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Chapter

LANGUAGE PROCESSING IN CHILDREN WITH SPECIFIC LANGUAGE IMPAIRMENT: A REVIEW OF EVENT-RELATED POTENTIAL STUDIES

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ABSTRACT

Recent advances in neuroimaging have allowed for insight into the millisecond-by-millisecond unfolding of language processing in the brain. In particular, event-related brain potentials (ERPs), non-invasive measures of scalp-based EEG (electroencephalographic) recordings of underlying brain activity, can reflect on-line neurocognitive processes involved in linguistic processing. In this chapter we will present a review of ERP research focusing on lexical-semantic, morphosyntactic and syntactic processing during language comprehension in children with and without specific language impairment (SLI). We will highlight results important for our understanding of SLI, as well as methodological issues and challenges involved in ERP research.

INTRODUCTION

Specific Language Impairment

Specific language impairment (SLI) is a language learning impairment often described as below-normal language proficiency in the presence of preserved general cognitive development (Leonard, 1998). SLI is usually diagnosed using exclusionary diagnostics and cannot be explained as being caused by other factors such as autism, neurological impairment or linguistic deprivation (Leonard, 2003). Children with SLI have reduced vocabulary development at early ages and typically exhibit difficulty in manipulating linguistic rules of inflection and derivation, as well as complex syntactic structures, in their native tongue. Their language comprehension is usually better than their production. Children with SLI can also present difficulties in domains such as articulation, pragmatics or even fine motor control, as well as reading and writing disorders. The study of children with SLI speaks directly to theories of language acquisition and language representation and processing, as the question arises as to what underlying problem is causing the observed language difficulties. It is not the goal of this chapter to present an extensive review of all theories of SLI. For this, we refer the reader to the seminal book by Leonard (1998) or a more recent review by Grela, Collisson, and Arthur (2013). Here we will present three hypotheses for the causes of SLI that can be empirically tested using ERPs.

A first hypothesis it that children with SLI present a general processing deficit, that is reflected in slower linguistic processing, but have relatively normal linguistic representations (e.g., Kail, 1994; Johnston, 1997; Leonard, 1998; Grela et al., 2013). The assumption here it that children with SLI have limits in their processing capacities, or a subset of general cognitive abilities, that slows down production, comprehension or language acquisition. Thus the observed difficulties in language production or comprehension are secondary to a more general cognitive processing deficit. A second hypothesis is that children with SLI have a developmental delay in language acquisition, that is they have normal linguistic and other cognitive abilities but later timing in the triggering or onset of language acquisition processes (Locke, 1994). Under this hypothesis, children with SLI should are believed to have relatively normal language acquisition abilities, but with later milestones than unimpaired children. A third hypothesis is that children with SLI have relatively intact cognitive abilities, with the exception of the grammar or specific subcomponents of grammar (e.g., Clahsen, 1989; Rice, Wexler & Cleave, 1995; Gopnik, Dalalakis, Fukuda, Fukuda, & Kehayia, 1997). In this case, general cognitive processes are not impaired in children with SLI but language-specific modules are, and in particular, productive rules of grammar such as tense marking, agreement, long-distance dependencies or other structural aspects of syntax, but also phonological and morpho-phonological rules. Various criteria are typically used to identify children with SLI in different languages (e.g., a difference between verbal and non-verbal IQ, having language scores below a certain cutoff as compared to unimpaired children, specific difficulties with sub-components of grammar, etc). Because languages differ in their typologies and complexities, these most probably play a role in the different criteria used to identify SLI. Thus, the experimental data are based on heterogeneous groups. Because few ERP studies have even investigated language processing in SLI using ERPs, we will include all studies that we find relevant to our review while leaving it up to the reader to check the sources for a fuller description of the populations studied, and their inclusion criteria.

Event Related Potentials

ERPs are measures of voltage change patterns from scalp-recorded electrical brain activity using EEG that are time-locked to the presentation of stimuli (Luck, 2005). Differences between the ERP "components" elicited by linguistic manipulations can be used to tease apart the action of brain-based neurocognitive behavior involved in different aspects of language processing. ERP components differ in whether they are negative or positive going (polarity), their timing (onset latency), how long they last (duration), what their scalp distribution is (topography), and whether the component peaks shift in latency (peak latency). This method has recently seen advances in the study of child language acquisition, both in impaired and neurotypical populations. Previous research has identified a number of ERP components relevant to identify and distinguish mental operations in linguistic sub-domains such as phoneme discrimination, word segmentation, prosodic and intonational phrasing, morphology, lexical semantics, syntax, discourse processing, and more.

Much of the ERP research (although not all) has focused on error-based paradigms, where a control condition (grammatical and semantically appropriate) is compared to ungrammatical, incongruous or otherwise difficult to process structures. These paradigms often use stimuli that resemble those of grammaticality judgment tasks traditionally used in behavioral research. One important feature of ERPs is that they can record ongoing sensitivity to grammatical or semantic errors across the entire utterance or sentence (measuring data points at each millisecond). This is a major advantage over traditional psycholinguistic tasks, but also online tasks such as lexical decision, self-paced reading and grammaticality judgment tasks, as the measurement is not based on a reaction time measure, linguistic output, or a judgment performed at the end of processing. In fact, grammaticality judgments are not even necessary to induce ERP effects (Royle, Drury, & Steinhauer, accepted). Rather, this method allows us to observe the unfolding of multiple domains of linguistic knowledge (phonetic, phonological, lexical, morphosyntactic, syntactic, and semantic) during the processing of linguistic stimuli. In the study of child language acquisition, a major selling point of ERPs is that you can elicit them without asking a child to perform any task. In some paradigms paying attention to the stimuli is not even necessary, although this is not usually the case for language structures involving lexical semantics and (morpho-)syntax at higher levels of processing.

Child ERPs

To date, relatively few studies have investigated ERP correlates of lexical-semantic, morphosyntactic and syntactic processing in children, and even less in SLI. Those studies that do, usually find differences between typically developing children and adults (when adults are included), but also between children with SLI and their peers, in terms of ERP latency, duration, scalp distribution or amplitude. However, as we will see below, specific patterns are influenced both by the linguistic domains studied and by age. Therefore, a good understanding of maturational effects on ERPs is necessary to understand the experimental data on SLI children. It has been suggested that linguistic and cognitive abilities in children influence their ERP patterns. Friederici (2002) links longer ERP latencies in children, as compared to adults, to slower processing speed in general. More recently Wray and Weber-fox (2013) establish a link between ERP patterns and performance on off-line cognitive and linguistic tasks in English-speaking children aged 7 to 9 years. In their study, children were divided into low- and high-normal groups on non-verbal IQ, morphosyntactic processing and word recall. Results seem to support the view that cognitive strengths (and weaknesses) might correlate with ERP patterns[1]. However, before we review the evidence on ERPs in children with and without SLI, we must first present some issues relating to their interpretation.

