Prosodic Boundary Effects on Syntactic Disambiguation in Children with Cochlear Implants, and in Normal Hearing Adults and Children

Talita Maria Fortunato
*Graduate Center, City University of New York*

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Prosodic Boundary Effects on Syntactic Disambiguation in Children with Cochlear Implants, and in Normal Hearing Adults and Children

by

Talita Maria Fortunato

A dissertation submitted to the Graduate Faculty in Speech-Language-Hearing Sciences in partial fulfillment of the requirements for the degree of Doctor of Philosophy, The City University of New York

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Richard G. Schwartz, Ph.D.

_________________________  ________________________________
Date  Chair of Examining Committee

Klara Marton, Ph.D.

_________________________  ________________________________
Date  Executive Officer

Richard Schwartz, Ph.D.
Derek Houston, Ph.D.
Klara Marton, Ph.D.
Supervisory Committee

Eliane Schochat, Ph.D.
External Reviewer

THE CITY UNIVERSITY OF NEW YORK
Abstract

Prosodic Boundary Effects on Syntactic Disambiguation in Children with Cochlear Implants, and in Normal Hearing Adults and Children

by

Talita Maria Fortunato

Adviser: Professor Richard G. Schwartz

Theoretical Framework: Manipulations of prosodic structure influence how listeners interpret syntactically ambiguous sentences. However, the interface between prosody and syntax has received very little attention in languages other than English. Furthermore, many children with cochlear implants (CI) have deficits in sentence comprehension. Until now, these deficits have been attributed only to syntax, leaving prosody a neglected area, despite its clear deficit on this population and the role it plays in sentence comprehension. Purposes: Experiment 1 investigates prosodic boundary effects on the comprehension of attachment ambiguities in Brazilian Portuguese while experiment 2 investigates these effects in Brazilian Portuguese speaking children with CIs. Both experiments tested two hypotheses relying on the notion of boundary strength: the absolute boundary hypothesis (ABH) and the relative boundary hypothesis (RBH). The ABH states that only the high boundary before the ambiguous constituent influences attachment whereas the RBH advocates that the high boundary before the ambiguous constituent can only be interpreted according to the relative size of an earlier low boundary. Specific predictions of the two hypotheses were tested. Relationships between attachment results and performance on psychoacoustic tests of gap detection threshold and frequency limen were also investigated. Materials: The experiments were designed on E-Prime 2.0 software (Psychology Software Tools, Pittsburgh, PA). The sentences were recorded on Praat software (Boersma & Weenink, 2013), controlling for F0, duration of components and pauses between components. The prosodic boundaries were measured with the ToBI coding system distinguishing acoustic measures of intermediate phrase (ip)
and intonational phrase (IPh) boundaries. **Methods:** Twenty-three normal hearing (NH) adults, 15 NH children and 13 children with CIs who are monolingual speakers of Brazilian Portuguese participated in a computerized sentence comprehension task. The target stimuli consisted of eight base sentences containing a prepositional phrase attachment ambiguity. Prosodic boundaries were manipulated by varying IPh, ip and null boundaries. Participants also engaged on psychoacoustic tests that investigated gap detection threshold and frequency discrimination ability on nonlinguistic stimuli. An adaptive 3-interval forced-choice procedure was used in gap detection. For the frequency discrimination task, participants completed a same-different two-alternative forced choice task. **Results and Discussion:** Unlike NH adults and children, children with CIs did not exhibit an overall effect of prosody on syntactic disambiguation. Nonetheless, adults and children with NH and children CIs had the same two predictions of the RBH confirmed, suggesting that they perceived and used the relative size of the boundaries similarly. Two predictions of the ABH were confirmed for adults with NH whereas only one was confirmed for children with NH. The ABH does not govern the syntactic disambiguation of children with CIs. Children with NH were significantly slower than adults with NH to indicate a high attachment response in all prosodic types. However, hearing status did not influence processing speed. Gap detection thresholds and frequency limens on nonlinguistic stimuli did not influence the attachment of syntactically ambiguous sentences with different prosodic boundaries in adults and children with NH. Although children with CIs exhibited a decreased ability to perceive the acoustic changes on a nonlinguistic level, no correlation was found between frequency limens and proportion of high attachment. In children with CIs, gap detection thresholds were only correlated with the proportion of high attachment on sentences with strong prosody contrasts, suggesting that gap detection thresholds possibly influenced the attachment of syntactically ambiguous sentences with strong prosodic dissimilarity between boundaries.
I dedicate this dissertation to my husband, Gustavo, whose unconditional love and encouragement have always empowered me, and to our children, Luca and Olivia, without whom this dissertation would have been completed earlier, but certainly lacking the mirror of all the love, joy and inspiration they have brought to my life.
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“The hardest arithmetic to master is that which enables us to count our blessings”, Hoffer (1973).

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Prosodic Boundary Effects on Syntactic Disambiguation in Children with Cochlear Implants, and in Normal Hearing Adults and Children

Although some children with cochlear implants (CI) acquire language similarly to typically developing children, some of these children still have deficits in many linguistic competences, including syntax (e.g., Fujiyoshi et al., 2012; Tobey et al., 2013) and prosody (e.g., Chin, Bergeson & Phan, 2012; Cleary, Pisoni, & Kirk, 2005; Meister, Landwehr, Pyschny, Walger, & von Wedel, 2009; Straatman, Rietveld, Beijen, Mylanus, & Mens, 2010). Individuals with CIs have syntactic deficits such as omission of morphological markers, agreement and omission of syntactic constituents (Friedmann & Szterman, 2005; Miyamoto, Houston, Kirk, Perdew, & Svirsky, 2003; Tur-Kaspa & Dromi, 2001). However, most studies of syntax in children with CIs rely on production and results from standardized measures that provide little information on specific syntactic structures or about the role of prosody in syntactic comprehension.

There is general evidence that children with CIs do exhibit deficits in prosody (e.g., Chin et al., 2012; Cleary et al., 2005; Meister et al., 2009; Straatman et al., 2010). However, it is difficult to determine which components of prosody are affected and to what extent. The studies on prosody and CI users mainly focus on tones and linguistic stimuli at word level, leaving prosody at the sentence level little understood. In general, an overall prosodic deficit is observed in production (Chin et al., 2012), discrimination of rising intonation on the last word of questions (Meister et al., 2009; Straatman et al., 2010), identification and discrimination of stress at word level (minimal pairs) (Meister et al., 2009; Lyxell et al., 2009), and discrimination of talker and gender (Cleary et al., 2005; Meister et al., 2009).

Prosody plays an important role in sentence comprehension (e.g., Carlson, Clifton, & Frazier, 2001; Schafer, Speer, & Warren, 2005; Snedeker & Trueswell, 2003). However, there has not been an attempt to investigate its role on the syntactic abilities of children with CIs. This study will examine whether children with CIs are able to perceive the acoustic characteristics of prosody, more specifically prosodic boundaries, and whether they are able to apply these cues as an aid to syntactic disambiguation.
Prosodic Boundaries and Syntactic Disambiguation

The comprehension of a sentence depends on several factors, such as the lexical content at a word level, the structure at a syntactic level, and the prosody form in which it is delivered. Prosody may influence lexical and syntactic interpretations and affect the resolution of lexical and syntactic ambiguities (e.g., Cooper & Paccia-Cooper, 1980; Garro & Parker, 1982; Kutik, Cooper, & Boyce, 1983). If your mother says to you, *I want chocolate cake and milk*, with no prosodic boundary (a break in the continuum of the sentence) between *chocolate* and *cake*, it means she wants a piece of chocolate flavored cake and some milk. However, if she puts a prosodic boundary between *chocolate* and *cake*, it means that she wants some chocolate, a piece of cake and some milk. Prosodic boundaries also have an effect on disambiguation of syntactic attachment ambiguities (Carlson et al., 2001; Clifton, Carlson & Frazier, 2002; Diehl, Friedberg, Paul, & Snedeker, 2014; Schafer, 1997, Snedeker & Trueswell, 2003; Snedeker & Casserly, 2010). For example, the sentence in (a) has two possible interpretations. The prepositional phrase *with blue backpacks* can be attached to *boys* or to *boys and girls*. If a low attachment is employed, only *girls* have blue backpacks. In contrast, *boys and girls* have blue backpacks when high attachment is employed.

a) Boys and girls with blue backpacks are at school.

Two hypotheses aim to explain the relationship between prosody and syntactic ambiguity. Both hypotheses rely on how prosodic boundaries affect the resolution of ambiguity. The Anti-attachment hypothesis (Watson & Gibson, 2005) focuses on the effect of a single prosodic boundary immediately before the ambiguously attached phrase (marked as B) in (b): the absence of a boundary at B favors low attachment, whereas the presence of a boundary at B favors high attachment (e.g., Marcus & Hindle,
Carlson and colleagues argued that previous studies based on the Anti-attachment hypothesis typically involved a larger boundary at B than the one marked at A below. They then demonstrated in a series of comprehension studies with different syntactic constructions (e.g., relative clauses, conjunctions, adverbial adjuncts, prepositional phrase modifiers, adverbs) that the relative boundary size of two boundaries (A and B) has an effect on interpretation (Carlson et al., 2001; Clifton et al., 2002). This lead to the Informative Boundary Hypothesis (Clifton et al., 2002), which suggests that prosodic boundaries interact with each other and the effect of the boundary at B depends on the size of any earlier relevant boundary (for example A, on (b) below). When boundary at A is bigger than B, low attachment is favored (only girls have blue backpacks); when boundary at B is bigger than A, high attachment is favored (boys and girls have blue backpacks); when the two boundaries are equivalent, neither low or high attachment is favored.

b) Boys$_{A}$ and girls$_{B}$ with blue backpacks are at school.

Snedeker and Casserly (2010) investigated how maintaining the size of the low boundary (B) constant while varying the size of the high (A) boundary changed the interpretation (basically, an inverse Anti-attachment Hypothesis). They also aimed to further generalize the influence of the relative boundary size, as most of the evidence to the Informative Boundary Hypothesis (Clifton et al., 2002) had come from one research group. Snedeker and Casserly (2010) introduced two hypotheses relying on the notion of boundary strength that clearly isolates these theories: the absolute boundary hypothesis (ABH) and the relative boundary hypothesis (RBH). The ABH relates to Watson and Gibson’s Anti-Attachment Hypothesis (2005) and states that the absolute size of the low prosodic boundary predicts syntactic attachment independent of the high boundary: a low boundary favors high attachment and the absence of a boundary at low favors low attachment. The Relative Boundary Hypothesis (RBH) relies on predictions of the Informative Boundary Hypothesis (Clifton et al., 2002) and states that the relative size of the two
boundaries (high and low) predicts attachment: a larger low than high boundary favors high attachment, a larger high than low boundary favors low attachment, and when the two boundaries are equivalent neither attachment is favored.

Most studies analyzing the effect of prosodic boundaries on syntactic ambiguity resolution assume a phonological system that specifies the size of a boundary and distinguishes between a word boundary, an intermediate phrase boundary (ip) and an intonational phrase boundary (IPh). This description follows the ToBI (tones and break indices) coding system, a prosodic annotation procedure (Beckman & Hirschberg, 1994; Pierrehumbert, 1980). This system represents the relative prominence of words in an utterance and their prosodic grouping. Furthermore, the ends of prosodic boundaries are associated with changes in F0, duration, and pauses, with IPhs involving more extreme changes than ips and null (0) boundaries. By adopting the ToBI system, Snedeker and Casserly (2010) developed specific predictions of ABH and RBH. All predictions relate to the placement of prosodic boundary pairs in high (A) and low (B) positions. In the current study, boundary pairs will be referred to as A, B to indicate which boundary type (0, ip or IPh) was placed in each position (A/high and B/low). Under the ABH, sentences with a low IPh have higher probabilities of high attachment than sentences with a low ip, which in turn, have higher probabilities of high attachment than sentences with a null (0) low boundary. Under this rationale, the predictions of the ABH are all considered regardless of the size of the high boundary: (0, 0) < (0, ip) < (0, IPh); (ip, 0) < (ip, ip) < (ip, IPh); (IPh, 0) < (IPh, ip) < (IPh, IPh). For the RBH, sentences in which the low boundary is bigger than the high boundary have higher probabilities of high attachment than sentences in which the low boundary is equal to the high boundary which, in turn, have higher probabilities of high attachment than sentences in which the low boundary is smaller than the high boundary: (ip, 0) < (0, 0) < (0, ip); (IPh, 0) < (ip, ip) < (0, IPh); (IPh, ip) < (IPh, IPh) < (ip, IPh).

Based on the ABH and the RBH (Snedeker and Casserly, 2010), the prosodic boundary pairs 0,ip; ip, IPh; and 0, IPh have high attachment predictions in both ABH and RBH and the boundary pairs ip, 0 and IPh, 0 have low attachment predictions under both hypotheses. Note that in all high attachment predictions, the high boundary is larger than the low boundary. Similarly, in all low attachment predictions,
the low boundary is smaller than the high boundary. The remaining three boundary pairs have different predictions under the two hypotheses: IPh,ip has a low attachment prediction under the RBH and a high attachment prediction under the ABH; 0,0 and ip,ip have neutral predictions under the RBH and low and high attachment predictions, respectively, under the ABH.

Snedeker and Casserly (2010) tested the unique predictions of ABH and RBH in normal hearing (NH) English-speaking adults and found that neither hypothesis alone was sufficient to account for the relation between prosodic phrasing and the attachment of an ambiguous phrase. Nevertheless, neither hypothesis was completely discarded. In support of the RBH, they found that the high boundary influenced interpretation when there was no boundary before the ambiguous phrase (0,0 > ip,0; 0,0 > IPh,0). Additionally, the high boundary influenced the interpretation of sentences that would be predicted to have neutral or low-attachment prosody based on the low boundary alone (ip,ip > 0,0; IPh,ip > IPh,0; IPh,ip > ip,0), supporting the ABH.

A few additional points about the study of these hypotheses and their predecessors arise. First, the predictions of these hypotheses have been tested mainly in English. The need for studies in other languages is important to clarify whether this phenomenon is language specific or is maintained regardless of prosodic specificities of each language. Second, until now these two hypotheses have been tested mainly in typically developing populations. Third, and most importantly, children with language impairment do not recognize linguistic prosody cues (Wells & Peppé, 2003) even when the linguistic information is filtered out (Fisher, Plante, Vance, Gerken & Glattke, 2007) and there is no information available on whether the deficits so far attributed only to syntax in children with CIs can also be a matter of their deficient prosodic input.

