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Gender Concord and Semantic Processing in French Children: An Auditory ERP Study

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1. Introduction

The present study used event-related brain potentials (ERPs) to investigate language processing in young children, focusing on gender agreement (determiner-noun and noun-adjective) and conceptual semantics in French.Electrophysiological measurement techniques provide a valuable addition to our methodological toolkit for studying agreement processing in this population, in particular concerning noun-adjective agreement (concord), since other traditional sources of data have tended to be uninformative. Although children arguably exhibit systematic constraints on their linguistic behavior, this is not always evident in the laboratory (e.g., where task demands may mask the presence of linguistic knowledge) or in investigations of child language corpora. For example, although French-speaking children seem to master adjective and determiner concord early on, productive use of gender-marked adjectives is not clearly supported in the corpus, where determiner use predominates (Valois & Royle, 2009), or in elicitation, where idiosyncratic gender marking on adjectives may result in variable mastery of feminine forms (Royle & Valois, 2010). Here we report on an auditory/visual ERP study that shows that the processing of gender agreement can be reliably tapped in young French children.

1.1. ERPs for semantic and agreement errors in adults

The N400, first described in Kutas and Hillyard (1980), is a negative going wave with a central/ parietal scalp distribution observed between 300 and 500 ms after stimulus presentation. It can be elicited by semantic expectancy

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violations (Kutas & Federmeier, 2000; Steinhauer & Connolly, 2008). Important for the present investigation is the fact that this component can be observed in bimodal (auditory-image or image-text) lexical-semantic violation conditions, where an incongruous or unexpected image is presented concurrently with an auditory or written utterance, whether it is in a noun phrase or a sentence context (Friedrich & Friederici, 2004; Willems, Özyürek, & Hagoort, 2008).

Gender agreement errors in auditory and visual paradigms have been shown to elicit left-lateralized anterior negativities (LANs) between 300 and 500 ms after stimulus presentation (Barber & Carreiras, 2005; Barber, Salillas, & Carreiras, 2004; Foucart & Frenck-Mestre, 2012; Gunter, Friederici, & Schriefers, 2000; Molinaro, Barber, & Carreiras, 2011; O'Rourke, 2008; Osterhout & Mobley, 1995). These are usually followed by a later positive-going wave (P600) emerging between 500 and 1000 ms after stimulus presentation (see reviews in Molinaro *et al.*, 2011, and O'Rourke, 2008; see also Foucart & Frenck-Mestre, 2010, for a recent study of French). Because, the P600 is elicited in many different paradigms (including those with complex grammatical structures), some have proposed that this component indexes processing load relating to syntactic analysis, and that it is not specifically dedicated to grammatical syntactic processing (Steinhauer & Connolly, 2008). Thus the LAN/P600 is thought to be an index of: (i) automatic morphosyntactic parsing (LAN), and (ii) structure integration or reanalysis (P600). Our own data on French-speaking adults show this biphasic pattern to both adjective-noun and determiner-noun agreement errors (Gascon, Lebel, Royle, Drury, & Steinhauer, 2011; Royle, Gascon, Drury, & Steinhauer, in preparation).

1.2. ERPs and first language acquisition

Few ERP studies have investigated the acquisition of semantic and syntacticprocessingin L1, and few of these include adult controls. Those studies that do, typically observe differences between children and adults in terms of ERP latency, scalp location and amplitude; however specific patternsare influenced both by the linguistic domains studied and by age.As in our paradigm, all the studies we discuss presented auditory stimuli to children.

*Lexico-semantic*N400 effects similar to those in adults can be observed in early childhood. Friedrich and Friederici (2004) showed that incongruous picture-word stimuli presented to 19-month-old children will elicit N400-like components. They compared semantically congruous (where the auditory name of the object matched the image) and incongruous conditions (where the name *chair*did not match the image BALL). In the incongruous conditions, the authors observed a broadly distributed negativity over frontal and centro-parietal scalp regions that reach significance between700 and 1400 ms after stimulus presentation. This negativity is similar to the N400 observed in adult controls, which however starts somewhat earlier (at about 300 ms) and has a more focal prominence at parietal sites. In the same bimodal stimuli presentation, children present N400 waves similar to adults in term of latency and scalp distribution, essentially centro-parietal, beginning at the age of 7 years old (Cummings & Čeponienė, 2010).