Methodological Issues

A number of caveats should be outlined before we move to the next section on linguistic ERP components. In particular, issues arise in child language studies that make our understanding of the data and results less than straightforward. A first challenge is to establish typical ERP profiles in normally developing children (Phillips, 2005). Few studies have focused on morphosyntactic and syntactic processing in normal language development, and the present state of knowledge is still quite sparse. Working with children also presents special challenges to the experimenter in terms of the ability of a child to do the task. In particular child participants' working memory and attentional capacities can strongly impact on language processing (see, e.g., Hildebrand, 1987 for children, and Friederici, Steinhauer, Mecklinger & Meyer, 1998 for adult ERP data). Because we still do not fully understand the impact of these factors on ERPs, especially in children, nor the interaction between these factors and language abilities, it is likely that further work on processing limitations is needed before we can fully understand their impact on child data.

Another issue linked to studies of children with language impairment is group matching with controls. Traditionally, research in language impairment will study psycholinguistic processing and clinical behavior in children with SLI and age-matched groups, in addition to language matched groups (e.g., matched on mean length of utterance, receptive vocabulary, or some other measure). In some cases, only language-matched groups are used as controls. These groups tend to be a few years younger on average then the children with SLI. However, as we shall see, the available data on brain maturation show important changes in neurotypical children's ERP profiles across different ages. It is therefore unwise to use only language-matched controls

[1] Non-verbal IQ is linked to processing speed (indexed by earlier onset of ERP components), verbal recall is linked to resource allocation for linguistic tasks (indexed by ERP componenet amplitude), while morpho-syntactic abilities are linked both to processing speed (as indexed by earlier onset of syntactic components) and to resource allocation (indexed by ERP componenet amplitudes). Note however that the morpho-syntactic condition presents baseline issues, see Methodological Issues.

in ERP experiments, as differences observed between impaired and unimpaired groups could simply be linked to maturation effects on brain organization, and to cognitive specialization and possibly automatization.

It goes without saying that stimuli must be adapted to the linguistic abilities of children. Complex structures and late acquired vocabulary (even if of high frequency) must be avoided. This is even more critical when studying children with language impairment, as lexical representation deficits and morphosyntactic abilities might be diminished in these groups. Unless the research question is directly related to syntactic complexity, syntactic structures should be as simple as possible and controlled across conditions. For example, ungrammaticality effects in passive structures in German show adult-like ERPs starting only at the age of 7 (Hahne, Eckstein & Friederici, 2004). Another issue is the use of written versus auditory stimulus presentation. A few of the studies presented below (for the most part with neurotypical children) use written stimuli, but most prefer auditory presentation. One advantage of written presentation is that stimuli are generally much easier to prepare, as no issues arise related to recording quality, splicing, avoiding intonation and other extraneous cues in the input. However, written presentation limits the lower ages at which we can test children's linguistic abilities and results from this type of study probably do not faithfully reflect true linguistic abilities in children. In addition, written presentation taxes working memory, as sentences are presented one word at a time to avoid eye-movement artifacts in the EEG recording. Children might be especially overloaded in these conditions, and children with reading disabilities, as is sometimes the case in children with SLI, even more so. However, auditory presentation also has its problems, because subtle cues as to the grammaticality of structures might be present long before the errors arise (for example, lengthening of vowels sentence-initially, intonation accent on errors or even abrupt changes in the intonation phrase when structures are spliced to create ungrammatical sentences). All of these cues are known to affect the ERP patterns and might even be the direct cause for some components that have been observed in the literature (Steinhauer & Drury, 2011).

Focusing on morphosyntactic and syntactic violation paradigms (see e.g., Friederici 2002), which are starting to be used in the study of language acquisition and SLI, a number of methodological concerns can be voiced. The two most important ones relate to how stimuli are created for ERP studies. A first issue is the nature of the errors created. Here we take two examples from Atchley, Rice, Betz, Kwasney, Sereno and Jongman (2006), but this study is by no means unique. They present agreement errors of the type '*Where *do a boy like to play?*' where the verb 'do' does not agree with the singular subject 'a boy'.[2] Note however that the sentence is not yet ungrammatical at the point where the ERP is analysed: at a. Consider the following alternative possible grammatical continuation after 'like': *Where do a boy like you and a girl like her like to play?* Other possible continuations are left up to the reader to discover. Importantly, this means that, when listening to this sentence, the point where we realize that it is ungrammatical is further downstream, at 'to'. The ERP wave elicited at 'a' is therefore not expected to reveal grammaticality effects. Another example, this time of a syntactic (structure) violation, is also taken from the same study. Here the auxiliary is deleted to create an outright structural violation as in '**Where Ø a boy like to play?*' Again, the sentence is not ungrammatical at the determiner. An alternative possible continuation would be '*Where a boy likes to play is anyone's guess*'. Again, it is only at 'to' that we can be certain of this sentence's ungrammaticality.

Other researchers create ungrammatical structures by inserting or transposing items, usually function words, as in *The scientist criticized Max's *of proof the theorem* (Neville, Nicol, Barss, Forster & Garrett, 1991), or by excluding an expected content word in a context that highly predicts it (e.g., *Die Gans wurde im gefüttert*, 'the goose was in-the fed', as compared to *Die Kuh wurde im Stall gefüttert* 'the cow was in-the barn fed', Hahne et al.,2004). In the second case, with deleted elements, it is quite difficult in fact to create outright violations. More importantly, both types of phrase structure errors also create baseline problems (see Steinhauer & Drury, 2011, for an in-depth discussion of these two issues). In ERPs, baseline corrections are used to correct for pre-target-word voltage differences (the target condition and its matched control), effectively bringing them to zero (also called *DC offset*) before the experimental manipulation. The baseline interval is a period of usually 50 to 200 ms pre-stimulus where the ERPs are 'brought together' in order to measure the 'true' effects linked to the critical stimulus of interest. The assumption is that up to the target word, the two conditions are identical and that any observed differences should be linked to the psycholinguistic manipulations of the experiment. We illustrate baselining in the hypothetical situations in Figure 1.[3] In Figure 1A, a comparison between correct and

[2] Throughout this chapter, the underlined word, here a, signals the point where the ERP was analyzed for a given condition.

