb one’s hair, to hammer, to switch on the light, and to throw a ball. Nonverbal intelligence scores were calculated by four subtests of the Wijnberg-Williams, & Laros, 1998) at the age of 3 years.

- Sentence comprehension was assessed by means of sentence comprehension. Here, the children were required to carry out verbal instructions.

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Table 1. Characteristics of Late Talkers (LTs) Divided into Late Bloomers (LBs) versus Non-LBs and Control Children at the Age of 4.7 Years

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- SETK 3-5 (Grimm, 2001).
Fp2 was used for elimination of vertical eye artifacts for this child. The EEG electrodes were referenced to the right mastoid during the recording. Data acquisition was carried out using a BrainAmp system (Brain Products, Gilching, Germany). The online bandpass filter was set to 0.16 and 30 Hz (sampling rate: 250 Hz; impedances at the beginning of measurements: <5 kΩ).

Data were analyzed off-line using Vision Analyzer. First, the scalp EEG was high-pass (0.8 Hz) and low-pass (20 Hz) filtered. Artifact correction was done in two steps. First, an independent component analysis (ICA) was conducted (Kalyakin, Gonzalez, Karkkainen, & Lyytinen, 2008) and eye movement and muscle artifacts were removed. Second, resting artifacts were rejected after re-referencing to linked mastoids by an amplitude criterion of ±80 mV for all central and frontal electrodes. Finally, the data were segmented (−100 to 600 ms) and averaged. Segmentation resulted in a mean number of 192 ± 6 epochs (range: 177–198) for the control children and a mean number of 194 ± 3 epochs (range 185–198) for the LTs. The mean number of epochs did not differ between groups (Mann-Whitney U test, Z = −1.25, p > .2).

**Data Analysis**

**ERP.** Event-related responses were averaged using the first tone of the trains in order to ensure that the number (200) and relative position of standards and deviants were comparable. MMN was obtained by subtracting standard from deviant-evoked responses for each ISI condition. The MMN was prevalent over frontal electrodes, and therefore F3, Fz, and F4 were used for further analyses. A frontal MMN maximum was also described in a previous study with 4–5.5-year-old children (Martin, Shafer, Morr, Kreuzer, & Kurtzberg 2003). Mean amplitudes of the MMN were calculated to quantify the MMN response. The time window for the mean amplitude was chosen based on running t tests (against zero) from the evoked responses of the combined group (LT and control group) for each ISI condition separately (p < .05 at ≥4 consecutive data points). The resulting time window covered all intervals of significant differences in any of the three frontal electrodes (Table 2).

According to this procedure, the MMN time windows were 120 to 272 ms after stimulus onset for the 500-ms ISI control condition and 84 to 156 ms for the 2000-ms experimental condition (see gray areas of Figures 2 and 3).

**Statistical analysis.** Statistical analysis of the ERP and neuropsychological data was performed using analysis of variance (ANOVA). Main effects and interactions were calculated for the between-subject factors group (LTs vs. control children) and language category (normal vs. impaired) to control for differences in language abilities between groups. For the ERPs, mean amplitudes of F3, Fz, and F4 were averaged. Additionally, the within-subject factor ISI (500 ms vs. 2000 ms) was part of the ERP analysis. In the case of significant interactions, follow-up analyses were conducted. Finally, because nonverbal intelligence differed between groups (see Table 1), this score was subsequently implemented as a covariate (analysis of covariance, ANCOVA).

The NRT score was determined only for children without articulation difficulties (LTs = 23; control children = 28), because incorrect NRT responses may have arisen because of poor articulation rather than limited short-term memory capacity.

Pearson correlations were calculated between MMN (2000 ms ISI) and the short-term memory measures word order and NRT to examine the relationship between neuropsychological

![Table 2. Time Window of Significant Differences between Standard and Deviant Responses in the Combined Group](image)

<table>
<thead>
<tr>
<th>ISI (ms)</th>
<th>n</th>
<th>F3</th>
<th>Fz</th>
<th>F4</th>
</tr>
</thead>
<tbody>
<tr>
<td>2000</td>
<td>71</td>
<td>84–148</td>
<td>92–148</td>
<td>92–156</td>
</tr>
</tbody>
</table>

Note: ISI: interstimulus interval. Running t test: p < .05 at ≥4 consecutive data points.

![Figure 2. Mismatch negativity (MMN) as a function of interstimulus interval (ISI). MMN in the 500-ms control (A) and 2000-ms experimental (B) ISI condition for control children (solid lines) and late talkers (dashed lines). The gray area illustrates the interval of the mean amplitude.](image)
and neurophysiological memory parameters.

Because neuropsychological scores depend on various cognitive abilities, the neuropsychological data were analyzed with principal component analysis (PCA; orthogonal transformation varimax solution) in order to distinguish memory abilities. Therefore, each test score and the mean amplitude of the MMN in the experimental condition (ISI: 2000 ms) was \( z \)-transformed. Missing data were substituted by means. Only factors with an eigenvalue greater than 1 were extracted.

Significant effects are reported for \( p < .05 \).