Morphosyntactic ERPs have also been studied in children.When grammatically incorrect sentencesare presented,a late positivity is observed in children aged 3 and older. Silva-Pereyra, Rivera-Gaxiola and Kuhl (2005) presented children 3 and 4 years of age with auditory sentences in which there was a clash between the auxiliary and the verb (*My uncle will *watching the movie*). In 3 year olds, the authors observed what they describe as a sequence of two broadly distributed positive waves in central and slightly left-lateralized frontal electrodes, the first between 200 and 600 ms and the second between 600 and 1000 ms (in fact it appears to be one continuous positivity). The same wave pattern was identified in 4-year-olds, with the "second" wave located more specifically in the central region of the scalp. Schipke, Friederici and Oberecker (2011) also observed a positive-going wave in young German speakers (3-, 4-and-a-half and 6-years-old) during the auditory presentation of sentences with double-nominatives and double accusatives, both morphosyntactic errors in German. In the double nominative condition, EPRs for the three groups were characterized first by a broadly distributed frontal negative-going wave between 300 and 700 ms after stimulus presentation. This negativity was followed by a late positive wave. This biphasic wave pattern, observed from 3 years of age, is assumed to reflect similar biphasic LAN/P600 patterns present in adults ERPs in similar conditions (Frisch & Schlesewsky, 2005).

Clahsen, Lück and Hahne (2007), observe no positivity similar to the P600 in younger children (aged 6 to 7 years) when they are presented with morphosyntactic errors (plural overregularization) in German. A broadly distributed negativity is observed for overregularizations until the age of 8 when a biphasic wave, a negativity in anterior sites followed by a late positivity in the occipital region at 1000 ms, is seen. By the ages of 11 to 12 year old, a slightly left-lateralized negativity in the anterior sites followed by a late positivity is found. The observed pattern is similar in distribution to adults' LAN/P600 in the same conditions, but with a longer latency in the P600. A biphasic wave pattern with latencies similar to the adult LAN/P600isfound in English-speaking children of similar ages (8.5- to 13-years-old) (Atchley, Rice, Betz, Kwasney, Sereno, & Jongman, 2006) for syntactically incorrect sentences with agreement violations (*Where *do <u>a</u> boy like to play?)* or auxiliary drop (*Where *__<u>a</u> boy like to play?*, ERPs were recorded at the underlined determiner, note however that the sentences are not ungrammatical at this point, e.g., consider the following alternative possible grammatical continuations after the determiner: *Where <u>a</u> boy likes to play is anyone's guess* or *Where do <u>a</u> boy like you and a girl like her like to play?*). Although the P600 latency was the same in both groups, small differences were found in its amplitude, which was larger in the child group. Children also displayed a more centro-parietal P600, while it was situated in the parietal zones in the adult group. According to the authors, differences found in amplitude and scalp location in the children's ERPs may be due to the kinds of "errors" that were presented to them (i.e. certain morphosyntactic violations might be too subtle for young language users to process). Relying on her study of latency differences between 14-to 17-year-olds and adults, Meier (2008) suggests that syntactic refinement continues in teenagers. In her study, sentences containing agreement violations were used (e.g., *Everyday, the musicians tune their *instrument*). Meier observed a positivity to these errors from 900 to 1400 msin the teenagers' ERPs. In the adults, the positive wave occurred in the 700-1500 ms time-range. This, along with the aforementioned studies, seems to indicate a developmental pattern towards a decrease in component latency and increased focalization as the child matures.

Based on this review, it appears that, early on, children and adults show similar EPR components for semantic but not morphosyntactic processing. In addition, it is unclear whether some morphosyntactic abilities mature earlier than others, as tasks on different grammar components (verb agreement, gender agreement, case and plural marking) seem to show different developmental patterns for morphosyntactic ERPs (note that some of the paradigms use structures that are not ungrammatical at the point where data was analyzed, e.g., Atchley *et al.*, 2006). If children replicate patterns found in second language (L2) learners (e.g., see Steinhauer, White, & Drury, 2009) we would expect to observe N400s on semantic violations at all ages, whereas morphosyntactic errors would not necessarily elicit adult-like biphasic LAN/P600 components. In beginning L2 speakers, ungrammatical structurescan initially elicit N400's. At higher levels of L2 mastery, they elicit small P600s, followed by larger P600s, and eventually, with complete mastery of the L2, they will show the native-like ERP profile (including the biphasic LAN/P600). This pattern (e.g., N400 → small P600 → large P600 → LAN/P600) may therefore also be observed in children learning their mother tongue. Because children tend to show P600s, we would expect our participants to pattern like advanced L2 learners, showing small P600s, large P600s or, eventually, a LAN/P600 if they have attained adult levels of competence.