Cross-linguistic Considerations of Intonation and Prosodic Boundaries

Many challenges arise when attempting to compare intonation across languages. The number of cross-linguistic studies is limited and comparing information presented in different studies is a difficult task. The approaches and frameworks vary considerably as many authors choose to develop their own description system. However, within this body of work, there is a group of researchers who have followed
a concise and community-based approach by adopting the conventions of the ToBI system, developed for English (Beckman & Hirschberg, 1994; Pierrehumbert, 1980). Adaptations of ToBI to other languages, such as Brazilian Portuguese (Lucente, 2008), Catalan (Prieto, 2014), German (Grice, Baumann & Benzmüller, 2005), Greek (Arvaniti & Baltazani, 2005), Japanese (Venditti, 2005), Spanish (Beckman, Díaz-Campos, McGory & Morgan, 2002) and many others have been successfully developed. As most studies analyzing prosodic boundaries make use of the description of null boundary (0), intermediate phrase (ip) and intonational phrase (IPh) as categorically described by the ToBI system, the cross-linguistic approach of the effects of prosodic boundaries on parsing should be more straight-forward than other aspects of prosody.

Although intonational systems vary considerably among languages – and, therefore, how pitch accents are distributed throughout a sentence according to the ToBI system also varies -, the categorical characterization of null boundaries, ip, and IPh remains in many languages. For instance, French and English - the two languages with most of the studies on the effect of prosodic boundaries on parsing - and Brazilian Portuguese - the language under investigation in the current study - have different intonation but share similar ip and IPh roles. English and Brazilian Portuguese have similar intonation in the sense that English (Abercrombie, 1967) and Brazilian Portuguese (Cruttenden, 1997) are both stress-timed languages (the duration between two stressed syllables is equal). French, however, is a syllable-timed (the duration of every syllable is equal) language (Gibbon & Williams, 2007) and, unlike English and Brazilian Portuguese (and many other languages), French intonation is characterized by a continuation pattern: stress is not placed on a particular syllable; rather, the final syllable of each rhythm group has a rising pitch (Lian, 1980). However, despite their differences and similarities, English, French and Brazilian Portuguese exhibit robustness of ip and IPh characteristics (Sneder & Trueswell, 2003; Millotte, Wales, Christophe, 2007; Tenani, 2002, respectively), which warrants the analysis of ABH and RBH in their current states.

**Prosodic Boundaries and Disambiguation in Brazilian Portuguese**

Most of the studies on prosodic boundaries and syntactic disambiguation in Brazilian Portuguese
have relied on reading. In general, these studies indicate that visual segmentation is used on reading, suggesting a prosodic boundary effect on disambiguation (Freitas, 2003; Lourenço-Gomes, 2008; Magalhães & Maia, 2006). Studies analyzing the prosody-syntax interface on an auditory level are more limited in number and have not yet focused on hypotheses related to prosodic boundary strength - as the Relative Boundary Hypothesis (RBH) and the Absolute Boundary Hypothesis (ABH) (Snedeker and Casserly, 2010) and their predecessors - and the role on syntactic disambiguation. In general, the studies on sentence interpretation and prosodic boundaries in Brazilian Portuguese are more limited in scope, focusing only on whether a prosodic boundary affects or not the comprehension of ambiguous sentences.

Lourenço-Gomes (2008) conducted experiments in reading and listening in which the ambiguity of sentences was resolved by gender agreement. These experiments revealed a greater acceptance of sentences with forced local attachment caused by a high boundary. In the auditory experiment, the only criterion used for the prosodic boundary creation was the insertion of pauses. It should be highlighted that the type of a prosodic boundary is not only determined by the characteristics of pauses between phrases. A more detailed analysis of other acoustic parameters of the boundaries such as changes in $F_0$ and word/syllable lengthening is necessary, so that related variables can be controlled. Other studies have focused on the question of which acoustic parameters of prosodic boundaries have the most influence on the interpretation of syntactically ambiguous sentences in Brazilian Portuguese (e.g., Fonseca & Magalhães, 2007; Serra & Frota, 2009). Serra and Frota (2009) concluded that, for Brazilian Portuguese, not all cues are relevant for the perception of prosodic boundaries. In a perception of prosodic boundaries task, the pauses were the main clue to the perception of an IPh boundary and consequent comprehension, followed by the extension of constituent. $F_0$ variation showed a lower consistency in the results. In contrast, a different study (Fonseca & Magalhães, 2007) that manipulated the prosody of test sentences in four different conditions ($F_0$ elevation, vowel lengthening, silent pause, and neutral reading), not focusing on specific prosodic types such as IPh or ip, found that $F_0$ elevation was the most significant clue to interpretation of syntactic ambiguity of Brazilian Portuguese. It is possible that pauses overcome $F_0$ effects in Brazilian Portuguese IPhs, and that, in contrast, $F_0$ is more relevant in Brazilian ips.
Experiment 1 of the current study investigated how null boundaries (0), ip, and IPh influence comprehension of syntactically ambiguous sentences in the auditory modality in Brazilian Portuguese by varying $F_0$ and length of the word preceding the boundary and the pause succeeding the boundary. It also tested the ABH and the RBH as predictors of attachment in ambiguous sentences, providing novel findings of how (or if) ABH and RBH govern attachment in Brazilian Portuguese. Furthermore, children and adults were included to investigate possible developmental differences on the effect of prosodic boundaries on syntactic disambiguation.

**Prosodic Boundary Perceptual Development**

Mothers provide infant-directed speech containing $F_0$ change, pre-boundary vowel lengthening, and pause duration - all of which are prosodic cues correlated with prosodic boundaries - regardless of the hearing status of their infants (Kondaurova & Bergeson, 2011; Silva & Name, 2014). Children exhibit early sensitivity to prosodic boundaries (Nazzi, Bertoncini & Mehler, 1998; Nazzi, Floccia & Bertoncini, 1998; Silva & Name, 2014) and there is evidence that infants use prosody to perceive the relevance of syntactic grouping (Hawthorne & Gerken, 2014). Studies have shown that children as young as 10 months old are sensitive to ip boundaries depending on the prosodic structure of the language they are exposed to. Gout, Christophe and Morgan (2004) showed that English-speaking children between 10 and 13 months are sensitive to the effect of ip in the recognition of lexical units. On the other hand, babies exposed to French only revealed this sensitivity at 16 months (Millotte, Margules, Dutat, Bernal, & Christophe, 2010), possibly due to less strong prosodic cues available in French.

The sensitivity to IPh has been reported in 5-month old infants who are exposed to German (Männel & Friederici, 2009). The authors investigated how the properties of the IPh boundary in German are processed by 5-months olds and how these properties are exploited differently when compared with adults. Like adults, the 5-months old infants in the study presented responses to stimuli in the presence of different cues that mark the IPh boundary ($F_0$ variation, lengthening and pauses), but responses were absent when pause cues were removed, which did not happen in adults. This demonstrates developmental differences in IPh processing for German. Brazilian children who are 13 months old are
sensitive to IPh and use that information to understand infant directed speech as showed by a preferential looking paradigm (Silva & Name, 2014). In that study, IPhs of infant directed speech were characterized by increases in pauses, $F_0$, and length of tonal vowels preceding the boundary.

However, sensitivity to prosodic boundaries at word level does not reflect the ability to apply prosodic boundary cues in syntactic disambiguation. Korean speaking children between three and four years used prosodic information to resolve lexical ambiguities, but were not able to use prosodic information to resolve syntactic ambiguities at five or six years of age (Choi & Mazuka, 2003). Similarly, Snedeker & Trueswell (2001) reported that mothers of four to six year olds varied their prosody systematically depending on the targeted interpretation but their children were unable to use prosody to resolve ambiguity. Snedeker and colleagues (Snedeker & Trueswell, 2001; Snedeker & Yuan, 2008) suggested that poor performance on syntactic disambiguation tasks by young children is the result of effects of executive function limitations, due to the required shifting of response among trials. Children have to overcome interpretation from previous trials to arrive at the current trial’s response. The authors achieved this conclusion by applying a between subjects design in which four and five year olds were subjected to a task with two blocks. In each block, children were exposed to only one of the two prosodic forms: You can pinch the bear/ with the barrette or You can pinch/ the bear with the barrette. Half of the children were exposed to the first prosodic form on the first block and half to the second form. On the second block, the prosodic forms were switched and children were exposed to the other form. On the first block, children performed as adults, and were able to use prosodic cues to correctly disambiguate the sentence. On the second block, children performed at chance, particularly in the initial trials, suggesting difficulty overriding the previous interpretation. The authors claimed that four and five year olds do have the ability to use prosodic forms to disambiguate syntax but they do not have the skills to override the previous interpretation in within subject designs.

Diehl and colleagues (2014) conducted the same experiment as Snedeker and Yuan (2008) with children and adolescents with typical language development and autism spectrum disorders. In the first block, the authors found main effect for prosody and no effect for age or diagnosis, indicating that children
and adolescents, regardless of being on the autism spectrum, applied prosodic boundary information to disambiguate the sentences. In the second block, however, the authors found a main effect for prosody and marginal interactions for prosody and age, prosody and group, and prosody and group and age, suggesting that the way children and adolescents used prosodic information to disambiguate sentences changed as the experiment progressed. In their study, eye movements also revealed age effects. Three eye tracking measures were made on each of the two blocks to reflect the looking time at the target at different time points of the sentences. In the sentence *You can turn over the bear with the stick*, the proportion of looking time to the target instrument (i.e., stick) was measured at the time window until *with* (0-200 ms), the second window (233-700 ms) included fixations after the critical word *stick*, and the third window included fixations after the end of the utterance. On the first block, they found only a marginal interaction between prosody type and age in the early window – no other interactions were significant. On the second block, significant interactions between age and prosody were observed for the first and second time frames, indicating that children and adolescents with typical development differed in how long they looked to the target instrument early on the sentence. This possibly suggests that adolescents found the target response faster than children. In the last time frame, however, this effect disappeared, possibly suggesting that children arrived at the target response and, therefore, looked at the target stimulus for as long as adolescents. Furthermore, on the second block children showed an early effect of prosody, with eye gaze indicating a preference for opposing stimuli to the target of the responses. This may be reflective of gaze preferences from the earlier trials. This early effect disappeared as sentences progressed, and the correct target became the major fixation of children with typical development. However, children with autism spectrum disorder showed no effect for prosody. Furthermore, the interference of prosodic interpretations of earlier trials across later trials disappeared by the age of eight years. The authors speculated that by this age children showed improved ability to overcome interference, as showed by eye tracking measures.

Together, these developmental studies show the importance of prosodic structure for language acquisition and that typically developing infants are able to perceive some acoustic characteristics of
prosodic boundaries in many languages. A possible inability to perceive prosodic boundaries caused by the poor prosody input that the CI provides might affect the correct segmentation of phrases and consequently cause comprehension deficits. There is also evidence of a developmental pattern involved in the perception of prosodic boundaries. Thus, if children who receive CIs do not follow the typical developmental pattern due to their input deficit, their ability to segment phrases and consequently correctly comprehend syntactic structures might also be affected.

**Acoustic Characteristics of Prosodic Boundaries**

One characteristic of the acoustic changes that create a prosodic boundary is a brief period of silence. Perception of this cue requires temporal resolution, which is the ability of the auditory system to respond to rapid changes in the envelope of a sound stimulus (Shinn, Chermak, & Musiek, 2009). Temporal resolution is typically evaluated through a psychoacoustic measurement known as gap detection. Assessment of acoustic gap detection involves the presentation of two stimuli that are separated in time by a gap (i.e., a brief period of silence). The purpose of the procedure is to determine the smallest interval that a listener can detect, which is also known as the gap detection threshold. Gaps vary in duration generally by ms. Gap detection thresholds in normal hearing (NH) adults range from one to 3 ms (Phillips, 1999) or marginally higher (Phillips & Smith, 2004).

It is uncertain exactly when temporal resolution develops in childhood, but it happens during the process of language acquisition. Barreira and colleagues (2011) investigated the performance of Brazilian children with no hearing complaints aged between seven and 12 years on the Gaps-in-Noise (GIN) test (Musiek et al., 2005). Although with increasing age there was improvement in gap detection thresholds, this improvement was minimal. This finding is in agreement with those of a norms study of GIN for the ages between seven and 18 years carried out in the United States (Shinn et al., 2009). In that study, the authors indicated that for English speaking individuals the temporal resolution reaches adulthood values at least at seven years of age. The gap detection thresholds obtained in the Brazilian study ranged between 4.75 and 5.65 ms. These values were very close to those obtained by the American researchers – 4.45 and 5.18 ms for 11 and seven year olds respectively - which suggests that American and Brazilian
children exhibit similar performance with respect to the temporal resolution when assessed by the GIN test. In general, behavioral studies using multichannel CIs have indicated that the mean gap detection threshold is approximately 30 ms with a wide range between 1.8 and 128 ms (Busby & Clark, 1999; Drennan, Longnion, Ruffin, & Rubinstein, 2008; Wei, Cao, Jin, Chen, & Zeng., 2007).

Another characteristic of prosodic boundaries is a change in $F_0$ (or pitch). Frequency discrimination is typically measured by comparing a stimulus tone to a reference tone in order to determine the minimum difference in Hz that the listener requires to differentiate the two tones (frequency limen). Individuals with NH have less difficulties discriminating frequencies at a low frequency base (for example between 1000 and 1004 Hz) than at a high frequency (for example between 4000 and 4004 Hz) (Musiek, 2009). The frequency limen for NH adults are between two and 3 Hz for standard frequencies at or below 500 Hz and increasingly higher for standard frequencies at or above 1000 Hz (Wei et al., 2007). Adults with CI usually have frequency limens that are 10 to 100 times poorer than adults with NH at 500 Hz, and have difficulties discriminating standard frequencies above 500 Hz (Wei et al., 2007). In general, a difference of 2.5 semitones is sufficient for children with NH to identify to stimuli as different. Children users of bimodal CI and hearing aid require, on average, a difference of at least 6.5 semitones, whereas children with CIs need an average of 10 semitones (Straatman et al., 2010).