**Results**

Descriptive data for MMN mean amplitudes and neuropsychological memory performance are listed in Table 3.

**Behavioral Results**

ANOVAs were performed for the neuropsychological memory scores word order and NRT with the between-subject factors group (LTs vs. control children) and language category (normal vs. impaired).

No main effects or interactions were found for word order.

The NRT analysis revealed a main effect for language category, \( F(1,47) = 20.41, \ p < .01 \), because children with average language abilities achieved better NRT scores. In addition, the interaction between language category and group was significant, \( F(1,47) = 6.88, \ p = .01 \). To explore this interaction further, \( t \)-tests for independent samples were conducted separately for LTs and controls, resulting in a significant effect for the control group, \( T(26) = 4.97, \ p < .01 \), but not for the LTs, \( T(21) = 1.44, \ p > .1 \).

Including nonverbal intelligence as a covariate did not alter the significance of the results.

**MMN Results**

An ANOVA for mean MMN amplitude was performed with the between-subject factors group (LTs vs. control children) and language category (normal vs. impaired) and the within-subject factor ISI (500 ms vs. 2000 ms).

Main effects for the between-subject factors group and language category were not found, but the within-subject factor ISI was significant, \( F(1,67) = 7.73, \ p < .01 \), with higher amplitudes in

![Figure 3](image)

**Table 3.** Means and Standard Deviations for Mean Amplitude of Mismatch Negativity (MMN) and Neuropsychological Memory Tests for Late Talkers (LTs) Divided into Late Bloomers (LBs) versus Non-LBs and Control Children

<table>
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<tr>
<td><strong>MMN</strong></td>
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<td></td>
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<td></td>
</tr>
<tr>
<td>ISI: 500 ms</td>
<td>-2.73 ± 3.25</td>
<td>-1.97 ± 3.25</td>
<td>-3.73 ± 3.05</td>
<td>-2.33 ± 2.53</td>
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<tr>
<td>ISI: 2000 ms</td>
<td>-0.27 ± 1.56</td>
<td>-0.09 ± 1.6</td>
<td>-0.52 ± 1.52</td>
<td>-1.49 ± 2.48</td>
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<tr>
<td>Neuropsychological tests</td>
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<tr>
<td>Word order</td>
<td>6.27 ± 1.97</td>
<td>6.71 ± 1.87</td>
<td>5.69 ± 1.99</td>
<td>7.41 ± 2.34</td>
</tr>
<tr>
<td>NRT*</td>
<td>9.09 ± 3.01</td>
<td>9.73 ± 2.28</td>
<td>7.88 ± 3.94</td>
<td>12.25 ± 3.16</td>
</tr>
</tbody>
</table>

*LTs: n = 23 (LB: n = 15, non-LB: n = 8), control children: n = 28.*

Note: ISI: inter-stimulus-interval; NRT: nonword repetition task.
the 500-ms ISI condition. A significant interaction was detected for ISI × Group, $F(1,67) = 6.06, p < .05$, in accordance with our hypothesis (Table 4).

This interaction resulted from differences between control children and LTs in the 2000-ms ISI condition, $F(1,68) = 6.81, p < .05$, but not in the 500-ms ISI condition, $F(1,68) = 0.54, p > .4$ (Figure 2). This discrepancy described above was also significant for late bloomers compared to control children in the 2000-ms ISI condition, $F(1,52) = 4.56, p < .05$, but not in the 500-ms ISI condition, $F(1,52) = 0.02, p > .8$ (Figure 3).

Entering nonverbal IQ as a covariate did not alter the significance of the interaction between ISI and group, $F(1,66) = 6.85, p < .05$.

Correlations
To examine the relationship between neuropsychological and neurophysiological memory parameters, Pearson correlations were obtained. A significant correlation was observed between word order and MMN (2000-ms ISI condition; $r = -.24, p < .05$). Here, high test scores were associated with larger MMN amplitudes (signed negative). The correlation between MMN and NRT did not reach significance ($r = -.09, p > .5$).

PCA performed on the neuropsychological and neurophysiological scores yielded two factors with an eigenvalue > 1. Each test measure was sorted into a two-dimensional vector space (Figure 4). Both identified factors accounted for 59.4% of the variance.

Late Bloomers versus Non-Late Bloomers
LTs who performed well in four language tests at the age of 4;7 years were classified as late bloomers ($n = 21$), whereas the remaining children showed persistent language deficits and were categorized as non-late bloomers ($n = 16$). Both groups differ in all language scores ($t$ test, $p < .05$). No group differences were found for nonverbal intelligence and memory achievements (NRT and the K-ABC's word order subtest; $t$ test, $p > .1$). The two groups did not differ in terms of handedness and sex (chi-quadrat test, $p > .2$).

Additionally, MMN mean amplitude differences for both ISI conditions were not observed ($t$ test, 500 ms: $p > .1$; 2000 ms: $p > .4$). Finally, a logistic binary regression analysis showed that none of the variables measured at the age of 2 years, including sex, handedness, intelligence, and receptive and productive language abilities, could predict the outcome of late bloomers or non-late bloomers at the age of 4;7 years.


REFERENCES