[3] Note that following European tradition, negative ERP deflections are plotted *up* and positive ones are plotted *down*.

incorrect conditions is made without baseline correction. What we can observe is that both conditions show early differences after stimulus presentation (0 to 300 ms), but also before it (-200 to 0 ms) and no differences in the middle time-window. When the baseline is brought back to zero (in B), to compare the specific effects of our conditions we observe that the differences now occur in the N400 time window (see below for a discussion of components). Since we know that different words (and especially the difference between content and function words) can modulate the ERP signal (e.g., Münte, Wieringa, Weyerts, Szentkuti, Matzke &

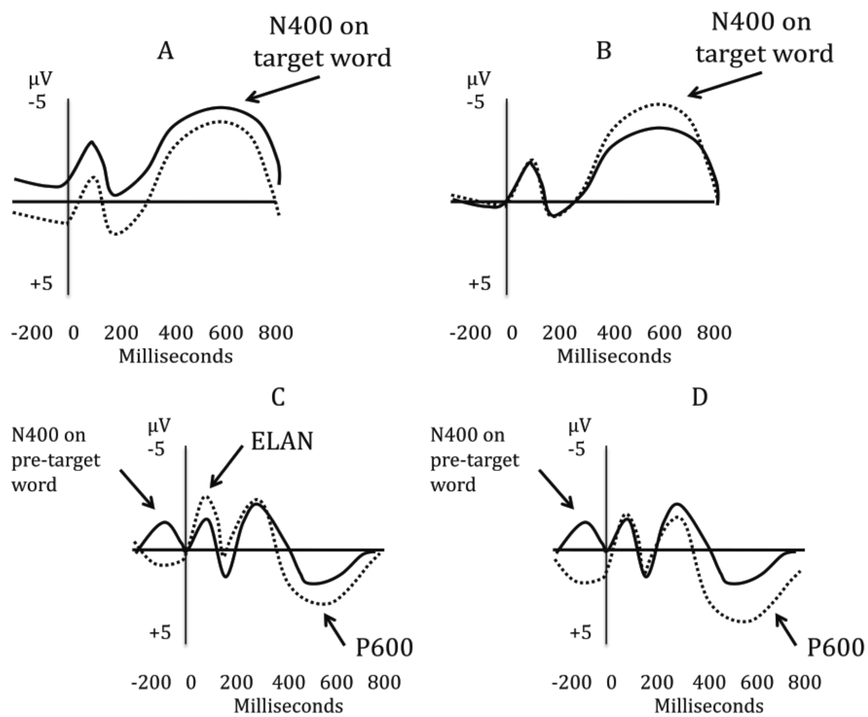

Figure 1. Comparison of hypothetical correct (full lines) and incorrect conditions (dotted lines) without baseline correction (A) and after baseline correction (B). In C we show how unmatched conditions can impact on ERP baseline correction and early negative and late positive ERP components by pushing up the negativity in early time-windows and reducing late positivities. In D we present an illustration of what the ERP components *might* look like without baseline correction problems. Negative is plotted up and positive is plotted down.

Johannes, 2001), having different types of lexical items in the baseline prior to the critical word can create DC offset effects into the ERP signal, most noticeably creating artifacts in the shape of stronger early negativities and smaller late positivities in the wave (1C), where the ungrammatical condition was more positive and the grammatical one more negative going in the baseline interval. Bringing these two conditions together in the baseline has the effect of pushing the ungrammatical condition into a more negative-going wave and the opposite effect for the grammatical one, thus creating an early negativity (the ELAN, see below) and reducing the amplitude of the P600. In 1D an example of how the results might look like without this DC offset effect is illustrated. Baseline correction problems are not a trivial matter and create serious issues in data interpretation.

Finally, we should note that many studies do not properly establish differences between participant groups by means of between-subjects ANOVAs. It is not sufficient to establish that one group shows a significant effect on some measure while a second does not (Nieuwenhuis, Forstmann & Wagenmakers, 2011). It is unclear to us why a number of these scientific articles do not perform direct statistical comparisons of their groups. Suffice it to say that for the reasons outlined here and above, we will often use conditional language in interpreting the available data. In the next section, we first present a review of well-known linguistic ERP components and move on to child language studies focusing on these same components. Following this we will review available ERP data on language processing in SLI.

ERP Components and Their Linguistic Correlates

The N400: Lexical-Semantic Integration

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 violations, for example *He spread the warm bread with !socks/ butter* (Kutas & Federmeier, 2000). 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; Courteau, Royle, Gascon, Marquis, Drury & Steinhauer, 2013).

The LAN/P600 Complex: Grammatical Processing

Grammatical errors involving tense, gender and subject verb agreement in auditory and visual paradigms elicit left-lateralized anterior negativity (LANs) or bilateral anterior negativities (ANs) between 300 and 500 ms after stimulus presentation (Gunter, Friederici, & Schriefers, 2000; Molinaro, Barber, & Carreiras, 2011; Royle et al., accepted). These are usually followed by a later positive-going wave (P600) emerging between 500 and 1000 ms after stimulus presentation (Osterhout & Mobley, 1995)[4]. Because, the P600 is elicited in many different paradigms (including those with complex syntactic structures), some have proposed that this component indexes processing load relating to syntactic integration or reanalysis, and that it is not specifically dedicated to grammatical processing (Steinhauer & Connolly, 2008). Thus the biphasic LAN/P600 complex is thought to reflect: (i) automatic morphosyntactic parsing indexed by the (L)AN, and (ii) structure integration or reanalysis indexed by the P600. Although the LAN is argued by some to be unstable and not a reliable component of morphosyntactic processing (e.g., Osterhout, McLaughlin, Kim, Greenwald & Inoue, 2004), others have argued that the P600 can be modulated by task, and is in fact more likely to reflect controlled processes than the LAN (e.g., Royle et al., accepted). In addition, these two components might appear at different stages in maturation, as we will see below. Suffice it to say that a majority of morphosyntactic ERP studies find both components for ungrammatical structures in adults. We thus review research showing both or either of these components to morphosyntactic errors.

[4] Note that the P600 also appears in semantically incongruent conditions discussed in the previous section (se e.g., Holcomb, Coffey & Neville, 1992; Juottonen, Revonsuo & Lang, 1996). Juottonen and colleagues do not observe it in children aged 5-11, while Holcomb's group demonstrates it in written and auditory ERPs with children (written: age 9-10; auditory: age 7-8) but do not discuss it in their article.