2. Experiment

We presented children with images of colorful objects, concurrently with concordant or discordant auditory stimuli, after having established that ERPs related to agreement errors (LAN/P600) can be elicited without grammaticality judgment in adults (Gascon *et al*., 2011). Based on our adult data for the same stimuli, semantic errors were expected to elicit N400s, while gender concord errors were expected to elicit biphasic waves or sustained positivities in children (NEG/P600 or P600) (Silva-Pereyra *et al*., 2005). As discussed above, the semantic N400 to visual-auditory mismatches for nouns has been observed in preverbal children (Friedrich & Friederici, 2004) while ERPs for morphosyntactic violations have rarely been studied in children (especially in French), and never for gender agreement.

2.1 Method

2.1.1. Participants

Fifty-two French-speaking children aged 4-8 (29F and 23M, aged from 4;6 to 8;9, *M*=6;8, SD=1;2) participated in the experiment, which was run at the *Institut universitaire de gériatrie de Montréal Research Centre* (CRIUGM).Children were recruited through advertisements posted atlocal schools, daycare centers, public libraries and sport centers in the area nearby the research center. They came to two separate recordings at the lab, and were paid for their participation. Their hearing was tested before the first recording.Testing protocols were approved by the internal review boardsof the *Sainte-Justine Research Centre* and the CRIUGM. Parents signed a consent form allowing children to participate in the study, and filled a demographic questionnaire that included questions about the child's health and linguistic development since birth. Children and parents could withdraw from the study at any time. In this preliminary analysis, the data of 14 children (7F and 7M, aged from 4;6 to 8;4, *M*=6;7, SD=1;2) were analyzed.

2.1.2. Stimuli

Stimuli selection was constrained by age of acquisition. 12 French nouns and 8 adjectives acquired before the age of three were used (Trudeau, Frank, & Poulin-Dubois, 1999). Online corpora were checked to provide frequency norms for our items. These include the Manulex (Lété, Sprenger-Charolles, & Colé, 2004), Novlex (Lambert & Chesnet, 2001) and Lexique (New, Pallier, Ferrand, & Matos, 2001), all frequency databases for written and spoken French, the first two based on children's books for grade-school. Nouns and color adjectives were combined to create 48 feminine and 48 masculine adjective-noun pairs that were inserted into carrying sentences containing a lead in (*je vois* 'I see'), and a sentence continuation prepositional phrase (*sur la table* 'on the table' or *dans la boîte* 'in the box') to avoid wrap up effects in the ERPs. Nouns and adjectives were chosen based on their imageability and were matched within category on age of acquisition (± 3 years old) and length. Half of the nouns were feminine and half of the adjectives were invariable (these have the same form in the feminine and the masculine). All critical nouns had consonantal onsets (to avoid elision — vowel erasure in the preceding determiner — an obligatory phonological process in French) and were unvoiced, to make sentence splicing more efficient. Auditory stimuli were recorded at 44.1KHz in a sound attenuated booth using a Sony DAT recorder (PCM-M1, 1997). All sentences were spoken by a native French Canadian actor who was trained to clearly articulate the words in a natural intonation while avoiding co-articulation at word boundaries. All conditions within a given block of stimuli were recorded together. However, only grammatical sentences were recorded, as tests in our lab have shown that ungrammatical structures cause subtle but systematic slowing in production as well as intonation modifications, even with trained speakers. Speaker intensity was maintained constant throughout the recording session by monitoring the speaker with a sonometer. Voice intensity was maintained at 65 dB (±5 dB) to reduce post-recording manipulations. Following stimuli recording, the sentences were normalized and spliced using Cool Edit software (Syntrillium Software, Phoenix, AZ). Sentences were normalised at 70%. Grammatical and ungrammatical sentences were constructed by cross-splicing the original recordings to prevent acoustic confounds (ex. … le | camion |brun … – … *la |camion|brun …. 'the.m| truck |brown.m – the.f|truck|brown.m') cutting at the onset of the determiner, the noun, the adjective, and the prepositional phrase (see examples in 1 with splicing points). Ungrammatical conditions were created by splicing determiners or adjectives of the wrong gender (masculine or feminine) into the sentence (1b/c). Incongruent nouns in the semantic condition (1a) did not share the initial phoneme of the congruent form (e.g., *train* [tʁɛ̃] 'train' – *soulier* [sulje] 'shoe') and belonged to a different semantic domain.A professional artist created a visual stimulus for each sentence, while emphasizing the relevant properties of interest. The drawings maintained a constant level of visual complexity, avoiding superfluous or distracting details. An example is presented in Figure 1.