The hearing loss itself and the use of CIs may impair the ability to identify gaps and discriminate frequencies when compared to NH. However, it is expected that the ability of a CI user to identify prosodic boundaries should not be extremely affected. The acoustic changes of prosodic boundaries are generally stronger than the thresholds obtained by most CI users in many studies. However, most psychoacoustic studies have used nonlinguistic stimuli. Nonlinguistic acoustic thresholds may overestimate identification and discrimination of acoustic changes in linguistic stimuli (Heeren et al. 2012). Thus, it remains unclear whether children with CIs are able to apply these acoustic cues at the sentence level. The second experiment of the current study examined whether children with CIs are able to perceive the acoustic characteristics of prosody, more specifically prosodic boundaries, at a nonlinguistic level, and whether they are able to apply these cues at the linguistic level as an aid to syntactic comprehension. These
nonlinguistic measures of gap detection and frequency discrimination were also applied to NH children and adults in experiment 1 to investigate whether performance on such psychoacoustic measures would correlate to linguistic performance on the prosody task.

**Purposes and Hypotheses**

The first experiment investigated the prosodic boundary effects in Brazilian Portuguese. The purpose of this experiment was to investigate how normal hearing (NH) adults and children who were monolingual speakers of Brazilian Portuguese benefited from acoustic parameters of prosodic boundaries to disambiguate syntactically ambiguous sentences. Experiment 1 served as a means to test the Informative/Relative Boundary Hypothesis (Clifton et al., 2002; Carlson et al., 2001; Snedeker & Casserly, 2010) and the Absolute Boundary Hypothesis (Snedeker & Casserly, 2010 based on Watson and Gibson, 2005) in Brazilian Portuguese. The two hypotheses were examined by varying the strength of the two boundaries in a sentence comprehension task. This manipulation permitted an examination of how relative and absolute boundary strengths influence the interpretation of syntactically ambiguous sentences. Processing speed of these syntactically ambiguous sentences was also investigated through response time measures for each prosodic form across groups. This experiment also applied psychoacoustic tests of frequency discrimination and gap detection to permit further understanding of the interaction between thresholds of acoustic correlates of prosodic boundaries and how prosodic boundaries are used for sentence disambiguation.

It was anticipated that prosodic boundaries would have an effect on children's and adults' syntactic disambiguation in Brazilian Portuguese, as it does in English. This was hypothesized because both languages share similar roles of intermediate phases (ip) and intonational phrases (IPh). Therefore, some, but not all specific predictions of ABH and RBH would be confirmed, as observed for English. No differences in specific predictions of the hypotheses were expected between children and adults, as children should already show developed perception abilities of ips and IPhs by the age of eight. Nonetheless, children would possibly be slower to process the ambiguities. Furthermore, it was also hypothesized that gap detection thresholds and frequency limens would be related to how prosodic
boundaries affect the interpretation of ambiguous sentences.

The second experiment examined whether children with CIs are able to perceive acoustic characteristics of prosodic boundaries on a nonlinguistic level and their ability to benefit from prosodic boundaries at a linguistic level to aid syntactic disambiguation. This study contrasts the Informative/Relative Boundary Hypothesis (RBH, Clifton et al., 2002; Carlson et al., 2001; Snedeker & Casserly, 2010) and the Absolute Boundary Hypothesis (ABH) (Snedeker & Casserly, 2010 based on Watson and Gibson, 2005) in children with CIs and a group of age-matched children with NH. The predictions of the RBH and the ABH have yet to be tested in children with CIs. The present study investigates whether both factors serve as characteristics of the prosody-syntax interface in this population. Furthermore, possible differences in processing speed between children with and without CIs was investigated through response time analyses. Experiment 2 also applied the psychoacoustic tests of frequency discrimination and gap detection to examine the interaction between thresholds of acoustic correlates of prosodic boundaries and the use of prosodic boundaries on syntactic disambiguation by children with CIs.

It was predicted that children with CIs would exhibit a decreased ability to perceive the acoustic changes related to prosodic boundaries when compared to their NH peers. Therefore, more acoustically salient prosodic boundaries, such as IPh, should be better perceived by children with CIs. Consequently, boundary salience would have a greater impact on syntactic disambiguation in these children, which would interfere with the ABH and RBH predictions. For example, predictions involving the contrast between an IPh and 0 (no boundary) would be more likely to be confirmed than predictions involving an ip, IPh contrast, which, in turn, would be more likely to be confirmed than predictions involving an ip, 0 contrast. The likelihood of confirmation of each prediction based on acoustic salience of the boundaries is expressed as more likely (predictions involving the contrast between IPh and 0), less likely (predictions involving IPh and ip) or unlikely (predictions with ip and 0). These predictions are illustrated on the chart below (Figure 1). Under this rationale, the specific RBH prediction IPh,0 < 0,0 would be more likely to be confirmed than predictions similar to the ABH 0,0 < ip,ip. It was anticipated that children with CIs would
possibly be slower than children with NH to process the ambiguous sentences due to their previously reported prosodic and syntactic deficits.

Figure 1. Chart displaying the likelihood of specific predictions of Relative Boundary Hypothesis (RBH) and Absolute Boundary Hypothesis (ABH) being confirmed for children with cochlear implants considering acoustic saliences of null (0), intermediate phrase (ip) and intonational phrase (IPh) boundaries.
General Method

Overview

The experiments reported here applied an auditory sentence comprehension task to investigate the role of prosodic boundaries in syntactic disambiguation in Brazilian Portuguese speaking adults with normal hearing (NH) and children with and without cochlear implants (CI). The two experiments also tested specific predictions of the Relative Boundary Hypothesis (RBH) and the Absolute Boundary Hypothesis (ABH) (Snedeker & Casserly, 2010). Gap detection and frequency discrimination tasks were applied to investigate the relationship between nonlinguistic thresholds of acoustic parameters of prosodic boundaries and the effect of those boundaries on syntactic disambiguation.

Participants

Characteristics of participants are described in Experiments 1 and 2.

Stimuli

Prosody. The target stimuli consisted of eight base sentences (see Appendix A), each containing a prepositional phrase attachment ambiguity like those in the example (c) below.

(c) TucanosA e galinhasB com maçãs verdes estão na gaiola.

ToucansA and chickensB with green apples are in the cage.

All sentences contained a noun phrase (NP) followed by a prepositional phrase (PP) and a verbal phrase (VP). Each NP, PP and VP had the same number of syllables in all eight sentences. Prosodic boundaries were placed at A and B, respectively high and low boundaries (illustrated as a prosodic boundary pair A, B). The sentences were recorded in each of the eight prosodic boundary pairs: 0, 0; 0, ip; 0, IPh; ip, 0; ip, ip; IPh; IPh, 0; IPh, ip. Please note that the boundary pair containing two intonational boundaries (IPh, IPh) was not included. Like Snedeker and Casserly (2010), it was verified that the IPh, IPh pair sounded unnatural.
Sixteen unambiguous filler sentences were mixed with the target experimental sentences in order to create two contrasting prosodies and decrease awareness of the target manipulation. Eight filler sentences contained a predicate attachment (see Appendix B), like in (d), and eight contained a reflexive assignment (see Appendix C), like in (e). These filler sentences were previously used in studies that did not investigate prosody (Fortunato-Tavares, et al., 2012; Fortunato-Tavares et al., 2015). New recordings of the original sentences were made, focusing on stress manipulations. For example, in sentences such as (d), stress was alternately placed on noun 1 (N1) (rabbit) or noun 2 (N2) (dog) and in sentences such as (e) stress was alternately placed on N1 (dad) or N2 (grandpa). There were no pauses after N1 or N2.

\[ d) \ O \ coelho_{N1} \ na \ frente \ do \ cachorro_{N2} \ é \ cinza. \]

The rabbit \(_{N1}\) in front of the dog \(_{N2}\) is grey.

\[ e) \ O \ pai_{N1} \ na \ frente \ do \ avô_{N2} \ está \ se \ lavando. \]

The dad \(_{N1}\) in front of the grandpa \(_{N2}\) is washing himself.

All sentence stimuli were produced by one female native speaker of Brazilian Portuguese and recorded using the Praat software (Boersma & Weenink, 2013), a Philips Stereo Headphone SBC HP195 - M-Audio Mobile Pre USB (preamp and audio interface) and a B-5 Behringer Gold- Sputtered Diaphragm Studio Condenser Microphone, at the Phonetics Laboratory of Universidade Federal de Minas Gerais. The speaker was a trained linguist and produced each utterance in the most natural manner possible. Recordings focused on phonetic properties of boundaries, where prosodic boundaries were characterized by changes in acoustic parameters, more specifically duration and \(F_0\) changes immediately before the boundary and pauses immediately after the boundary. Therefore, intonational phrase (IPh) boundaries were accompanied by pauses of approximately 300 ms and the intermediate phrase (ip) boundary contained pauses of approximately 100 ms – null boundaries had no pauses. Increased durations and \(F_0\) of the nouns should be observed when prosodic boundaries followed them. More specifically, these
increments were bigger on IPh than on ip than on null boundaries. The words preceding IPh boundaries were longer than those preceding ip boundaries, which in turn should show more lengthening than the ones prior to null boundaries. The same pattern was aimed for $F_0$ on the word preceding the boundary. The parameters related to prosodic boundaries ($F_0$ and duration of nouns preceding boundaries and pauses after boundaries) were posteriorly measured and statistically analyzed to ensure that consistent prosody was created across items in the same condition and that the different conditions satisfactorily contrasted each other. Table 1 shows the $F_0$ and duration values (summed duration of the noun preceding the boundary and the pause after the noun) for each boundary type, independently of the boundary position (A or B).

Table 1.

Mean (Standard Deviation) and [Range] of $F_0$ Values of the Noun that Preceded the Prosodic Boundary (in Hz) and of the Summed Duration of the Noun and Pause that Preceded the Prosodic Boundary (in ms) According to Prosodic Boundary Type

<table>
<thead>
<tr>
<th>Boundary Type</th>
<th>Noun $F_0$</th>
<th>Noun + Pause Duration</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>228.6 (20.8)</td>
<td>857.7 (180.2)</td>
</tr>
<tr>
<td></td>
<td>[193 – 317]</td>
<td>[557 – 1310]</td>
</tr>
<tr>
<td>Ip</td>
<td>255.4 (27.6)</td>
<td>1557.2 (165.0)</td>
</tr>
<tr>
<td></td>
<td>[210 – 343]</td>
<td>[1156 – 1901]</td>
</tr>
<tr>
<td>IPh</td>
<td>289.2 (42.2)</td>
<td>1829.1 (228.7)</td>
</tr>
<tr>
<td></td>
<td>[241 – 447]</td>
<td>[1448 – 2430]</td>
</tr>
</tbody>
</table>

Note. IPh = intonational boundary; ip = intermediate boundary; 0 = null boundary; $F_0$ = fundamental frequency; Hz = Hertz; ms = millisecond.

One-way ANOVA revealed that the $F_0$ of nouns preceding the three boundary types differed ($F(2, 143) = 44.720, p < .001, r = .62$). Post hoc tests with Bonferroni corrections showed that the difference
occurred at each comparison (all $p < .001$). The duration of the noun preceding the boundary summed with the duration of the boundary pause also differed across the three boundary types ($F(2, 143) = 322.910, p < .001, r = .91$). Post Hoc tests with Bonferroni corrections revealed that the differences occurred among all prosodic boundary types (all $p < .001$).

Table 2 displays $F_0$ values of $N_1$ and $N_2$ (preceding boundaries A and B, respectively) according to boundary pair. As expected, t-tests revealed that boundary pairs with identical prosodic boundaries in both A and B showed no differences in $F_0$ of nouns 1 and 2 and an increased $F_0$ in IPh when compared to ip, as well as ip when compared to null boundaries. The only exception was the 0, ip condition, in which the $F_0$ of the two nouns did not differ. This could be related to the fact that there is a debate on whether $F_0$ changes aid on interpretation of syntactically ambiguous sentences in Brazilian Portuguese (Fonseca & Magalhães, 2007; Serra & Frota, 2009). However, if this were true, the lack in $F_0$ difference should be seen in the contrast between ip and null boundaries regardless of boundary position, which was not true (see Table 1). The high variation of $F_0$ values on the second noun could also be a source of explanation for the lack of significance.