The Elan/P600 Complex: Syntactic Processing

Violations of syntactic structure (i.e., word category violations) also elicit biphasic biphasic waves that are often considered to be different from those found for morphosyntactic errors. Structural errors such as that found in *The scientist criticized Max's *of proof the theorem* elicit very early (often left-lateralized) anterior negativities (ELANs) between 100 and 200 ms after the target word, followed by the later P600 (Neville et al, 1991; Hahne et al., 2004). Similar to the LAN, the first negativity is thought to be an index of automatic parsing, but in this case of word category information (i.e., Noun, Verb, Preposition, etc). A few studies of syntactic error processing have found LAN/P600 complexes rather than ELAN/P600s for this type of structural error (see a review in Friederici, 2002). An issue with a majority of the studies showing ELAN/P600 complexes to syntactic errors is that they suffer from baseline correction issues, which might be driving the ELAN effects observed (see Steinhauer & Drury, 2012). However, baseline correction problems were avoided in Hasting and Kotz (2008), who observed ELAN/P600 complexes to phrase-struccure violations in two word utterances (e.g., *er kegelt* 'he bowls' vs. *er *Kegel_* '*he cone (noun)').

LINGUISTIC ERPS IN CHILDREN

Lexical-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 elicit N400-like components. They compared semantically congruous (where the auditory name of the object *chair* matched the image CHAIR) 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 between 700 and 1400 ms. This negativity is similar to the N400 observed in adults, which however starts somewhat earlier (at about 300 ms) and has a more focal prominence at parietal sites. Undergoing similar bimodal stimuli presentation, English-speaking children present N400 waves similar to adults in terms of latency and scalp distribution at the age of 7 years old (Cummings, Čeponienė, Dick, Saygin & Townsend, 2008). A developmental study of lexical-semantic processing in sentence contexts by Holcomb, Coffey, and Neville (1992) shows that a semantically incongruous noun (e.g., *Kids learn to read and* *write in !finger/school*) elicits a N400 in children as young as five years old in the auditory modality. Similar results have been found in English-speaking children aged 3 and 4 years (Silva-Pereyra, Rivera-Gaxiola & Kuhl, 2005), English-speaking children aged 8 to 13 years (*Where does a !chair/boy like to play?*)[5] Atchley et al. (2006), German-speaking children between the ages of 6 and 13, using sentences such as *Das !Baby/Lineal wurde gefüttert* 'The baby/straight edge was fed' (Hahne, Eckstein & Friederici, 2004), and in French-speaking children aged 4 to 9 using sentence-visual presentation with a visual mismatch to the auditory noun (i.e., hear: *Je vois un train brun sur la table* 'I see a brown train on the table', see: [a brown SHOE on the table], Courteau et al., 2013). Thus the lexical-semantic N400 for auditory sentence processing appears at very early stages of language acquisition in visual-auditory single-word or sentence paradigms, as well as in auditory sentence paradigms. The N400 amplitude differences between control and incongruous conditions, as well as amplitude means, appear to be larger in younger children (Juottonen, Revonsuo & Lang 1996; Holcomb et al., 1992). The N400 can also be delayed (Juottonen et al., 1996), longer lasting (Hahne et al., 2004) and have wider or different scalp distributions than that which is observed in adults (Hahne et al., 2004; Juottonen et al., 1996; Holcomb et al., 1992). In the written modality, Holcomb et al. (1992) elicited the N400 for *Kids learn to read and write in !finger/school*, in the youngest group able to read (i.e., 7-8 years-old).

Morphosyntactic ERPs have also been studied in children. When grammatically incorrect sentences are presented, a late P600-like positivity is observed in children aged 3 and older but early negativities (LANs or bilateral ANs) tend to take longer to emerge, possibly being preceded by sustained and often anterior positivities. Silva-Pereyra and colleagues (2005) presented children 3 and 4 years old with sentences in which there was a clash between the auxiliary and the verb (*My uncle will *watching the movie*). In 3-year-olds, children produced a continuous, widely distributed, and sustained positivity to ungrammatical structures, lasting between 200 and 1000 ms.

In a study of French-speaking children aged 4 to 9 using visual-auditory stimuli involving determiner gender agreement errors (e.g., *Je vois *une/un soulier brun sur la table* 'I see *a.f brown.m shoe.m on the table'), Courteau

[5] Note that these sentences are problematic, as the incongruency could appear at 'like', unless 'like' is taken to be an adjective, which would create other data interpretation difficulties. This is another problem with the Atchley et al. (2006) stimuli, as many of the sentences used contain this specific lexical item.

et al. (2013) observed both a sustained frontal positivity and a later P600 to gender agreement errors. The later P600 is similar to that found in adult speakers, but the early frontal positivity showed the opposite polarity than that found in adults (Gascon, Lebel, Royle, Drury & Steinhauer, 2011). In an auditory study of English-speaking children aged 8 to 13-years-old, a biphasic wave pattern with latencies similar to the adult LAN/P600 was found for sentences with agreement violations (*Where *do a boy like to play?*, Atchley et al., 2006). However, these data remain difficult to interpret for the methodological reasons discussed above. In her unpublished dissertation on agreement violations in 14- to 17-year-olds and young adults (19-23 years-old), with auditory sentences such as *Everyday, the musicians *tunes their instrument*, Meier (2008) observed late P600s, from 900 to 1400 ms in the teenagers' ERPs, while the adults' P600s occurred in the 700-1500 ms time-range. An anterior negativity found in adolescents was unreliable and none was observed in adults. However, an additional N400-like negativity was found in adolescents. 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 and less reliable effects for ANs than for the P600s. In addition, (L)ANs might change in polarity over the course of maturation. This polarity instability is observed in mismatch negativities (MMNs), termed mismatched responses (MMR) in child research, due to their instability in infants (see e.g., Morr, Shafer, Kreuzer & Kurzberg, 2002; Trainor, McFadden, Hodgson, Darragh, Barlow, Matsos & Sonnadara, 2003), and might also become more lateralized, although there is not yet any evidence for this. These data illustrate why it is important to take into account age/maturation effects in groups with wide age ranges.