(1) visual [BROWN SHOE ON TABLE]

a. Je vois | un | !train | brun | sur la table.
(visual-semantic error)
I see | a.m | train | brown.m | on the table
'I see a brown train on the table.'

b. Je vois | un.m | soulier | *brune | sur la table.
(adjective agreement error)
I see | a.m| shoe | brown.f| on the table
'I see a brown shoe on the table.'

c. Je vois | *une | soulier | brun | sur la table.
(determiner agreement error)
I see | a.f| shoe| brown.m | on the table
'I see a brown shoe on the table.'

Figure 1. Example of drawing used for 'there is a brown shoe on the table'.

2.1.3. Design

Conceptual semantic processing was investigated by creating semantic violations where the image did not correspond to the noun presented in the auditory stimulus (e.g., the sound file describes ‘a browntrainon the table’ and the image is of a brownSHOE on a table). Morphosyntactic agreement processing was studied by creating gender mismatches between the noun and the determiner, or the noun and adjective, in the auditory stimulus, that is by splicing in a feminine adjective or determiner with a masculine noun, or vice versa.

At each testing, we presented 288 stimuli sentences to each participant. Half were congruent (for gender agreement or semantics). Stimuli included grammatical control sentences (e.g., *je vois un soulier brun sur la table* ‘I see a brownshoe on the table’), semantically incongruous sentences (e.g., the same auditory stimulus with a picture of a brownTRAIN), and sentences with agreement errors on the determiner or the adjective (e.g., … **un/e soulier *brun/e* ... ‘a.m/f shoe.fbrown.m/f'). All violations were matched with a corresponding set of control sentences, which, as a whole contained the exact same words as the violations (balanced design, Steinhauer & Drury, 2012). In total, 576 sentence-picture pairs were presented in 36 eight-item blocs (288 items on each session). These were pseudo-randomized into four different lists. Prior to testing, children were assigned to one of the four lists.

The sentences were presented in the context of a story (our ‘Alien learning paradigm’ Labelle & Valois, 2003)in which an alien (named Zilda) is trying to learn French in order to visit Quebec.This storyline contained filler sentences, images and animations, which were interspersed throughout the experiment to maintain children's interest and attention. In this story, Zilda had to practice her French on the way to earth (in the first session) and while unpacking her boxes in her new house (in the second session). Children were familiarized with the procedure for a maximum of 15 practice trials followed by a testing period. During the story, children were reminded that Zilda had to practice her French. No feedback was given to children other than asking them to stay still (*Statue!*).

2.1.4. Procedure

Participants were invited for two visits (with a one-to-two week interval) to the lab at the CRIUGM. After a hearing screen, participants were fitted with a Biosemi ActiveOne cap with 32 electrodes (Figure 2) and were seated in a comfortable chair in an electromagnetically shielded room in front a computer screen. There was always a minimum of two research assistants during the procedure, one who remained at all times with the participant and one monitoring the experiment presentation and data acquisition. The visual stimuli were presented in the center of the computer screen simultaneously with the auditory stimuli, which were presented through internal headphones. Before each test trial, a fixation cross appeared on the screen for 2 seconds, followed by the visual and auditory stimuli. Children were instructed to keep their eyes open and to stay still during the presentation of stimuli (i.e., when something was shown on the computer screen and when hearing Zilda the alien speak).