Table 3 displays the duration values (noun plus pause) of boundaries A and B in each prosodic boundary pair. As for $F_0$, the t-tests on duration measures revealed no significant differences between boundaries A and B when the two prosodic pairs were identical (0, 0 and ip, ip). Statistically significant differences were found when the two prosodic boundaries were different on the pair – longer for IPh when compared to ip, and longer on ip when compared to null boundaries.
Table 2

Mean (Standard Deviation) and [Range] of $F_0$ Values of Noun 1 and Noun 2 (in Hz) According to the Prosodic Boundary Pair

<table>
<thead>
<tr>
<th>Prosodic Boundary (A, B)</th>
<th>Noun 1 $F_0$</th>
<th>Noun 2 $F_0$</th>
<th>T-Test</th>
</tr>
</thead>
<tbody>
<tr>
<td>0, 0</td>
<td>219.4 (8.5)</td>
<td>207.1 (10.2)</td>
<td>$t(7) = 2.944, p = .220, r = .55$</td>
</tr>
<tr>
<td></td>
<td>[210 – 237]</td>
<td>[193 - 221]</td>
<td></td>
</tr>
<tr>
<td>0, ip</td>
<td>235.1 (14.9)</td>
<td>288.9 (41.7)</td>
<td>$t(7) = -2.834, p = .250, r = .53$</td>
</tr>
<tr>
<td></td>
<td>[216 – 263]</td>
<td>[242 – 343]</td>
<td></td>
</tr>
<tr>
<td>0, IPh</td>
<td>248.4 (32.0)</td>
<td>309.2 (64.8)</td>
<td>$t(7) = -3.820, p = .007^*, r = .68$</td>
</tr>
<tr>
<td></td>
<td>[221 – 317]</td>
<td>[242 – 447]</td>
<td></td>
</tr>
<tr>
<td>ip, 0</td>
<td>253.1 (16.3)</td>
<td>228.1 (12.3)</td>
<td>$t(7) = 5.161, p = .001^*, r = .79$</td>
</tr>
<tr>
<td></td>
<td>[227 – 271]</td>
<td>[205 – 248]</td>
<td></td>
</tr>
<tr>
<td>ip, ip</td>
<td>256.6 (18.6)</td>
<td>237.6 (16.2)</td>
<td>$t(7) = 2.225, p = .061, r = .41$</td>
</tr>
<tr>
<td></td>
<td>[232 – 288]</td>
<td>[210 – 255]</td>
<td></td>
</tr>
<tr>
<td>ip, IPh</td>
<td>254.4 (14.0)</td>
<td>334.0 (23.3)</td>
<td>$t(7) = -9.767, p &lt; .001^*, r = .93$</td>
</tr>
<tr>
<td></td>
<td>[237 – 278]</td>
<td>[304 – 385]</td>
<td></td>
</tr>
<tr>
<td>IPh, 0</td>
<td>274.1 (14.7)</td>
<td>233.2 (14.2)</td>
<td>$t(7) = 5.461, p = .001^*, r = .81$</td>
</tr>
<tr>
<td></td>
<td>[254 – 292]</td>
<td>[212 – 251]</td>
<td></td>
</tr>
<tr>
<td>IPh, ip</td>
<td>266.0 (17.2)</td>
<td>241.6 (21.3)</td>
<td>$t(7) = 2.804, p = .026^*, r = .53$</td>
</tr>
<tr>
<td></td>
<td>[241 – 284]</td>
<td>[221 – 283]</td>
<td></td>
</tr>
</tbody>
</table>

Note. IPh = intonational boundary; ip = intermediate boundary; 0 = null boundary; $F_0 =$ fundamental frequency; Hz = Hertz; *significant differences.
Table 3

Mean (Standard Deviation) and [Range] of the Duration (in ms) of the Nouns Summed with their Subsequent Pauses According to Prosodic Boundary Pair

<table>
<thead>
<tr>
<th>Prosodic Boundary (A, B)</th>
<th>Noun 1 + Pause A Duration</th>
<th>Noun 2 + Pause B Duration</th>
<th>T-Test</th>
</tr>
</thead>
<tbody>
<tr>
<td>0, 0</td>
<td>827.9 (126.9)</td>
<td>921.5 (169.9)</td>
<td>t(7) = -1.008, p = .347, r = .13</td>
</tr>
<tr>
<td></td>
<td>[568 – 984]</td>
<td>[808 – 1310]</td>
<td></td>
</tr>
<tr>
<td>0, ip</td>
<td>693.6 (110.7)</td>
<td>1626 (103.0)</td>
<td>t(7) = -17.414, p &lt; .001*, r = .98</td>
</tr>
<tr>
<td></td>
<td>[557 – 836]</td>
<td>[1521 – 1823]</td>
<td></td>
</tr>
<tr>
<td>0, IPh</td>
<td>678.9 (94.9)</td>
<td>1881.0 (243.2)</td>
<td>t(7) = -12.168, p &lt; .001*, r = .95</td>
</tr>
<tr>
<td></td>
<td>[565 – 823]</td>
<td>[1589 – 2430]</td>
<td></td>
</tr>
<tr>
<td>ip, 0</td>
<td>1209.4 (127.9)</td>
<td>1019.4 (117.7)</td>
<td>t(7) = 3.775, p = .007*, r = .67</td>
</tr>
<tr>
<td></td>
<td>[1156 – 1558]</td>
<td>[847 – 1145]</td>
<td></td>
</tr>
<tr>
<td>ip, ip</td>
<td>1605.5 (77.7)</td>
<td>1669.7 (115.7)</td>
<td>t(7) = -1.560, p = .163, r = .26</td>
</tr>
<tr>
<td></td>
<td>[1490 – 1718]</td>
<td>[1564 – 1901]</td>
<td></td>
</tr>
<tr>
<td>ip, IPh</td>
<td>1659.2 (104.1)</td>
<td>2147.4 (206.7)</td>
<td>t(7) = -5.802, p = .001*, r = .83</td>
</tr>
<tr>
<td></td>
<td>[1528 – 1872]</td>
<td>[1713 – 2340]</td>
<td></td>
</tr>
<tr>
<td>IPh, 0</td>
<td>1793.6 (121.1)</td>
<td>1005.0 (101.4)</td>
<td>t(7) = 17.267, p &lt; .001*, r = .98</td>
</tr>
<tr>
<td></td>
<td>[1710 – 2065]</td>
<td>[886 – 1163]</td>
<td></td>
</tr>
<tr>
<td>IPh, ip</td>
<td>1811.0 (96.6)</td>
<td>1492.2 (69.6)</td>
<td>t(7) = 6.400, p &lt; .001*, r = .85</td>
</tr>
<tr>
<td></td>
<td>[1726 – 2031]</td>
<td>[1372 – 1597]</td>
<td></td>
</tr>
</tbody>
</table>

Note. IPh = intonational boundary; ip = intermediate boundary; 0 = null boundary; ms = milliseconds; *significant differences.
Figures 2 and 3 illustrate spectrograms of the recordings of the target sentence *Aranhas e camelos com copos azuis estão no deserto* (Spiders and camels with blue cups are in the desert) in two different prosodic forms (IPh, 0 and 0, IPh, respectively). The first tier on the image on the Praat software (Boersma & Weenink, 2013) indicates the transcription of words, the second tier indicates the F₀ values of words near the boundary and the third tier indicates the duration values of pauses and words close to the boundary.

![Figure 2. Spectrogram of the target sentence Aranhas e camelos com copos azuis estão no deserto (Spiders and camels with blue cups are in the desert) recorded in the prosodic form IPh, 0 illustrating word, F₀, and duration tiers.](image-url)
Figure 3. Spectrogram of the target sentence Aranhas e camelos com copos azuis estão no deserto (Spiders and camels with blue cups are in the desert) recorded in the prosodic form 0, IPh containing word, F₀, and duration tiers.

A pair of visual stimuli (pictures) was created for each sentence. For the target sentences, one picture reflected the low attachment and the other represented the high attachment interpretation of the sentence. Positioning of the pictures on the left and right halves of the computer screen was assigned randomly by the E-Prime software (Psychology Software Tools, Pittsburgh, PA). Below (Figure 2) is an example of visual stimuli for the target sentence Tucanos e galinhas com maçãs verdes estão na gaiola (Toucans and chickens with green apples are in the cage). The picture on the right reflects a high attachment response, while the picture on the left reflects a low attachment response. See Appendix D for the pairs of figures corresponding to the eight target sentences. All pictures of the target sentences were drawn by a single artist.
Figure 4. Visual stimuli for the target sentence *Tucanos e galinhas com maçãs verdes estão na gaiola* (Toucans and chickens with green apples are in the cage).

Filler sentences and their visual stimuli were selected from a previous experiment on predicate attachment and reflexive assignment (Fortunato-Tavares et al., 2012; Fortunato-Tavares et al., 2015). All pictures of the filler sentences were drawn by a single artist. Figure 3 illustrates the picture stimuli for a predicate filler sentence.

Figure 5. Visual stimuli for the filler sentence *O coelho na frente do cachorro é cinza* (The rabbit in front of the dog is grey).
**Gap detection.** Gap detection stimuli included broad-band white noises with no rise and fall that had a duration of 500 ms and a silent interval inserted in the temporal center of the noise (Zeng, Oba, Garde, Sininger, & Starr, 1999). Gaps ranged from one to 500 ms, with increments of 1 ms on the first tenth, 5 ms on gaps between 10 to 50 ms, 10 ms on gaps ranging from 50 ms to 100 ms, and 50 ms thereafter. Stimuli with gaps had a duration of 500 ms plus the duration of the gap. Stimuli containing no gap had the duration of 500 ms.

**Frequency discrimination.** The frequency discrimination task included 200-ms pure-tones with standard frequencies from 500 to 2,000 Hz in octave steps. Frequency increments were created in semitone steps from the reference frequencies (500, 1000, and 2000 Hz).

**Procedure**

E-Prime 2.0 software (Psychology Software Tools, Pittsburgh, PA) was used for stimuli presentation and data collection in all tasks. Participants were individually tested in a quiet room where they were seated in front of the computer with a serial response box (SRBOX) and high definition speakers placed before them. Participants completed the prosody task followed by the gap detection and frequency discrimination tasks. The total duration of the three tasks was approximately one hour. The tasks were carried out in one or two sessions, depending on fatigue and availability of participants. All stimuli were presented at the most comfortable loudness level on an individual basis.

**Prosody.** In each trial, participants heard a sentence once. Immediately after the offset of the sentence, two figures with the two possible interpretations appeared on the screen. For target stimuli, such as the sentence *Toucans and chickens with green apples are in the cage*, the two picture options were: toucans with green apples and chickens with green apples inside the cage and toucans without green apples and chickens with green apples inside the cage. With the pictures still visible, after an interstimulus interval of 200 ms, the sentence was repeated. Participants had to press a button on the SRBOX to indicate their selection of interpretation. To select the figure on the left, they needed to press 1, the leftmost button on the SRBOX. To select the figure on the right, they needed to press 5, the rightmost button on the SRBOX. Responses were accepted no earlier than the offset of the second sentence
stimuli. Inter-trial intervals had the duration of 100 ms. A practice session containing 10 trials preceded the experiment.

Each participant heard 64 target stimuli and 32 filler stimuli. The stimuli were presented to participants in four blocks. Block 1 referred to strong prosody contrasts, containing trials with one intonational phrase and one null boundary (IPh, 0 and 0, IPh). Block 2 consisted of trials reflecting neutral prosody with identical prosodic boundaries on A and B (0, 0 and ip, ip). Block 3 referred to trials with weak prosody contrasts, with trials containing intermediate phrase and null boundary (ip, 0 and 0, ip). Block 4 contained trials with two prosodic boundaries (IPh, ip and ip, IPh). Within the block, the stimuli were presented in a random order to avoid length, order, or familiarization effects. The average length of time to complete the prosody task was 20 minutes.

**Gap detection.** An adaptive forced-choice procedure was used to examine gap detection. Participants heard one stimulus at a time and were asked to respond whether they heard one or two sounds by pressing 1 or 2 on the SRBOX to indicate their selection. Once a selection was made, visual feedback was provided following each response with a smiley or a frowning face presented on the computer screen. The task began with a gap of 500 ms. The 1-up 2-down decision rule was applied. When participants responded incorrectly in a trial containing a gap, the gap size increased by the order of one (i.e. an easier stimulus, with the next larger gap was presented). When participants made a correct response in a trial containing a gap, the gap size decreased by the order of two (i.e. a more difficult stimulus, with the second following smaller gap was presented). Stimuli with no gap (500 ms) were randomly interposed, but responses to these stimuli were not part of the 1-up 2-down rule. The adaptive procedure continued until eight reversals occurred, or the lowest threshold was achieved three times, or 50 trials were completed. Gap detection thresholds were calculated as the average gap size for the final three reversals. Length of time to complete the task varied according to performance, but in general ranged from five to 15 minutes.

**Frequency Discrimination.** For the frequency discrimination task, participants completed a same-different two-alternative forced choice task. Participants listened to two tones and were asked to
decide whether the two sounds heard were identical or different by clicking on the buttons that corresponded to two red balloons (identical) or one red balloon and one blue balloon (different). Once a selection was made, visual feedback of the correct response was provided following each response. Trials with identical stimuli contained two stimuli with the base frequency. The 1-up 2-down decision rule was applied and trials containing identical tones were not part of the rule. The adaptive procedure continued until eight reversals occurred, or the lowest limen was achieved three times, or 50 trials were completed. Frequency limens were calculated as the average frequency difference for the final three reversals. Three separate tasks were completed for each base frequency (500 Hz, 1000 Hz and 2000 Hz). Results were analyzed separately for each base frequency and the mean limen of the three base frequencies was also computed in order to reflect the frequency of the linguistic stimuli. Similarly to the gap detection task, length of time to complete the frequency discrimination task varied according to performance, but in general ranged from 10 to 20 minutes.

Data Analysis

The prosody task consisted of a binomial experiment, as there were only two mutually exclusive possible responses. Therefore, the data was analyzed according to sample proportions ($\hat{p}$): the proportion of high attachment responses was calculated for each of the eight prosodic forms within each participant. These numbers were analyzed using mixed repeated-measures and one-way ANOVAs and contrasts were applied where necessary. Planned between-group comparisons were carried out using independent-means t-test for each prosodic form with Bonferroni corrections. The specific predictions of the Absolute Boundary Hypothesis (ABH) and the Relative Boundary Hypothesis (RBH) (Snedeker & Casserly, 2010) were tested using planned dependent-means t-tests with Bonferroni corrections.

Response times were calculated from the offset of the second time the target sentence was played to the push of the response button on the serial response box. Only response times for high attachment responses were considered. Outliers were removed to calculate the mean response times and perform the inferential analyses. Outliers were identified as response times that were more than 1.5 interquartile range (distance between the first and third quartiles) below the first quartile (minor outliers) or
above the third quartile (major outliers). No minor outliers were identified. A total of 18 major outliers were identified (four in the group of adults, eight in the group of children with NH and six in the group of children with CIs). Mixed repeated-measures ANOVA were calculated and contrasts applied where necessary. Planned between-group comparisons were carried out using independent-means t-test with Bonferroni corrections for each prosodic form.

Pearson correlation coefficients were calculated between the proportions of high attachment according to prosodic strength and both gap detection thresholds and mean frequency limens (mean of 500, 1000 and 2000 Hz).
Experiment 1: Prosodic Boundary Effects on the Comprehension of Attachment Ambiguities in Normal Hearing Adults and Children Speakers of Brazilian Portuguese

This experiment investigated the effects of different prosodic boundaries on syntactic disambiguation in normal hearing (NH) children and adults who are monolingual speakers of Brazilian Portuguese. The absolute boundary hypothesis (ABH) and the relative boundary hypothesis (RBH) (Snedeker & Casserly, 2010) were tested on a computerized sentence comprehension task in the auditory modality. It was also investigated whether children and adults differed in the processing speed of syntactically ambiguous sentences according to different prosodic forms. Acoustic correlates of prosodic boundaries were investigated through a gap detection and a frequency discrimination task, and later correlated to sentence comprehension performance.