In a study of case marking in German a similar pattern was identified in 4-year-olds, with a more focal distribution on central and right lateralized sites. Schipke, Friederici and Oberecker (2011) observed a positive-going wave in young German children (3-, 4-and-a-half and 6-years-old) during the auditory presentation of sentences with double-nominatives (e.g. *Der Tiger küsst *der/den Frosch* 'The-Nom tiger kisses the-Nom frog')[6], a thematic error in German that elicits N400/P600 waves in adults (Frisch & Schlesewsky, 2005). ERPs for the three age groups were characterized first by a broadly distributed frontal negative-going wave between 300 and 700

[6] Nominative case denotes subjects in German. The direct object of the verb should be in the accusative case.

ms after stimulus presentation. The negativity was followed by a late P600-like positive wave. This biphasic pattern was similar to the N400/P600 present in adult ERPs in equivalent conditions (Frisch & Schlesewsky, 2005), considering that N400s tend to be more broadly distributed in children than adults. However, in the same study, double-accusative violations (e.g. *Den Tiger küsst *den/der Frosch* 'The-Acc tiger kisses the-Acc frog')[7] do not elicit the adult-like pattern, but rather an early positivity in the youngest group, a late negativity in the 4-and-a-half year old group and a two negativities in the in the 6 year-olds (between 600–800 ms and 1300–1600 ms). The authors link ERP patterns in the double accusative condition to processing difficulties with accusative case due to its later acquisition.It thus appears that the N400/P600 complex can emerge in children, but depends on the structures studied, and most probably, the child's mastery of said structures.

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 plural overregularization errors in German (e.g., *Ein Kran belädt die grossen *Waggonen/Waggons im Hafen* 'A crane is loading the large wagons in the harbour'). A broadly distributed N400-like negativity is observed for these errors until the age of 8 when a biphasic wave — a negativity in anterior sites followed by a late P600 in the occipital region at 1000 ms — is seen. By the ages of 11 to 12 year old, a biphasic LAN/P600 pattern similar in distribution to adults is found, but with a longer latency in the P600. It thus appears, that ERPs for different types of errors within the same language (here overregularization versus case-marking errors in German) might show different emergence and refinement patterns.

Syntactic ERPs have been sparsely researched in children. In the study by Atchley et al. (2006) discussed above, the condition with auxiliary drop (*Where *Ø a boy like to play?*) was used to study syntactic processing. This condition results in a biphasic pattern similar to that for morphosyntactic errors, i.e., a LAN/P600 complex in English children aged 8 to 13. Using a word deletion paradigm (e.g., *Die Gans wurde im Ø *gefüttert* 'the goose was in-the fed'), Hahne, Eckstein and Friederici (2004) studied syntactic processing in German speaking children aged 6 to 13. All the groups except the six year olds showed the ELAN/P600 complex to ungrammatical structures, with older children showing earlier onset of the P600, similar to

[7] Accusative case denotes direct objects in German. One of the nouns should bear nominative case for subjecthood.

adults. The six-year-old group also showed a small P600, but this was preceded by an early positivity. However a previous study by Oberecker, Friedrich and Friederici (2005) observed a delayed ELAN in two-year-olds. Similarly to the data for morphosyntactic processing, these studies seem to indicate a process of maturation for syntactic processes, with late positivities emerging at young ages and showing earlier latencies with advancing age, while early negativities appear only around or after age 6. However, for methodological reasons discussed previously (mainly baseline correction problems, but in the case of Atchley et al. (2006) the additional absence of group comparisons), these data remain inconclusive.

Based on this short review, it appears that, at very young ages, children and adults show globally similar EPR components for lexical-semantic but not morphosyntactic and syntactic processing. Adult-like morphosyntactic and syntactic ERPs seem to emerge at different ages depending on the structures studied and the input modality (auditory or written). At the present time, it is unclear which morphosyntactic abilities mature earlier than others, as tasks on different grammatical processing domains (verb agreement, gender agreement, case and plural marking) have been undertaken in different languages. It could also be that the same linguistic process (e.g., agreement) matures at various time points in different languages, simply due to the variety in complexity, structures, or idiosyncrasy of the processes involved. However, the use of ERPs to study child language development is clearly motivated by the fact that some of the innovative studies presented above have provided data that shows, on the one hand, that ERPs can reflect lexical-semantic, morphosyntactic and syntactic processing in children, and on the other hand, that ERPs are sensitive to changes in the neurocognitive mechanisms underlying these processes. Based on these facts, we can extend the study of neurolinguistic processing using ERPs to children with SLI, in order to better understand the cognitive processes underlying their language difficulties.

If children with SLI replicate patterns found in unimpaired children we would expect to observe N400s on lexical-semantic violations at very young ages, while morphosyntactic, thematic role, and syntactic errors would show developmental trends on LAN/P600, N400/P600 and ELAN/P600 components, similar to their unimpaired peers. However, if children with SLI use different cognitive processes to acquire and process language, we would expect ungrammatical and semantically incongruous structures to elicit a number of diverging patterns. Based on the theories of SLI outlined above, we could expect children with language learning disorders to present one of the following patterns.

1) If children with SLI manifest general slowing in processing but normal patterns in their linguistic development, they should show normal ERP patterns with longer onset and offset latencies than unimpaired children. A possible outcome is that the timing of ERP components should be slower. Another is that slowing in early components could block later ones from emerging.[8]
2) If children with SLI manifest a delay in acquisition but normal pattern in their linguistic development, they should show similar ERP patterns but at later ages than those observed in unimpaired children. That is, their ERP signatures should be 'immature' as compared to age-matched peers, but similar to younger controls.
3) If children with SLI manifest deviance or difference in their linguistic development, they should show different or deviant ERP patterns from controls at all ages. These different patterns would signal the use of compensatory or alternative cognitive mechanisms for language processing.

Note that it is possible that children show one of these patterns in one specific linguistic domain (say lexical-semantic processing), but a different pattern in another (for example morphosyntactic processing). ERPs can allow us to tease these apart. It therefore seems that ERPs are a useful tool for the study of language processing in children with SLI, as we would expect processing difficulties to be reflected in their ERP components. Bearing this in mind, we now present a review of ERP studies involving children with SLI that focus on the domains of lexical-semantic, morphosyntactic and syntactic processing. We will present the studies and results by linguistic domain, as some issues with methodology and data interpretation are relevant only to certain paradigms.

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[8] This would be a cascade effect in the ERPs whereby an early process (say phonological encoding) is slowed town, causing a later one (say morphosyntax) to be slower to unfold, or even causing it to be unable to operate.