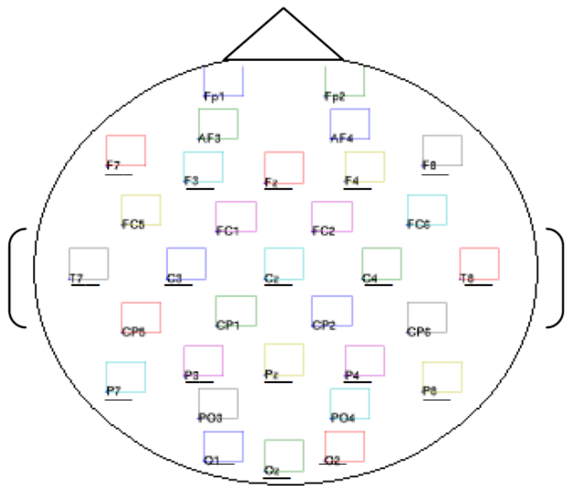

Figure 2. Electrode positions for EEG recording. Electrodes included in the analyses are underlined.

To avoid movement artifacts in the EEG recording, the research assistant sitting in the room with the child would play the 'statue' game (i.e., call out 'Statue!' and both the child and research assistant would stop moving). Children did not have any task to fulfill except for paying attention to presented stimuli. Each session of the test was divided into four parts, each divided into shorter blocks of eight stimuli, which were followed by filler sentences and animations. Pauses were scheduled throughout each session (minimally after five blocks of eight stimuli, more often if the child was becoming tired, produced excessive amounts of alpha or requested a pause) during which children could pick from an array of activities (e.g., making a postcard for Zilda's family and friends, coloring Zilda's home, feeding Zilda, etc.).

2.2. Data recording and analyses

The children's electroencephalograms (EEG) were recorded continuously during the experiment with a sampling rate of 250Hz using a Biosemi amplifier. EEG data were imported into EEProbe software for subsequent ERP analyses. Raw data were filtered offline (band-pass 0.3 to 30 Hz), after which we eliminated all trials contaminated with movement artifacts (+/- 30 mV). The preliminary data of 14 children chosen for the present analysis had high rates of uncontaminated trials (90% of all experimental trials retained). Data from electrodes F7, P7, T7, F3, C3, P3, O1, Fz, Cz, Pz, Oz, F4, C4, P4, O2, F8, T8 and P8 were entered in the analyses (see Figure 2).

Separate analyses were run for the three conditions. Using a baseline of 300 ms, data was analyzed for each condition starting at the onset of the determiner (lasting approx. 100 ms) and up to 1500 ms (for determiner-gender and semantic mismatch conditions) and 2000 ms (for adjective-gender mismatch conditions). Ungrammatical and incongruent conditions were compared to matched correct conditions. Repeated measures ANOVAs were conducted separately for midline and lateral electrodes with the factors CONDITION (C) (2 levels: congruent/grammatical, incongruent/ ungrammatical), ANTERIORITY (A) (2 levels: anterior, posterior) and ELECTRODE (E) (4 levels) in the midline and lateral analyses. The lateral analysis included the additional topographical factors HEMISPHERE (H) (2 levels: Left and Right) and LATERALITY (L)(2 levels: more vs. less lateral). An alpha of .05 was used for all statistical analyses and a Greenhouse-Geisser correction for sphericity was used for conditions where there was more than one degree of freedom in the numerator.

2.3. Results

Following averaging of incongruent or ungrammatical and control conditions over trials, visual inspection of the grand average ERP data revealed different patterns in the three conditions. First, in the semantically incongruent condition, we observed a negative-going, slightly left-lateralized wave in posterior central and lateral electrodes,emerging at approximately 350 ms and lasting until 700 ms. In the midline analysis, a trend towards significance of C*A was found in the time windows 400-500 ms ($p< 0.1$) and 500-700 ms ($p< 0.1$). In the lateral analysis, significant interactions of C*A(400-500 ms: $p> 0.01$; 500-700 ms: $p< 0.01$), and C*H(400-500 ms: $p> 0.01$; 500-700 ms: $p< 0.01$) were found in both time windows. This effect, resembling a classic N400, is illustrated in Figure 3.

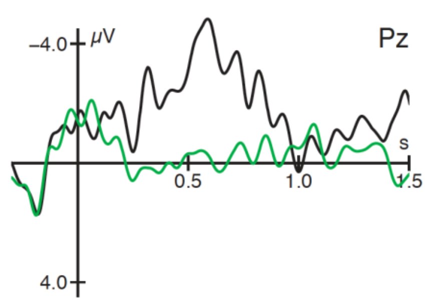

Figure 3. The semantic violation condition as illustrated by electrode Pz. The dark line indicates the semantically incongruent and the pale line indicates the congruent condition.