Participants

Twenty-three normal hearing (NH) adults (15 women) with mean age of 26;4 (±4;8) years and 15 NH children (seven girls) with mean age of 9;9 (1;3) years participated in this experiment. All participants were monolingual speakers of Brazilian Portuguese who had not lived in a different country at any time before the age of 12 or for any period longer than a year during their lives. All adults reported no history of language impairment, no hearing impairment, no uncorrected visual impairment. Adult participants were undergraduate students or had higher educational degrees and were classified as middle or upper middle class according to the Brazilian Economic Classification Criterion questionnaire (CCEB - Critério de Classificação Econômica Brasil [ABEP, 2008]). All children had expressive vocabulary scores on the ABFW Child Language Test (Andrade, Befi-Lopes, Fernandes, Wetzner, 2004) within normal limits (mean standard score = 93; SD = 2.5), normal nonverbal intelligence coefficient (IQ) measured by the Test of Non-Verbal Intelligence 4 (TONI-4; Brown, Sherbenou & Johnsen, 2010) (mean standard score = 106; SD = 7.7) and no history of language impairment as reported by their parents and school-based speech-language pathologists. All families of children were middle class based on a socio-economic questionnaire (ABEP, 2008) and all passed a hearing screening at 25dB HL (ASHA, 1997).
Results

The results are divided into three sections. First, the attachment results of the prosody task and the specific predictions of the Absolute Boundary Hypothesis (ABH) and Relative Boundary Hypothesis (RBH) are presented. Second, the response times of each of the eight prosodic forms are displayed. Third, gap detection thresholds and frequency limens are analyzed and correlated to the proportions of high attachment according to prosodic strength.

Attachment. The proportions of high attachment responses for each of the eight prosodic sentence types were calculated for each group (see Figure 3). Sentences with no boundaries (0,0) had the most high attachment interpretations for both groups.
Figure 6. Mean proportion of high attachment responses according to prosody type and group. Error bars denote 95% confidence interval. IPh = intonational boundary. ip = intermediate boundary. 0 = null boundary.

Mixed design ANOVA revealed a significant effect for prosodic type $F(7,252) = 12.136$, $p < .001$, $\eta^2 = .252$, indicating that interpretation of the target sentences varied according to their prosodic forms. Contrasts revealed that sentences with two null boundaries received the highest number of high attachment responses (all $p < .05$). There was also a significant interaction between prosodic type and group $F(7,252) = 2.509$, $p = .016$, $\eta^2 = .065$, indicating that children and adults differed in how they used prosodic forms to disambiguate sentences. There was a trend to a significant effect of group, $F(1,36) =$
3,645, \( p = .064, \eta^2 = .092 \), which possibly missed significance due to the small sample size. Planned pairwise independent samples t-tests with Bonferroni corrections comparing the two groups for proportion of high attachment interpretations according to prosodic type were calculated (Table 4). Results indicated that children and adults differed in the proportion of high attachment interpretations in the IPh, ip condition, with adults showing more high attachment responses than children.

Table 4

Mean (Standard Error) of the Proportion of High Attachment Response According to Prosodic Boundary Type and Group. Between-group Comparisons are Indicated by Independent t-tests with Bonferroni Corrections

<table>
<thead>
<tr>
<th>Prosodic Boundary (A, B)</th>
<th>Children</th>
<th>Adults</th>
<th>T-Test</th>
</tr>
</thead>
<tbody>
<tr>
<td>0, 0</td>
<td>.94 (.03)</td>
<td>.88 (.04)</td>
<td>t(36) = -1.250, ( p = .872, r = .20 )</td>
</tr>
<tr>
<td>0, ip</td>
<td>.48 (.09)</td>
<td>.46 (.07)</td>
<td>t(36) = -.162, ( p = 1.00, r = .03 )</td>
</tr>
<tr>
<td>0, IPh</td>
<td>.68 (.06)</td>
<td>.59 (.06)</td>
<td>t(36) = -.944, ( p = 1.000, r = .16 )</td>
</tr>
<tr>
<td>ip, 0</td>
<td>.44 (.08)</td>
<td>.57 (.06)</td>
<td>t(36) = 1.256, ( p = .872, r = .20 )</td>
</tr>
<tr>
<td>ip, ip</td>
<td>.43 (.07)</td>
<td>.56 (.05)</td>
<td>t(36) = 1.560, ( p = .512, r = .25 )</td>
</tr>
<tr>
<td>ip, IPh</td>
<td>.47 (.10)</td>
<td>.69 (.05)</td>
<td>t(36) = 2.350, ( p = .096, r = .36 )</td>
</tr>
<tr>
<td>IPh, 0</td>
<td>.41 (.07)</td>
<td>.57 (.07)</td>
<td>t(36) = 1.561, ( p = .512, r = .25 )</td>
</tr>
<tr>
<td>IPh, ip</td>
<td>.39 (.08)</td>
<td>.65 (.05)</td>
<td>t(36) = 2.888, ( p = .024^*, r = .43 )</td>
</tr>
</tbody>
</table>

*Note. IPh = intonational boundary; ip = intermediate boundary; 0 = null boundary; *significant difference.

To investigate the specific predictions of RBH and ABH, planned pairwise comparisons were conducted for each group. Results of RBH are displayed in Table 5.
Table 5

Tests of Unique Predictions of RBH According to Prosodic Form for the Groups of Children and Adults

<table>
<thead>
<tr>
<th>Hypothesis</th>
<th>Prosody</th>
<th>Prediction</th>
<th>Group</th>
<th>t-test</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>No low boundary</td>
<td></td>
<td>IPh, 0 &lt; 0, 0</td>
<td>Children</td>
<td>$t(14) = -7.400, p &lt; .001^*, r = .89$</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Adults</td>
<td>$t(22) = -4.208, p &lt; .001^*, r = .75$</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>ip, 0 &lt; 0, 0</td>
<td>Children</td>
<td>$t(14) = -5.563, p &lt; .001^*, r = .83$</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Adults</td>
<td>$t(22) = -3.920, p = .001^*, r = .72$</td>
<td></td>
</tr>
<tr>
<td>RBH</td>
<td>IPh, ip &lt; 0, ip</td>
<td>Children</td>
<td>$t(14) = -7.31, p = .238, r = .19$</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Adults</td>
<td>$t(22) = 2.393, p = .026^{**}, r = .54$</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Low ip boundary</td>
<td></td>
<td>ip, ip &lt; 0, ip</td>
<td>Children</td>
<td>$t(14) = -4.37, p = .334, r = .12$</td>
</tr>
<tr>
<td></td>
<td>Adults</td>
<td>$t(22) = 1.098, p = .284, r = .28$</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>IPh, ip &lt; ip</td>
<td>Children</td>
<td>$t(14) = -8.57, p = .203, r = .22$</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Adults</td>
<td>$t(22) = 1.854, p = .077, r = .44$</td>
<td></td>
</tr>
</tbody>
</table>

Note. RBH = Relative Boundary Hypothesis; IPh = intonational boundary; ip = intermediate boundary; 0 = null boundary; **significant difference with inverse relationship of prediction (0, ip < 0, IPh).

For NH children and adults, only two specific predictions of the RBH were confirmed. When a low boundary (null boundary in position B) was absent, the size of the high boundary (position A) influenced attachment. Thus, a larger boundary in A led to more high attachments than a smaller boundary, confirming the first two specific predictions of the RBH. Contrastively, when there was a low ip boundary (ip in B), the relative size of the high boundary (A) did not influence attachment in the way predicted by the RBH. Sentences with a high null boundary and a low ip led to less high attachment responses than sentences with a high ip or IPh, in contrast to what the RBH predicted. Furthermore, the number of high attachment did not differ from sentences with two ips and sentences with a smaller (0) or bigger (IPh).
high boundary, rejecting, in this case, the prediction of the RBH that the size of the high boundary would guide attachment.

Planned pairwise comparisons were also carried out to investigate the specific predictions of ABH in each group and results are displayed in Table 6.

Table 6

Tests of Unique Predictions of ABH According to Prosodic Form for the Groups of Children and Adults

<table>
<thead>
<tr>
<th>Hypothesis</th>
<th>Prosody</th>
<th>Prediction</th>
<th>Group</th>
<th>t-test</th>
</tr>
</thead>
<tbody>
<tr>
<td>Equal boundaries</td>
<td>0, 0 &lt; ip, ip</td>
<td>Children</td>
<td>$t(14) = 6.082, p &lt; .001^{*\ast}, r = .85$</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Adults</td>
<td>$t(22) = 5.833, p &lt; .001^{*\ast}, r = .84$</td>
<td></td>
</tr>
<tr>
<td>Larger high boundary</td>
<td>IPh, 0 &lt; IPh, ip</td>
<td>Children</td>
<td>$t(14) = .349, p = .366, r = .09$</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Adults</td>
<td>$t(22) = -1.141, p = .266, r = .29$</td>
<td></td>
</tr>
<tr>
<td></td>
<td>ip, 0 &lt; IPh, ip</td>
<td>Children</td>
<td>$t(14) = .771, p = .226, r = .20$</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Adults</td>
<td>$t(22) = -1.189, p = .247, r = .30$</td>
<td></td>
</tr>
<tr>
<td>Larger low boundary</td>
<td>0, ip &lt; 0, IPh</td>
<td>Children</td>
<td>$t(14) = -2.195, p = .023^{*}, r = .51$</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Adults</td>
<td>$t(22) = -2.893, p = .008^{*}, r = .61$</td>
<td></td>
</tr>
</tbody>
</table>

Note. ABH = Absolute Boundary Hypothesis; IPh = intonational boundary; ip = intermediate boundary; 0 = null boundary; ^{*}\ast = significant difference with inverse relationship of prediction (ip, ip < 0, 0).

The ABH predicts that only the absolute size of the low boundary affects attachment. Thus, under the condition of two equal boundaries, sentences that have larger boundaries would lead to more high attachment responses than those with smaller boundaries. This prediction was not confirmed for either group, as sentences with two null boundaries had more high attachment responses than sentences with two ips.
According to the ABH, the absolute value of the low boundary should command attachment regardless of the size of the high boundary. In other words, the larger the low boundary the higher the proportion of high attachment responses regardless of the size of the high boundary. When there was a larger high boundary (i.e., A was bigger than B), the absolute size of B did not influence attachment in Brazilian Portuguese-speaking adults, in contrast to the prediction of the ABH.

Different outcomes for children and adults were observed when the low boundary was larger than the high boundary (i.e., B was bigger than A). For children, the absolute value of the boundary at B affected interpretation as predicted by the ABH only when there was no low boundary. For adults, however, both predictions involving a larger low boundary were confirmed, regardless of whether the high boundary was an ip or a null boundary.

In sum, the same two predictions of the RBH (0, 0 > IPh, 0; 0, 0 > ip, 0) were confirmed for both groups, indicating that the RBH is partially confirmed for children and adults who speak Brazilian Portuguese (all \( p < .001 \)). In contrast, the ABH testing had different outcomes for the two groups. Two specific predictions of ABH (0, ip < 0, IPh; 0, ip < ip, IPh) were confirmed for adults with NH (\( p = .008, p = .006 \), respectively). However, only one of the predictions (0,ip < 0,IPh) was confirmed for children (\( p = .023 \)). One prediction (ip, ip < 0, 0) of the ABH had inverse outcome for both children and adults: a bigger boundary lead to less high attachment responses than a sentence with no boundary.

Thus, eight to 12 year-old, NH speakers of Brazilian Portuguese do use prosodic information to disambiguate sentences. However, children subtly differed from adults in the way they used prosodic boundaries to resolve syntactically ambiguous sentences. Two of the RBH predictions were confirmed for NH adults and children. These results suggest that children and adults perceive and use the relative size of the boundaries in the same manner. When there was no low boundary, the relative size of the boundary in the higher position (A) affected attachment; the presence of a bigger high boundary discouraged high attachment. In contrast, two predictions of the ABH were confirmed for adults whereas only one of the five predictions were confirmed for the children. Furthermore, for children, only predictions of RBH and ABH that involved sentences with no low or no high boundaries were confirmed. In sentences
with two boundaries children were not able to benefit from prosodic boundary information to choose the attachment site as predicted by the two proposals.

**Response time.** Figure 4 illustrates the mean response times (in ms) according to prosodic form and group. Overall, children exhibited longer response times than adults and had greater variation across prosody types.

![Graph](image)

*Figure 7.* Mean response times (in ms) according to prosody type and group. IPh = intonational boundary; ip = intermediate boundary; 0 = null boundary.

Mixed design ANOVA revealed a significant effect for prosodic type $F(7,154) = 2.145$, $p = .042$, $\eta^2 = .089$, indicating that response times varied according to prosodic forms. There was a significant
interaction between prosodic type and group $F(7,154) = 2.151, p = .042, \eta^2 = .089$, indicating that children and adults differed in how fast they gave high attachment responses according to the examined prosodic types.