Lexical-semantic Processing in SLI

Available evidence on lexical-semantic processing of isolated nouns or within sentences tends to show a developmental pattern whereby younger children with SLI (or at risk for language impairment) show reduced N400s for lexical-semantic anomalies or other lexical-semantic incongruencies, while older adolescents show pattern normalization. A number of the studies reviewed here compare lexical-semantic to syntactic or morpho-syntactic processing in children with SLI. In this section we refer only to data on lexical-semantic processing and will return to other aspects of grammatical processing in the following sections.

Friedrich and Friederici (2006) investigated lexical-semantic processing in very young children with and without a risk for language impairment. They observed that the absence of an N400 at 19 months was a predictor of weaker language abilities at 30 months. They selected forty children from a previous study (Friedrich & Friederici, 2004) who had been further evaluated on expressive and comprehensive language abilities at a later age (30 months). Two groups of children were established, with one (n = 18) being at risk for language delay. Retrospective analyses of the ERP components obtained at 19 months show a strong and broadly distributed early positive component (starting at 150 ms) to lexical-semantic incongruencies in the at-risk group, while the second group showed a typical N400 preceded by a small early frontal positivity. According to these authors, the absence of an N400 at 19 months would predict language delay or language impairment. Sadly, no follow up study was undertaken to establish the existence of language impairment in the at-risk children at later ages.

Older children with a confirmed diagnosis of SLI show longer latencies for the lexical-semantic N400, as compared to controls. Cummings and Čeponienė (2010) presented bimodal stimuli to 16 children with SLI aged 7-15 years. Using visual-auditory presentation of images (e.g., ROOSTER) with verbs (the lexical condition, e.g., *crowing*) or environmental sounds (e.g., a rooster crowing)[9] they observed that children with SLI show longer latencies on the N400 to lexical incongruencies as compared to controls, whereas both groups show similar latencies on environmental sound N400s. Because these effects are not found with environmental sound-word pairings in children with SLI, the authors conclude that the observed integration

[9] Note that the items were not matched accross lists for length either in terms of "syllables" or duration.

difficulties are specific to the lexical-semantic domain. However, these data are not strongly supported by the statistical analyses on group effects and interactions with stimuli types (differences between environmental sounds and lexical N400s were about 27 ms longer in the SLI group, but amplitudes and distributions were astonishingly similar, as can bee seen in their ERP waves).

Studies of lexical-semantic processing in older children tend to find differences between children with SLI and their peers at relatively younger ages but not older ones. Sabisch, Hahne, Glass, von Suchodoletz and Friederici (2006), do not observe any (late or early) N400s to lexical-semantic anomalies in sentences containing incongruous verbs (e.g., *!Der Vulkan/Das Brot wurde gegessen*, 'The volcano/bread was eaten') in 16 German children with SLI aged 9-and-a-half on average. N400 amplitudes were also correlated with verbal short-term memory measures. However both children with SLI and controls show similar later P600s to these same errors. Sabisch and colleagues interpret the differences in the N400s as an indication of difficult lexical integration for verbs in SLI children. However, the additional computation linked to passive structures used in this study, and known to be difficult for children with SLI (van der Lely, 2005), could also have played a role. In her unpublished dissertation, Betz (2005) studied preteens (aged 11-13) and teenagers with SLI (aged 13-14) as well as teenager and adult controls, on lexical-semantic processing of sentences from Atchley et al. (2006), that is sentences of the type *Where does a !chair/boy like to play?*[10] Because the younger SLI group made unstable grammaticality judgments, only the older group was included in statistical analyses. All groups showed a relative negativity to semantic incongruencies, with no significant interactions between groups. Fonteneau and van der Lely (2008) studied lexical-semantic processing in teenagers and adults (aged 10-21 years) with G-SLI (Grammatical SLI, a subgroup of patients with difficulties specific to grammar processing, van der Lely, 2005) compared to language matched, aged-matched and adult controls. Sentences containing semantic anomalies (e.g., *Barbie bakes the !people/bread in the kitchen*) resulted in similar N400 patterns in all groups, with slightly different scalp distributions (more right lateralized) in younger language matched-controls. Weber-Fox, Leonard, Wray, and Tomblin (2010) studied lexical-semantic processing in teenagers with SLI and controls (aged 14-18), using sentences such as *Every day, the children !rust/pretend to be super-heroes*. No statistical difference

[10] See footnote 5.

was observed between participant groups on the N400 elicited by the semantically anomalous verb.

In the written modality, similar data are found. An early study of visual sentence processing by Neville, Coffey, Holcomb, and Tallal (1993) investigated sentence final incongruous nouns (e.g., *Giraffes have long !scissors/necks*) in nine-year old children with SLI and concurrent reading disorders, as compared to age-matched controls. Both groups showed the N400 for anomalous sentences with a tendency toward larger and more delayed components for the SLI group. Only the delay difference was significant in the between-group analyses. Another set of data from this same study shows that children with SLI showed larger N400s than controls to both open and closed class words. Finally, in a series of recent unpublished studies of visual lexical decision on single words using ERPs, Sizemore and colleagues show that English-speaking adolescents with SLI (aged 15 years) are less sensitive to word frequency than controls: that is they do not show modulation of the N400 by frequency (Sizemore, Evans & Hughes, 2009)[11]. In addition, in the SLI group, N400 effects might be correlated with non-word repetition abilities and receptive and expressive vocabulary scores, while it correlates only with receptive vocabulary scores in controls (Sizemore & Evans 2012). Unfortunately, these conference presentations have not yet been published as complete studies, and are difficult to evaluate in their present form. The majority if studies on lexical-semantic processing thus argue for a delay-with-normalization picture for the development of lexical-semantic processing in SLI. However, more subtle difficulties in lexical-semantic processing might still be present, as signaled by Sizemore's research.

Morphosyntactic Processing in SLI

Based on a limited set of experiments on morphosyntactic processing in SLI, it appears that ERPs might differ in children with SLI as compared to their peers. However, the available data is contradictory. Betz (2005) studied ERP responses to agreement errors (e.g., *Where *do a boy like to play?*, from Atchley et al., 2006) in teenagers 15-16 years old. While adults show a P600-like positivity to these "errors", none of the adolescents (SLI or control) show

[11] See Kutas & Federmeier (2011) for a review of N400 modulation by different factors including lexical status and frequency.

significant effects. However, the SLI group does show a trend, with an observable P600 in one parietal electrode (Pz). Again, for methodological reasons we discussed above, these data are inconclusive. More recently, Weber-Fox, Leonard, Wray, and Tomblin (2010) studied subject-verb agreement processing in teenagers with SLI (e.g., *Every day, the children *pretends/pretend to be super-heroes*). They observe a right anterior negativity (RAN) in both control and SLI groups, and a reduced P600 in the SLI group as compared to controls. This astonishing (and counter-intuitive) piece of data could be interpreted as meaning that automatic feature checking (as indexed by RANs) is intact, but that later integration and reanalysis processes (as indexed by reduced P600s) are impaired in SLI. To sum up, the studies reviewed show reduced or absent P600s to verb agreement errors in adolescents with SLI as compared to controls, but the Weber-Fox group also shows robust early negativities which are usually interpreted as automatic detection of grammatical errors. The data thus seems to support, in part, deviance or difference[12] in processing abilities in children with SLI.