Due to technical problems, adjective data are not presented here. In the determiner agreement condition we first observed a sustained slightly left-lateralized frontal positivity, starting at approximately 200 ms after stimulus onset, and lasting throughout the whole analysis window (2 seconds). A second positive wave emerges in posterior slightly right-lateralized electrodes after 750 ms and last up to 2000 ms. In the midline analysis, no main effects or interactions involving CONDITION were observed. In the lateral analysis, a trend towards interactions of C*A*H is observed in the 250-500 ms time window ($p< 0.1$), as well as the 500-1000 ms time-window ($p< 0.1$). A trend towards a main effect of CONDITION is observed in the 1100-1500 ms time-window ($p< 0.1$). These effects are illustrated in Figure 4.

3. Discussion

Results show that children elicit distinct ERPs for semantic (N400s) and gender agreement violations (P600-like late positivities) in tasks without grammaticality judgments. In particular, semantic incongruencies resulted in posterior negative-going waves in typical time windows that have been shown for N400 effects (Kutas & Federmeier, 2000), while the ungrammatical condition resulted in positive going waves in frontal left-lateralized sites as well as posterior right-lateralized ones. The data for the Determiner-Noun agreement condition do not reach significance and should therefore be interpreted with caution. However, this condition elicits roughly similar patterns to those found in the child litterateure. These biphasic positivities could possibly be viewed as homologous to adult LAN-P600 patterns, even though the frontal patterns show polarities that are the opposite valence of those found in adults. Because of their left-lateralized distribution and strongest effects in T7, we surmise these might be "immature" reflexes of the adult LAN. One could argue that because these positivities are unlike those found in adults, and because children do not seem to show reliable negativities preceding the P600, that agreement concord processes are not yet automatized in children. Another interpretation of our data could be that children do process agreement, but that their brains processes it somehow differently from adults. Recall that the picture was presented at the onset of the sentence, before the onset of the determiner. This could explain the short latency of the frontal positivity (around 200 ms after determiner onset, or 100 ms after noun onset). In our adult data (Gascon *et al.*, 2011, Royle *et al.*, in preparation), we observed a similarly early ERP effect, which however, had a negative polarity. We tentatively interpret these effects as a combination of phonological and morphosyntactic mismatches.

Parallels can be made between first language acquisition and studies of second language (L2) acquisition using ERPs (Steinhauer *et al*., 2009) where L2 learners seem to go through different phases in the acquisition of their second language's linguistic constraints. The adult L2 ERP pattern (i.e., N400 → small P600 → large P600 → LAN/P600) could be expected to emerge in children learning their mother tongue. However, this does not seem to be the case in the

French children studied here. They seem to rather be going through the following pattern: Early positivity/P600 → LAN/P600. In order to support this, we will have to analyze a larger set of data with different age groups and check whether these changes do in fact occur.

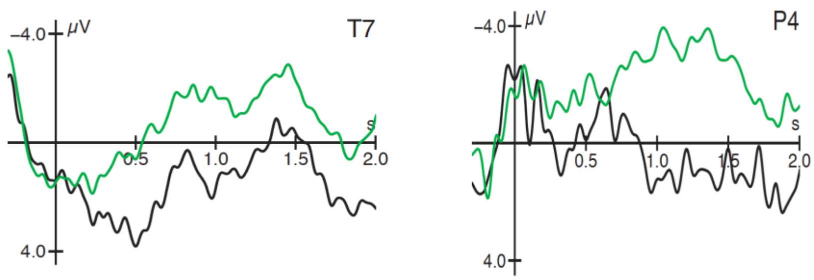

Figure 4. The Determiner-Noun gender mismatch condition as illustrated by electrodes T7 and P4. Dark line indicates the gender incongruent and the pale line indicates the grammatical condition.

In conclusion, we have demonstrated that ERPs can be used to investigate the development of semantic and grammatical abilities in children using oral language and visual (picture) stimuli, without grammaticality judgments. In addition, we have shown that ERP components elicited for semantic and gender agreement conditions are quite different and can thus be dissociated using this method. Potential for use with children who have, or are suspected of having, developmental language impairments are straightforward. In addition, this paradigm can prove useful in adult populations with communication impairments who cannot make grammaticality judgments of the traditional kind. Finally, comparisons of children and L2 learners would allow us to better understand similarities and differences in the maturation and development of brain-based linguistic processing in these two groups. By using finer-grained age-grouping based on or whole data set, we will be able to address a number of these questions.

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