Planned pairwise comparisons with Independent samples t-tests and Bonferroni corrections for response times for high attachment interpretations were calculated according to prosodic type. Results indicate that children were significantly slower to indicate a high attachment response than adults in all but the 0,0 prosodic type (see Table 7). The lack of significance could be a reflection of the high variability exhibited by children on this specific prosodic condition.
Table 7

*Mean (Standard Error) of Response Times (ms) to High Attachment Responses According to Prosodic Boundary Type and Group. Between-group Comparisons are Indicated by Independent t-tests with Bonferroni Corrections*

<table>
<thead>
<tr>
<th>Prosodic Boundary (A, B)</th>
<th>Adults</th>
<th>Children</th>
<th>T-Test</th>
</tr>
</thead>
<tbody>
<tr>
<td>0, 0</td>
<td>401 (26)</td>
<td>2909 (1381)</td>
<td>(t(35) = -2.348, p = .200, r = .37)</td>
</tr>
<tr>
<td>0, ip</td>
<td>449 (47)</td>
<td>1321 (207)</td>
<td>(t(28) = -4.915, p &lt; .001^*, r = .68)</td>
</tr>
<tr>
<td>0, IPh</td>
<td>521 (33)</td>
<td>1638 (253)</td>
<td>(t(34) = -5.159, p &lt; .001^*, r = .66)</td>
</tr>
<tr>
<td>ip, 0</td>
<td>390 (24)</td>
<td>1738 (450)</td>
<td>(t(30) = -3.638, p = .008^*, r = .55)</td>
</tr>
<tr>
<td>ip, ip</td>
<td>441 (33)</td>
<td>1788 (416)</td>
<td>(t(33) = -4.487, p &lt; .001^*, r = .62)</td>
</tr>
<tr>
<td>ip, IPh</td>
<td>375 (29)</td>
<td>1337 (312)</td>
<td>(t(34) = -4.090, p &lt; .001^*, r = .57)</td>
</tr>
<tr>
<td>IPh, 0</td>
<td>551 (58)</td>
<td>2732 (656)</td>
<td>(t(32) = -4.224, p &lt; .001^*, r = .60)</td>
</tr>
<tr>
<td>IPh, ip</td>
<td>446 (23)</td>
<td>1536 (322)</td>
<td>(t(32) = -4.918, p &lt; .001^*, r = .66)</td>
</tr>
</tbody>
</table>

*Note. IPh = intonational boundary; ip = intermediate boundary; 0 = null boundary; ms = milliseconds; *significant differences.*

Although children subtly differed from adults on how different prosodic boundaries affected attachment, they needed significantly more time than adults did to integrate prosodic and syntactic information in order to arrive at similar interpretations than adults.

**Acoustic tests.** Table 8 displays the results of the acoustic tests according to group, including gap detection thresholds and frequency limens.
Table 8

Mean (Standard Deviation) and [Range] of Gap Detection Threshold and Frequency Limen (Hz)

According to Frequency and Group

<table>
<thead>
<tr>
<th>Group</th>
<th>Gap detection (ms)</th>
<th>500Hz</th>
<th>1000Hz</th>
<th>2000Hz</th>
<th>Mean (500Hz, 1000Hz and 2000Hz)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Adults</td>
<td>2.3 (1.2)</td>
<td>4.5 (4.5)</td>
<td>9.3 (10.8)</td>
<td>11.6 (13.2)</td>
<td>8.5 (7.3)</td>
</tr>
<tr>
<td></td>
<td>[1-5]</td>
<td>[1.0-16.7]</td>
<td>[1.0-48.3]</td>
<td>[1.3-60.0]</td>
<td>[1.3-26.9]</td>
</tr>
<tr>
<td>Children</td>
<td>2.3 (1.9)</td>
<td>10.0 (14.7)</td>
<td>10.4 (9.4)</td>
<td>18.0 (17.9)</td>
<td>12.9 (11.7)</td>
</tr>
<tr>
<td></td>
<td>[1-8]</td>
<td>[1-55]</td>
<td>[2-30]</td>
<td>[1.3-60]</td>
<td>[2-41]</td>
</tr>
</tbody>
</table>

Note. ms = milliseconds; Hz = hertz.

Although a few participants exhibited higher than expected thresholds, their gap detection thresholds were still below the difference in pauses observed on the ip, 0 and IPh boundaries (differences in pauses ranged from 100 to 200 ms). However, the frequency discrimination test revealed that some participants exhibited higher than expected thresholds that exceeded some of the differences in F0 that characterized the different forms of prosodic boundaries (0, ip, and IPh). To investigate whether the gap detection thresholds and mean frequency limens had an influence on the syntactic disambiguation, correlation coefficients were calculated between the thresholds and the proportion of high attachment according to prosodic strength (see Table 9).
Table 9

*Pearson Correlation Coefficients (Significances) Between Prosodic Conditions and Gap Detection (in ms) and Mean Frequency Limen (in Hz)*

<table>
<thead>
<tr>
<th>Group</th>
<th>Prosodic conditions</th>
<th>Gap</th>
<th>Frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>IPh, 0; 0, IPh</td>
<td>.164 (.288)</td>
<td>-.039 (.430)</td>
</tr>
<tr>
<td>Adults</td>
<td>ip, 0; 0, ip</td>
<td>.063 (.388)</td>
<td>.182 (.203)</td>
</tr>
<tr>
<td></td>
<td>IPh, ip; ip, IPh</td>
<td>.306 (.078)</td>
<td>.130 (.277)</td>
</tr>
<tr>
<td></td>
<td>0, 0; ip, ip</td>
<td>.143 (.257)</td>
<td>-.029 (.447)</td>
</tr>
<tr>
<td></td>
<td>IPh, 0; 0, IPh</td>
<td>-.081 (.387)</td>
<td>.264 (.171)</td>
</tr>
<tr>
<td>Children</td>
<td>ip, 0; 0, ip</td>
<td>.004 (.494)</td>
<td>.263 (.172)</td>
</tr>
<tr>
<td></td>
<td>IPh, ip; ip, IPh</td>
<td>-.220 (.216)</td>
<td>-.024 (.466)</td>
</tr>
<tr>
<td></td>
<td>0, 0; ip, ip</td>
<td>.221 (.214)</td>
<td>.117 (.339)</td>
</tr>
</tbody>
</table>

*Note. Frequency limen reflects the mean limens collapsed across frequencies of 500 Hz, 1000 Hz and 2000 Hz. IPh = intonational boundary; ip = intermediate boundary; 0 = null boundary; ms = milliseconds; Hz = hertz. No correlation was significant (all p > 0.05), suggesting that gap detection thresholds and frequency limens of the participants of the current study did not influence the attachment of syntactically ambiguous sentences with different prosodic boundaries.*
Experiment 2: Prosodic Boundary Effects on Syntactic Disambiguation in Children with Cochlear Implants

This experiment examined whether children with cochlear implants (CI) are able to benefit from prosodic boundary cues to aid in syntactic disambiguation. The Informative/Relative Boundary Hypothesis (Clifton et al., 2002; Carlson et al., 2001; Snedeker & Casserly, 2010) and the Absolute Boundary Hypothesis (Snedeker & Casserly, 2010 based on Watson & Gibson, 2005) were contrasted in a sentence comprehension experiment including children with CIs and a group of age-matched children with normal hearing (NH). The role of prosodic boundaries on syntactic disambiguation has not been previously investigated in children with CIs and the present experiment investigates whether both factors are characteristics of their prosody-syntax interface. This experiment also investigated whether these children are able to perceive the acoustic correlates of prosodic boundaries (pauses and $F_0$ changes) on nonlinguistic stimuli and whether the nonlinguistic thresholds are correlated with performance on the sentence comprehension task.

Participants

Thirteen children (seven girls) with CIs and the same 15 children (seven girls) with NH from experiment 1 participated in this experiment. All children were monolingual speakers of Brazilian Portuguese who have not lived in a different country for any period during their lives. All children had vocabulary scores on the ABFW Child Language Test (Andrade et al., 2004) within normal limits, and normal intelligence coefficient (IQ) measured by the TONI-4 (Test of Non-Verbal Intelligence 4, Brown et al., 2010). Children with NH had no history of language impairment as reported by their parents and school-based speech-language pathologist, and passed a hearing screening at 25dB HL (ASHA, 1997). The families of NH and CI children were middle class based on the Brazilian Economic Classification Criterion questionnaire (CCEB - Critério de Classificação Econômica Brasil [ABEP, 2008]). See Table 10 for demographic information of both groups.
Table 10

Mean (Standard Deviation) and [Range] of Age, Nonverbal IQ, Expressive Vocabulary and Gender Information According to Group (NH and CI). Between-group Comparisons are Indicated by Independent-Sample t-tests

<table>
<thead>
<tr>
<th></th>
<th>NH</th>
<th>CI</th>
<th>T-test</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(n = 15)</td>
<td>(n = 13)</td>
<td></td>
</tr>
<tr>
<td>Age</td>
<td>9;9 (1;3)</td>
<td>10;5 (1;6)</td>
<td>t(26) = -0.986, p = .333, r = .19</td>
</tr>
<tr>
<td></td>
<td>[8;8 – 12;7]</td>
<td>[8;0 – 12;3]</td>
<td></td>
</tr>
<tr>
<td>IQ*</td>
<td>106.1 (7.7)</td>
<td>99.5 (5.5)</td>
<td>t(26) = 2.536, p = .018*, r = .45</td>
</tr>
<tr>
<td></td>
<td>[94 – 120]</td>
<td>[92-107]</td>
<td></td>
</tr>
<tr>
<td>Vocabularyb</td>
<td>93 (2.5)</td>
<td>91.7 (1.6)</td>
<td>t(26) = 1.604, p = .121, r = .30</td>
</tr>
<tr>
<td></td>
<td>[88.8 – 96.9]</td>
<td>[88.8 – 93.8]</td>
<td></td>
</tr>
</tbody>
</table>

Note. NH = normal hearing; CI = cochlear implant; IQ = intelligence quotient; *significant difference. *TONI-4 (Test of Non-Verbal Intelligence 4, Brown, Sherbenou & Johnsen, 2010); bABFW Child Language Test (Andrade, Befi-Lopes, Fernandes, Wetzner, 2004).

All children with CIs were prelingually deafened. Their audiograms demonstrated severe to profound bilateral hearing loss. The CI group included both unilateral and bilateral CI users. All received their implant(s) before four years of age. These children have no other associated impairments and are participants of rehabilitation programs with an emphasis on residual hearing training and an auditory-oral approach. One of the children, subject 9, used a hearing aid contralateral to the CI. Demographic data of children with CIs and details on implants are displayed on Table 11.
Table 11

Demographic Information and Details of Implants of Children with Cochlear Implants

<table>
<thead>
<tr>
<th>Subject</th>
<th>Gender</th>
<th>Age (years;months)</th>
<th>Ear</th>
<th>Implant</th>
<th>Processing Strategy</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>F</td>
<td>12;0</td>
<td>L</td>
<td>Nucleus 24</td>
<td>ACE</td>
</tr>
<tr>
<td>2</td>
<td>F</td>
<td>10;6</td>
<td>R</td>
<td>Nucleus 24</td>
<td>ACE</td>
</tr>
<tr>
<td>3</td>
<td>M</td>
<td>12;0</td>
<td>L</td>
<td>Nucleus 24</td>
<td>ACE</td>
</tr>
<tr>
<td>4</td>
<td>M</td>
<td>8;8</td>
<td>R L</td>
<td>Nucleus 5</td>
<td>ACE</td>
</tr>
<tr>
<td>5</td>
<td>M</td>
<td>8;0</td>
<td>R L</td>
<td>Nucleus 5</td>
<td>ACE</td>
</tr>
<tr>
<td>6</td>
<td>F</td>
<td>10;8</td>
<td>R L</td>
<td>Nucleus 24</td>
<td>ACE</td>
</tr>
<tr>
<td>7</td>
<td>F</td>
<td>12;2</td>
<td>R</td>
<td>Nucleus 24</td>
<td>ACE</td>
</tr>
<tr>
<td>8</td>
<td>F</td>
<td>10;6</td>
<td>R L</td>
<td>Nucleus 24</td>
<td>ACE</td>
</tr>
<tr>
<td>9</td>
<td>M</td>
<td>12;1</td>
<td>L</td>
<td>Nucleus 24</td>
<td>ACE</td>
</tr>
<tr>
<td>10</td>
<td>F</td>
<td>12;3</td>
<td>L</td>
<td>Sonata</td>
<td>FSP</td>
</tr>
<tr>
<td>11</td>
<td>M</td>
<td>8;1</td>
<td>R L</td>
<td>Nucleus 5</td>
<td>ACE</td>
</tr>
<tr>
<td>12</td>
<td>F</td>
<td>9;2</td>
<td>L</td>
<td>Sonata</td>
<td>FSP</td>
</tr>
<tr>
<td>13</td>
<td>M</td>
<td>9;3</td>
<td>R L</td>
<td>Nucleus 24</td>
<td>ACE</td>
</tr>
</tbody>
</table>

Note. F = female; M = male; R = right; L = left; ACE = advanced combination encoder; FSP = fine structure processing.

Prior to the prosody task, all children underwent a two-alternative forced choice lexical decision task containing all the animals (16) and colors (5) necessary to the comprehension of the target sentences. All children from both groups correctly identified all animals and colors, exhibiting 100% accuracy.
Results

The results are divided into four sections. First, attachment results are presented according to the eight prosodic forms and the specific predictions of the Absolute Boundary Hypothesis (ABH) and the Relative Boundary Hypothesis (RBH). Second, the analyses of response times for each of the eight prosodic forms are presented. Third, gap detection thresholds and frequency limens are analyzed and correlated to proportion of high attachment. Last, findings concerning the filler sentences (stress placement on comprehension of predicates and reflexives) are displayed.

**Attachment.** Figure 5 displays the proportion of high attachment responses for each of the eight prosodic types of the sentences for each group. Children with CIs exhibited an overall stronger preference for high attachment than children with NH.
Figure 8. Mean proportion of high attachment responses according to prosody type and group. Error bars denote 95% confidence interval. NH = normal hearing; CI = cochlear implant; IPh = intonational boundary; ip = intermediate boundary; 0 = null boundary.

A mixed model ANOVA conducted on the proportions of high attachment responses revealed a significant effect for prosodic type $F(7,182) = 7.765, p < .001, \eta^2 = .230$, indicating that, overall, interpretation of the target sentences varied according to their prosodic forms. There was a significant interaction between prosodic type and group $F(7,182) = 2.375, p = .024, \eta^2 = .084$. This indicates that children with NH and children with CIs differed in how they used prosodic forms to disambiguate sentences. There was a significant effect of group $F(1,26) = 4.131, p = .052, \eta^2 = .137$, indicating that proportions of high attachment responses of children with NH and children with CIs were in general different.
Planned independent sample t-tests with Bonferroni corrections for proportion of high attachment interpretations indicated that children with NH and children with CIs differed in the proportion of high attachment interpretations in three prosodic types: ip, ip; IPh, 0 and IPh, ip (Table 12).