Syntactic Processing in SLI

As with morposyntactic studies, the data on syntactic processing in SLI is still quite tenuous, because only a small number of ERP studies have probed these questions in children and adolescents with SLI, and most suffer from baseline correction issues. Many studies presented here were discussed in the above section on semantic processing, where information on age groups and controls is provided. Betz (2005), used *do*-omission structures from Atchley et al. (2006, e.g., *Where *Ø a boy like to play?*) to study syntactic processing in her teenage groups. All participants show a P600 to these "errors" with a later onset, larger amplitude and broader scalp distribution for the teenaged SLI group, which the author interprets as indicating later component maturation in SLI. Fonteneau and van der Lely (2008) studied syntactic processing in their four groups using sentences such as: *Who did Barbie push the clown into the *wall?* (as compared to *What did Barbie push the clown into?*)[13]. They found group differences in the ERP

[12] Since a mojority of studies inidcate that youger children tend to show similar, more distributed, or larger P600s than adults, smaller P600s are not interpreted here as a delay in language development abilities. However, further research might modify this picture.

[13] It is not clear whether the authors directly compared these two conditions, because they were in two different lists, and each participant heard only one list. Within the list, the control

patterns to ungrammatical structures, with LAN/P600 complexes in all participants except the G-SLI one, which showed a P600 followed by a late negativity. However, these data are astonishing, as the stimuli used should have elicited thematic-role N400/P600 biphasic waves (e.g., Friederici & Frisch, 2000; Frisch & Schlesewsky, 2005) rather than the ELAN/P600 complex. Moreover, at the point where the data are analyzed (i.e., *clown*) the sentences were not yet ungrammatical (consider *Who did Barbie push the clown into?*).

In addition to their study of lexical-semantic processing, Sabisch and colleagues (2009) probed sensitivity to syntactic errors to word-category violations in German children. In their syntactic condition (e.g. *Der Stock wurde ins *<u>geworfen</u>*, ‘The stick was in-the *thrown’, in comparison to *Der Stein wurde ins Wasser <u>geworfen</u>* 'The Stone was in the water thrown'), results showed a biphasic pattern linked to syntactic structural errors (ELAN/P600, with the AN being in fact bilateral and sustained over 1500 ms) in typical children, while the group with SLI showed a reduced LAN becoming significant between 700 to 1000 ms, followed by a P600. The second component was more largely distributed over the scalp, as well as having longer onset and offset latencies, than in controls. However, differences between groups on both components are not strongly supported by the statistical analyses, as interactions with group were either marginal or not present in certain contrasts. Again, for methodological reasons discussed at the beginning of this chapter (mainly ERP baseline correction problems, but also the fact that these structures are not properly ungrammatical, e.g., one could say *Der Stock wurde ins geworfen wirkende Stroh befördert.* ‘The stick was in-the apparently thrown straw moved’, and possibly, interference from prosodic effects due to splicing, Steinhauer & Drury, 2012), these data remain inconclusive.

In a study of grammatical subject and object Wh-question processing (e.g., *Who$_i$ t$_i$ kissed the hippo?* and *Who$_i$ did the hippo kiss t$_i$?*)[14] in 13

sentence was *Who did Alice in Wonderland push the <u>ball</u> into?*, which poses problems, as the subject noun phrases differ significantly in length (and most probably in frequency) in the two sentences, and might have an effect on the downstream ERP (including the baseline). In addition the design compares two different target words, where frequency, animacy and other factors might also influence ERP responses.

[14] Indices indicate where the Wh-word has moved from in the underlying structure. Object questions such as *Who$_i$ did the hippo kiss t$_i$* are known to cause processing difficulties typical in adults and children, and are hypothesised to be more difficult to process because of the long distance between the underlying syntactic position of the Wh-word and it’s surface position.

English-speaking children with SLI and 17 controls with an average age of 9, as well as 18 adults, Tropper, Hestvik, Shafer and Schwartz (2008) expected to show reduced sustained anterior negativities to object questions in children with SLI. These sustained negativities are linked to increased memory load in complex sentence structure processing (see e.g., Ruchkin, Johnson, Grafman, Canoune & Ritter, 1992; Friederici et al., 1998). While adults showed sustained negativities to object questions, typical children exhibited sustained positivities, and children with SLI showed similar but reduced positivities. However, no statistically significant differences were found between the two groups of children. (In a concurrent offline task, SLI children were at chance when judging these sentences for grammaticality.) However, the authors did not control for working memory abilities in their participants, thus introducing a confound in their design. In the same experiment, sentences preceding the ones with Wh-questions (with filled gaps, such as 'the camel' in *The zebra that the hippo kissed *[the camel] on the nose ran far away.*[15] as compared to adjunct structures like *The weekend that the hippo kissed [the camel] on the nose he ran far away*), were also presented to the children (Hestvik, Epstein, Shafer & Schwartz, submitted). Note, however that the filled-gap sentence is not ungrammatical at 'the' (consider *The zebra that the hippo kissed the other day…*). Control children elicit a bilateral AN at the filled gap between 0-200 ms and reappearing as a RAN at 500-600 ms, while children with SLI show late posterior negativities to this condition between 500-700 ms. The authors interpret this result as indicating a delay in grammatical processing in children with SLI. This interpretation does not consider the fact that the components in both groups are of a different nature (i.e., a posterior negativity in contrast to the RAN). If only a delay in processing was being observed, we would expect to observe the same types of components with different timing in both groups.