Table 12

Mean (Standard Error) of the Proportion of High Attachment Response According to Prosodic Boundary Type and Group. Between-group Comparisons are Indicated by Independent t-tests with Bonferroni Corrections

<table>
<thead>
<tr>
<th>Prosodic Boundary (A, B)</th>
<th>Children with NH</th>
<th>Children with CIs</th>
<th>T-Test</th>
</tr>
</thead>
<tbody>
<tr>
<td>0, 0</td>
<td>.94 (.03)</td>
<td>.81 (.05)</td>
<td>t(26) = 2.230, p = .136, r = .40</td>
</tr>
<tr>
<td>0, ip</td>
<td>.48 (.09)</td>
<td>.67 (.08)</td>
<td>t(26) = -1.587, p = .496, r = .30</td>
</tr>
<tr>
<td>0, IPh</td>
<td>.68 (.06)</td>
<td>.70 (.08)</td>
<td>t(26) = -0.186, p = 1.000, r = .04</td>
</tr>
<tr>
<td>ip, 0</td>
<td>.44 (.08)</td>
<td>.58 (.09)</td>
<td>t(26) = -1.118, p = .411, r = .21</td>
</tr>
<tr>
<td>ip, ip</td>
<td>.43 (.07)</td>
<td>.74 (.08)</td>
<td>t(26) = -2.984, p = .024*, r = .51</td>
</tr>
<tr>
<td>ip, IPh</td>
<td>.47 (.10)</td>
<td>.63 (.09)</td>
<td>t(26) = -1.242, p = .896, r = .24</td>
</tr>
<tr>
<td>IPh, 0</td>
<td>.41 (.07)</td>
<td>.62 (.09)</td>
<td>t(26) = -1.826, p = .032*, r = .34</td>
</tr>
<tr>
<td>IPh, ip</td>
<td>.39 (.08)</td>
<td>.63 (.09)</td>
<td>t(26) = -2.043, p = .016*, r = .37</td>
</tr>
</tbody>
</table>

Note. NH = normal hearing; CI = cochlear implant; IPh = intonational boundary; ip = intermediate boundary; 0 = null boundary; *significant difference.

Children with Normal Hearing. A repeated measure one-way ANOVA revealed that the proportion of high attachment responses of children with NH was significantly influenced by the prosodic type \( F(7,98) = 8.703, p < .001, \eta^2 = .383 \). To investigate the specific predictions of ABH and RBH, planned pairwise comparisons were conducted and the results are displayed in Table 13.
Table 13

Tests of Unique Predictions of Relative Boundary Hypothesis (RBH) and Absolute Boundary Hypothesis (ABH) According to Prosodic Form for the Group of Children with NH

<table>
<thead>
<tr>
<th>Hypothesis</th>
<th>Prosody</th>
<th>Prediction</th>
<th>t-test</th>
</tr>
</thead>
<tbody>
<tr>
<td>No low boundary</td>
<td>IPh, 0 &lt; 0, 0</td>
<td>(t(14) = -7.400, p &lt; .001^*, r = .89)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>ip, 0 &lt; 0, 0</td>
<td>(t(14) = -5.563, p &lt; .001^*, r = .83)</td>
<td></td>
</tr>
<tr>
<td>RBH</td>
<td>IPh, ip &lt; 0, ip</td>
<td>(t(14) = -7.31, p = .238, r = .19)</td>
<td></td>
</tr>
<tr>
<td>Low ip boundary</td>
<td>ip, ip &lt; 0, ip</td>
<td>(t(14) = -4.37, p = .334, r = .12)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>IPh, ip &lt; ip, ip</td>
<td>(t(14) = -8.57, p = .203, r = .22)</td>
<td></td>
</tr>
<tr>
<td>Equal boundaries</td>
<td>0, 0 &lt; ip, ip</td>
<td>(t(14) = 6.082, p &lt; .001^*, r = .85)</td>
<td></td>
</tr>
<tr>
<td>ABH</td>
<td>IPh, 0 &lt; IPh, ip</td>
<td>(t(14) = .349, p = .366, r = .09)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>ip, 0 &lt; IPh, ip</td>
<td>(t(14) = .771, p = .226, r = .20)</td>
<td></td>
</tr>
<tr>
<td>Larger high boundary</td>
<td>0, ip &lt; 0, IPh</td>
<td>(t(14) = -2.195, p = .023^*, r = .51)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>0, ip &lt; ip, IPh</td>
<td>(t(14) = .125, p = .451, r = .03)</td>
<td></td>
</tr>
</tbody>
</table>

Note. RBH = Relative Boundary Hypothesis; ABH = Absolute Boundary Hypothesis; IPh = intonational boundary; ip = intermediate boundary; 0 = null boundary; *significant difference; ^significant difference with inverse relationship of prediction (ip, ip < 0, 0).

For children with NH, two specific predictions of the RBH were confirmed. The relative size of the high boundary (position A) influenced attachment when there was no low boundary (null boundary in position B). Contrastively, when there was a low ip boundary (ip in B), the relative size of the high boundary (A) did not influence attachment as predicted by the RBH.

This study confirmed only one of the ABH predictions for children with NH: for sentences with large low boundary (larger boundary in B than in A), the size of the boundary in B commanded
attachment in one of the predictions (0, ip < 0, IPh).

*Children with Cochlear Implants.* A repeated measure one-way ANOVA revealed that the proportion of high attachment responses was not significantly influenced by the prosodic type, $F(7,84) = 1.444, p = .199, \eta^2 = .107$, indicating that children with CIs did not benefit from prosodic changes to guide attachment. Planned pairwise comparisons were conducted to investigate the specific predictions of ABH and RBH. Results are displayed in Table 14.

Table 14

Tests of the Relative Boundary Hypothesis (RBH) and Absolute Boundary Hypothesis (ABH)

According to Prosodic Form for the Group of Children with Cochlear Implants

<table>
<thead>
<tr>
<th>Hypothesis</th>
<th>Prosody</th>
<th>Prediction</th>
<th>t-test</th>
</tr>
</thead>
<tbody>
<tr>
<td>RBH</td>
<td>IPh, 0 &lt; 0, 0</td>
<td>$t(12) = -2.175, p = .025^*, r = .53$</td>
<td></td>
</tr>
<tr>
<td></td>
<td>ip, 0 &lt; 0, 0</td>
<td>$t(12) = -2.299, p = .020^*, r = .55$</td>
<td></td>
</tr>
<tr>
<td></td>
<td>IPh, ip &lt; 0, ip</td>
<td>$t(12) = -0.536, p = .301, r = .15$</td>
<td></td>
</tr>
<tr>
<td></td>
<td>ip, ip &lt; 0, ip</td>
<td>$t(12) = 0.775, p = .227, r = .22$</td>
<td></td>
</tr>
<tr>
<td></td>
<td>IPh, ip &lt; ip, ip</td>
<td>$t(12) = -1.287, p = .111, r = .35$</td>
<td></td>
</tr>
<tr>
<td>ABH</td>
<td>0, 0 &lt; ip, ip</td>
<td>$t(12) = 0.719, p = .243, r = .20$</td>
<td></td>
</tr>
<tr>
<td></td>
<td>IPh, 0 &lt; IPh, ip</td>
<td>$t(12) = 0.078, p = .528, r = .02$</td>
<td></td>
</tr>
<tr>
<td></td>
<td>ip, 0 &lt; IPh, ip</td>
<td>$t(12) = -1.162, p = .134, r = .32$</td>
<td></td>
</tr>
<tr>
<td></td>
<td>0, ip &lt; 0, IPh</td>
<td>$t(12) = -0.474, p = .322, r = .14$</td>
<td></td>
</tr>
<tr>
<td></td>
<td>0, ip &lt; ip, IPh</td>
<td>$t(12) = 0.369, p = .359, r = .11$</td>
<td></td>
</tr>
</tbody>
</table>

Note. RBH = Relative Boundary Hypothesis; ABH = Absolute Boundary Hypothesis; IPh = intonational boundary; ip = intermediate boundary; 0 = null boundary; *significant difference.

Only predictions of the RBH were confirmed for children with CIs. When there was no low
boundary (null boundary in position B), the size of the high boundary (position A) influenced attachment; a larger high boundary led to more high attachments than a smaller boundary. Contrastively, when there was a low ip boundary (ip in B), the relative size of the high boundary (A) did not influence attachment in the way predicted by the RBH. Sentences with a high null boundary and a low ip led to similar high attachment responses than sentences with a high IPh, also contradicting the RBH prediction. Furthermore, sentences with two ips and sentences with a low ip and a high IPh did not differ in the number of high attachment responses, rejecting, in this case, the prediction of the RBH that the size of the high boundary would guide attachment. The ABH predicts that only the absolute size of the low boundary affects attachment. None of the predictions were confirmed for children with CIs; they do not benefit from the absolute size of the low boundary to guide attachment.

In sum, the same two predictions of the RBH were confirmed for both groups. Sentences with two null boundaries (0, 0) had more high attachment responses than sentences with an intonational or intermediate phrase on the low position and a null boundary in a high position ((IPh, 0) and (ip, 0), respectively) in both groups. This indicates that children with CIs and children with NH seem to follow the same pattern predicted by the RBH. According to the hypotheses based on boundary salience (see Figure 1), one of the RBH predictions for children with CIs was more likely to be confirmed whereas the other was unlikely. Therefore, boundary salience did not influence attachment of syntactic ambiguities as predicted. Although the ABH did not predict syntactic disambiguation in the children with CIs, it was not completely irrelevant for the children with NH. For children with NH, the size of (larger) low boundary influenced attachment: a low intonational phrase (IPh) encouraged more high attachment then a low intermediate phrase (ip). Children with CIs may not have been able to perceive the acoustic differences between IPh and ip, which hindered the ABH governance as observed in NH children.

Response time. Figure 6 illustrates the mean response times (in ms) according to prosodic form and group.
Figure 9. Mean response times (in ms) according to prosody type and group (CI and NH). NH = normal hearing; CI = cochlear implant; IPh = intonational boundary; ip = intermediate boundary; 0 = null boundary.

A mixed model ANOVA conducted on response times for high attachment responses revealed a significant effect for prosodic type $F(7,133) = 2,066$, $p = .051$, $\eta^2 = .098$, revealing that response times varied according to prosodic types. There was no significant interaction between prosodic type and group $F(7,133) = 1,659$, $p = .125$, $\eta^2 = .080$, indicating that children with CIs and children with NH exhibited similar speed in providing high attachment responses according to prosodic type. There was no significant effect of group $F(1,19) = 1,540$, $p = .230$, $\eta^2 = .075$, indicating that response times of children with CIs and children with NH were in general the same.
Planned pairwise comparisons with independent samples t-tests and Bonferroni corrections on response time for high attachment interpretations were calculated according to prosodic type (see Table 15). Results indicate that children with NH and with CI did not differ in their speed to provide a high attachment response in all prosodic types, although they showed differences in attachment responses (see the Attachment section).

Table 15

*Mean (Standard Error) of Response Times to High Attachment Responses According to Prosodic Boundary Type and Group (CI and NH). Between-group Comparisons are Indicated by Independent t-tests with Bonferroni Corrections*

<table>
<thead>
<tr>
<th>Prosodic Boundary (A, B)</th>
<th>Children with NH (Mean, SE)</th>
<th>Children with CI (Mean, SE)</th>
<th>T-Test</th>
</tr>
</thead>
<tbody>
<tr>
<td>0, 0</td>
<td>2909 (1381)</td>
<td>1200 (143)</td>
<td>t(25) = 1.185, p = .984, r = .23</td>
</tr>
<tr>
<td>0, ip</td>
<td>1321 (207)</td>
<td>1223 (215)</td>
<td>t(22) = 0.331, p = 1.000, r = .07</td>
</tr>
<tr>
<td>0, IPh</td>
<td>1638 (253)</td>
<td>2155 (344)</td>
<td>t(25) = -1.237, p = 1.000, r = .24</td>
</tr>
<tr>
<td>ip, 0</td>
<td>1738 (450)</td>
<td>1257 (254)</td>
<td>t(24) = 0.929, p = 1.000, r = .19</td>
</tr>
<tr>
<td>ip, ip</td>
<td>1788 (416)</td>
<td>1670 (290)</td>
<td>t(23) = 0.236, p = 1.000, r = .05</td>
</tr>
<tr>
<td>ip, IPh</td>
<td>1337 (312)</td>
<td>1142 (168)</td>
<td>t(24) = 0.550, p = 1.000, r = .11</td>
</tr>
<tr>
<td>IPh, 0</td>
<td>2732 (656)</td>
<td>2058 (440)</td>
<td>t(23) = 0.839, p = 1.000, r = .17</td>
</tr>
<tr>
<td>IPh, ip</td>
<td>1536 (322)</td>
<td>1364 (212)</td>
<td>t(22) = 0.406, p = 1.000, r = .10</td>
</tr>
</tbody>
</table>

*Note. NH = normal hearing; CI = cochlear implant; IPh = intonational boundary; ip = intermediate boundary; 0 = null boundary.*

Although there were differences between children with NH and children with CIs in how attachment of ambiguous sentences was influenced by prosody, hearing status did not influence the
processing speed for these sentences. Considering only the trials on which children selected a high attachment response, children with CIs were as fast as children with NH to respond. However, it is possible that children with CIs had a preference for high attachment and, therefore, were able to respond quickly based on this bias.

**Acoustic tests.** Table 16 displays the results of the acoustic tests according to group, including gap detection thresholds and frequency limens.

Table 16

<table>
<thead>
<tr>
<th>Group</th>
<th>Gap detection (ms)</th>
<th>Mean (500, 1000, 2000 Hz)</th>
<th>Mean (500, 1000, 2000 Hz)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CI</td>
<td>12.8 (28.7)</td>
<td>56.8 (58.7)</td>
<td>109.8 (124.1)</td>
</tr>
<tr>
<td></td>
<td>[12-100]</td>
<td>[4-217]</td>
<td>[18-383]</td>
</tr>
<tr>
<td></td>
<td>1000Hz</td>
<td>54.1 (57.6)</td>
<td>73.3 (65.4)</td>
</tr>
<tr>
<td></td>
<td>[9-233]</td>
<td>[10-194]</td>
<td></td>
</tr>
<tr>
<td>NH</td>
<td>2.3 (1.9)</td>
<td>10.0 (14.7)</td>
<td>18.0 (17.9)</td>
</tr>
<tr>
<td></td>
<td>[1-8]</td>
<td>[1-55]</td>
<td>[1-69]</td>
</tr>
<tr>
<td></td>
<td>1000Hz</td>
<td>10.4 (9.4)</td>
<td>12.9 (11.7)</td>
</tr>
<tr>
<td></td>
<td>[2-30]</td>
<td>[2-41]</td>
<td></td>
</tr>
<tr>
<td></td>
<td>2000Hz</td>
<td>18.0 (17.9)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>[1-60]</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
| Note. CI = cochlear implant; NH = normal hearing; ms = milliseconds; Hz = hertz.