DISCUSSION

As mentioned above, lexical-semantic processing seems to show delay or difference in younger children with SLI, but also appears to normalize with age, at least in part. Because young children with SLI tend to have reduced

[15] Here the sentence is ungrammatical because 'the zebra' is the direct object of 'kissed', and the gap left by its movement to the head of the sentence cannot be filled with another complement, such as 'the camel'.

vocabularies as compared to their peers, the data on word recognition for very young children is not astonishing. However, it also appears that older children with SLI can process lexical semantics in ways similar to their peers. The ability to process lexical items might be modulated by phonological processing or mnesic abilities in children with SLI (Sizemore et al, 2009; Sizemore & Evans, 2012). These data seem to indicate that if studies on lexical access in SLI factor in psycholinguistic properties that are known to correlate with language difficulties (for example, phonological, morphological or semantic knowledge) we could beneficially use relatively simple ERP paradigms for the study of SLI. For example, priming studies on lexical access are a traditional approach to these questions and could be a useful approach to the study of lexical access in SLI (see Royle, Jarema & Kehayia, 2002, for a classic priming study with teenagers and adults with SLI). A number of ERP studies have fruitfully adapted primed lexical decision to brain imaging (see, Royle Drury, Bourguignon & Steinhauer, 2012, and references therein). This approach would allow for a better understanding of specific difficulties in lexical processing in subgroups of children with SLI (e.g., children with phonological disorders, or semantic pragmatic difficulties). Note that research on word recognition has shown that, in gating tasks, children with SLI do not differ from controls when recognizing frequent real words but do so only when they are required to recognize non-words (Dollaghan, 1998; Montgomery, 1999). Dollaghan (1998) interprets this as showing that word comprehension difficulties in children with SLI are related to lexical status. At present, most ERP research on auditory processing in children with SLI has not focused on words but rather on segments (phonemes and syllables), in conjunction with ERP components that have not been reviewed here. Further studies are needed to improve our understanding of lexical processing in these children. Studies should also be aware that sentences such as *Giraffes have long !scissors/necks* can elicit phonological mismatch negativities (PMN) whether the task is written or oral (Connolly & Phillips, 1994; Newman, Connolly, Service & McIvor, 2003). The PMN is linked to the expectation that the sentence final word is 'neck' and the initial letter or phoneme (in 'scissors') mismatches this expectation. The PMN can overlap with the N400 in the ERP wave (Connolly & Phillips, 1994) and care must be taken not to confuse lexical-semantic processing difficulties with phonological ones.

There is still too few data on morphosyntactic processing using ERP techniques to positively conclude whether children with SLI show differences or delay in this type of processing. Interestingly, Weber-Fox et al.

(2010) show apparently normal RANs followed by reduced P600s to subject-verb agreement errors. We could interpret these data as showing normal automatic agreement processing, but difficult controlled reanalysis and integration. Because only one study has presented interpretable data on the question, we must remain cautious with this explanation. However, processing of grammatical errors is a potentially rich area for research with children with SLI. Because these paradigms usually do not suffer from ERP baseline correction issues, their development should be straightforward in both written and auditory modalities.

One question the reader might ask is why do we observe P600 in morphosyntactic conditions that are not truly ungrammatical in teenagers with SLI (e.g., in Betz, 2005). As discussed in the introduction section, P600s can be elicited by hard-to process (e.g., passive) or garden path structures, as well as semantic incongruencies. Thus the appearance of a given ERP wave does not necessarily mean that we are measuring what we think we are, and these P600s could be linked to a number of other processing difficulties, which remain to be defined and studied.

Our review of the available studies of syntactic processing in children and teenagers with SLI leaves us with few interpretable data sets, mainly due to ERP baseline correction problems. It is clear that differences in processing are being revealed, but it is unclear what most of these studies are truly tapping. Data from Tropper et al. (2008) on Wh-questions could be interpreted as support for a hypothesis of syntactic processing difficulties in children with SLI, however, because they do not control for working memory abilities in their groups, this interpretation remains tenuous. Thus, new avenues of research in syntactic processing for SLI, and for children in general, need to be refined and run for us to gain a better understanding of neurocognitive processes underlying syntax in children with and without SLI. In particular, paradigms that avoid baseline correction problems should be developed (Steinhauer & Drury, 2012).

CONCLUSION

In this chapter, we reviewed a number of innovative research using ERPs with children and showed that ERPs are a useful tool for the understanding of normal and impaired language processing in children and adolescents. We observed that research on lexical-semantics has provided some insights into language processing in children with SLI. The data seems to support a pattern of delay followed by normalization in lexical-semantic processing. However, research on morphosyntactic processing is lacking, and research on syntax is at present mostly uninterpretable. Promising avenues of research have been suggested. In particular, lexical-semantic (and lexical-phonological as well as lexical-morphological) processing can be studied using classic lexical decision, naming and priming tasks in conjunction with ERP methods. In addition, lexical-semantic processing within sentences, as has been undertaken with adults and a small number of children studies, is also a promising avenue. Furthermore, research on morphosyntactic processing can easily be developed, as paradigms already used in language acquisition research can be adapted to ERP techniques (e.g., Courteau et al., 2013), as long as one pays careful attention to avoid methodological issues outlined above. Syntactic processing is harder to study, because of the difficulties in developing balanced designs where ungrammatical and control conditions differ only at the critical onset of the structural error. However, this is not an impossible task and would certainly shed light on (dis)abilities in sentence processing in children with SLI. Another avenue of research is to study grammatical, rather than ungrammatical, sentence processing, as Tropper et al. (2008) do. In their study, grammatical structures (e.g., *Who*$_i$ t_i *kissed the hippo?* and *Who*$_i$ *did the hippo kiss* t_i*?*) are compared in terms of processing load. The development of this type of paradigm holds the potential to highlight similarities and differences in normal sentence processing in children with SLI.

However, future research must involve sound designs. There serious issues with psycholinguistic designs used in some of the existing experiments reviewed, either in terms of the stimuli themselves or in terms of identifying the point in time when the incongruency or ungrammaticality appears in the sound stream or the text, need to be addressed. A recurring problem when adapting traditional psycholinguistic sentence stimuli for ERP experiments is the question of when exactly a sentence becomes ungrammatical. When looking at the sentence from a dynamic versus a static perspective, it quickly becomes apparent that some structures can be ‘rescued’ (or are in fact not ungrammatical) where they are expected to be. This has to be taken into consideration when developing designs for the on-line study of language processing. Interdisciplinary ERP research should always involve teams including experienced ERP scientists, to avoid erroneous critical timing for data recording and artifactual data interpretation, as well as language professionals (linguists and psycholinguists) to ensure that experimental designs are appropriate for the experimental questions addressed and the populations studied.

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