Independent samples t-tests revealed that children with CIs had significantly higher gap detection thresholds ($t(26) = 3.980, p < .001, r = .62$) and mean (500, 1000, 2000 Hz) frequency discrimination thresholds ($t(26) = 3.518, p = .002, r = .57$) than children with NH. Some children with CIs exhibited gap detection and frequency limens that were above the acoustic difference observed among ip, IPh and null boundaries. To investigate whether gap detection thresholds and mean frequency limens were related to syntactic disambiguation, correlation coefficients were calculated between the thresholds and limens and the proportion of high attachment according to prosodic strength: strong (IPh, 0 and IPh, 0), weak (ip, 0
and 0, ip), two-boundary (IPh, ip and ip, IPh) and neutral (0, 0 and ip, ip) prosody. Pearson correlation coefficients and their probability levels are displayed in Table 17.

Table 17

*Pearson Correlation Coefficients (Significances) Between High Attachment According to Prosodic Conditions and Gap Detection Thresholds (in ms) and Mean Frequency Limens (in Hz)*

<table>
<thead>
<tr>
<th>Group</th>
<th>Prosodic conditions</th>
<th>Gap</th>
<th>Frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>IPh, 0; 0, IPh</td>
<td>- .652 (.008*)</td>
<td>.140 (.324)</td>
<td></td>
</tr>
<tr>
<td>CI</td>
<td>ip, 0; 0, ip</td>
<td>-.395 (.091)</td>
<td>.379 (.100)</td>
</tr>
<tr>
<td></td>
<td>IPh, ip; ip, IPh</td>
<td>-.095 (.379)</td>
<td>.336 (.131)</td>
</tr>
<tr>
<td></td>
<td>0, 0; ip, ip</td>
<td>.033 (.458)</td>
<td>.424 (.074)</td>
</tr>
<tr>
<td>NH</td>
<td>IPh, 0; 0, IPh</td>
<td>-.081 (.387)</td>
<td>.264 (.171)</td>
</tr>
<tr>
<td></td>
<td>ip, 0; 0, ip</td>
<td>.004 (.494)</td>
<td>.263 (.172)</td>
</tr>
<tr>
<td></td>
<td>IPh, ip, ip, IPh</td>
<td>-.220 (.216)</td>
<td>-.024 (.466)</td>
</tr>
<tr>
<td></td>
<td>0, 0; ip, ip</td>
<td>.221 (.214)</td>
<td>.117 (.339)</td>
</tr>
</tbody>
</table>

*Note. CI = cochlear implant; NH = normal hearing; ms = milliseconds; Hz = hertz; frequency limen reflects the mean limens for the frequencies of 500, 1000 and 2000Hz; IPh = intonational boundary; ip = intermediate boundary; 0 = null boundary; *denotes a significant correlation.*

None of the correlations was significant for the children with NH, suggesting that gap detection
thresholds and frequency limens were not related to the attachment of syntactically ambiguous sentences with different prosodic boundaries. For children with CIs, however, a significant negative correlation between gap detection threshold and the number of high attachment on strong prosodic condition was observed, possibly indicating that a higher gap detection threshold leads to fewer high attachment responses. This correlation is significant for each of the strong prosodic forms (IPh, 0: \( r_{13} = \text{-.576}, p = .020 \); 0, IPh: \( r_{13} = \text{-.689}, p = .005 \)).

Although children with CIs exhibited more limited ability to perceive the acoustic changes, no correlation was found between frequency limen and proportion of high attachment based on different prosodic boundaries, possibly suggesting that the relation between linguistic and nonlinguistic thresholds of acoustic differences are to some extent independent. Children might rely on other cues of linguistic stimuli that are not present on pure tones. Gap detection thresholds were only correlated with the proportion of high attachment on sentences with strong (IPh, 0 and 0, IPh) prosody contrasts, suggesting that gap detection thresholds influenced the attachment of syntactically ambiguous sentences with strong prosodic dissimilarity between boundaries.

**Fillers (stress).** Filler sentences were unambiguous sentences that contained stress manipulations. Stress was placed either on the first (N1) or the second (N2) noun of sentences like The rabbit\textsubscript{N1} in front of the dog\textsubscript{N2} is grey (see appendices B and C for lists containing all filler sentences). The first noun was always the correct antecedent. The purpose of the filler sentences (besides decreasing awareness of the target sentences) was to investigate whether stress would interfere with the selection of antecedent in syntactically unambiguous sentences.

Table 18 displays mean and standard deviation values of proportion accuracy according to syntactic form (predicate and reflexive) and stress placement (N1 and N2) for both groups.
Table 18

Mean (Standard Deviation) of Proportion of Correct Responses on Filler Sentences Containing Predicate Attachment and Reflexive Assignment According to Group

<table>
<thead>
<tr>
<th>Group</th>
<th>Predicates</th>
<th></th>
<th>Reflexives</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>N1</td>
<td>N2</td>
<td>N1</td>
<td>N2</td>
</tr>
<tr>
<td>NH</td>
<td>.82 (.11)</td>
<td>.74 (.26)</td>
<td>.94 (.14)</td>
<td>.88 (.19)</td>
</tr>
<tr>
<td>CI</td>
<td>.69 (.20)</td>
<td>.68 (.18)</td>
<td>.75 (.20)</td>
<td>.70 (.24)</td>
</tr>
</tbody>
</table>

Note. NH = normal hearing; CI = cochlear implant; N1 = stress placed on the first noun of the sentence (correct antecedent); N2 = stress placed on the second noun of the sentence (incorrect antecedent).

A mixed design repeated measures ANOVA with syntax (predicate and reflexive) and stress (N1 and N2) as within-subject factors and group (NH and CI) as between-subject factors was conducted with proportion of correct responses of each subject. There was a significant main effect of syntax, $F(1,26) = 25.906$, $p < .001$, $\eta^2 = .499$, indicating that in general children exhibited higher accuracy for reflexives than for predicates. There was no effect for stress, $F(1,26) = 3.839$, $p = .061$, $\eta^2 = .129$, indicating that responses in general did not vary according to stress placement. A main effect of group was observed, $F(1,26) = 4.848$, $p = .037$, $\eta^2 = .157$, revealing that in general children with NH had higher accuracy than children with CIs.

A significant interaction between syntax and group was observed, $F(1,26) = 7.900$, $p = .009$, $\eta^2 = .233$, indicating that accuracy of predicates and reflexives differed in children with NH and children with CIs. Planned pairwise comparisons with Bonferroni corrections indicated that children with CIs did not differ in accuracy for predicates and reflexives $F(1,26) = 1.311$, $p = .275$, $\eta^2 = .098$, whereas children with
NH exhibited a significantly higher accuracy for reflexives, $F(1,26) = 123,586, p < .001, \eta^2 = .898$.

There was no interaction between stress and group, $F(1,26) = 0.602, p = .445, \eta^2 = .023$, indicating that accuracy according to stress placement did not differ for children with NH and children with CIs. However, planned pairwise comparisons with Bonferroni corrections indicates that children with CIs exhibited no difference in accuracy for different stress placements, $F(1,26) = 0.602, p = .453, \eta^2 = .048$, whereas children with NH exhibited a trend to such difference $F(1,26) = 4.350, p = .056, \eta^2 = .237$ - higher accuracy rates were found for sentences with stress on the correct noun (N1).

The interaction between syntax and stress was not significant, $F(1,26) = 0.044, p = .835, \eta^2 = .002$. This indicates that accuracy of sentences with different stress positions did not differ according to their syntactic type. The interaction among syntax, stress and group was not significant, $F(1,26) = 0.283, p = .599, \eta^2 = .011$, indicating that the interaction between syntax and stress was not different for children with NH and children with CIs.
General Discussion

This study examined prosodic boundary effects in Brazilian Portuguese by analyzing how children with cochlear implants (CI) and normal hearing (NH) adults and children benefit from prosodic boundaries to disambiguate syntactically ambiguous sentences. The Informative/Relative Boundary Hypothesis (Clifton et al., 2002; Carlson et al., 2001; Snedeker & Casserly, 2010) and the Absolute Boundary Hypothesis (ABH; Snedeker & Casserly, 2011 based on the Anti-Attachment Hypothesis, Watson & Gibson, 2005) were contrasted. No studies have examined prosodic boundary strength effects on syntactic disambiguation in Brazilian Portuguese or in children with CIs (regardless of their language). The studies on Brazilian Portuguese have so far examined only whether a boundary affects interpretation (mainly in reading), but different sizes of boundaries have not yet been examined. Furthermore, the studies on prosodic boundary effects have focused on English and French and there is a need for studies on other languages to determine whether this phenomenon is language specific, whether it is manifested similarly across languages and whether it plays a similar role in syntactic processing in different languages with different prosodic specificities. Here, prosodic boundaries had an overall effect on the syntactic disambiguation of NH adults and children in Brazilian Portuguese. However, this effect differed for children and adults and had different outcomes than the ones reported for English speaking individuals. Children with CIs did not exhibit an overall effect of prosodic boundaries on syntactic disambiguation and, therefore, differed from children with NH in how ABH and Relative Boundary Hypothesis (RBH) predicted attachment.

The analyses of specific predictions by ABH and RBH revealed that neither of the two models could completely explain how Brazilian Portuguese speaking adults with NH and children with and without CIs use prosody to disambiguate sentences. Similarly, neither model alone was sufficient to explain the relationship between prosody and syntactic ambiguity attachment in English-speaking adults (Snedeker & Casserly, 2010). Nonetheless, some of the specific predictions of the two models were confirmed for both languages and for different ages and hearing status.

Relative Boundary Hypothesis
In the current study, two predictions of the RBH were confirmed for adults and children with NH and for children with CIs, suggesting that they perceive and use the relative size of the boundaries in the same manner. When there was no low boundary, the relative size of the boundary in a higher position affected attachment; the presence of a bigger high boundary discouraged high attachment. The same effect has been found for English-speaking adults (Schafer, 1997; Snedeker & Casserly, 2010). Therefore, as predicted by the RBH, it is likely that the relative size of the high boundary has an effect on syntactic disambiguation when there is no low boundary, regardless of age or hearing status.

However, the RBH did not hold true when the low boundary was an intermediate phrase (ip) boundary. The presence of a low ip did not allow the size of the high boundary to influence attachment as predicted by the RBH in the comprehension of Brazilian Portuguese-speakers, regardless of age and hearing status. Snedeker and Casserly (2010) also did not find robust support to this claim; the effect was reliable in the subject analyses but not significant in the items analyses. Clifton and colleagues (2002) tested several different syntactic structures (e.g., relative clauses, conjunctions, adverbal adjuncts, prepositional phrase modifiers, -ly adverbs) and although they found an overall support for RBH, these predictions (ip, ip > IPh, ip; 0,ip > IPh, ip) were not confirmed for all structures under investigation. Therefore, the debate on whether the relative size of the higher boundary influences attachment when there is a low ip boundary warrants more attention. Word stress could explain the lack of effect of the low ip. Schafer and colleagues (2000) suggested that the biggest prosodic boundary generally corresponded to the largest syntactic boundary, as listeners were able to use the relative size of boundaries to disambiguate sentences. However, in that study, adult listeners attended to unknown and unspecified information beyond the prosodic boundary sizes in ambiguous sentences that could be syntactically resolved. Listeners were asked to complete sentences without the part that resolved the ambiguity. They were able to correctly resolve the ambiguity without hearing the prosodic boundary. The authors speculated that stress patterns could have provided information to resolve ambiguity, as prosodic boundaries often follow the most important accent in a phrase. A boundary can increase the salience of the preceding word, increasing the likelihood of attachment to that word. In the current study, the
presence of an IPh in the prosody boundary pair IPh, ip increased stress on the first noun (as shown by 
$F_0$ and duration analyses in Tables 2 and 3, respectively), which might have forced attachment to a higher 
position. The same effect could have occurred in the study by Snedeker and Casserly (2010). That study 
also included sentences with a high attachment preference (more high than low attachment responses 
were given in the prosodic uninformative sentence - 0, 0). In contrast, the study by Carlson and 
colleagues (2002) yielded a low attachment bias. It is possible that placement of stress overcomes the 
effects of prosodic boundaries – at least in sentences with a high attachment preference and a low ip. 
Indeed, for Brazilian Portuguese-speaking adults, one of the predictions involving a low ip boundary had 
the reverse of the outcome predicted by the RBH. A larger high than low boundary (IPh, ip) lead to more 
high attachment responses than a sentence with a larger low boundary (0, ip) This suggests that an IPh 
in a high position discouraged low attachment. Responses to the filler sentences of experiment 2 reflect 
the influence of stress. The filler sentences were unambiguous utterances containing predicate 
attachment or reflexive assignment that had stress manipulated on either the first or the second nouns 
(and no prosodic boundaries). For children with NH, stress on the second noun (the incorrect antecedent) 
affected interpretation, decreasing their accuracy. Their accuracy increased when stress was placed on 
the correct antecedent (for example, barn in the sentence The horse behind the barn is pink).

The acoustic salience of prosodic boundaries were expected to override the patterns predicted by 
the RBH and the ABH in children with CIs. For children with CIs, two predictions of the RBH were 
confirmed, one that was very likely (IPh, 0 < 0, 0) and one that was unlikely (ip, 0 < 0, 0) based on 
acoustic salience of boundaries. In the first case, a straightforward explanation arises from prosodic 
strength, as the contrast between IPh and null boundary is more acoustically salient and, therefore, more 
likely to differ from other forms and confirm predictions. However, the second contrast (ip, 0 < 0, 0) 
warrants a more in depth speculation as predictions involving the contrast between ip and null boundary 
was considered unlikely to be confirmed under the approach of acoustic boundary salience. Furthermore, 
no differences in attachment responses among the 0, 0 and ip, and ip sentences were observed, 
eliminating an acoustic contrast explanation. The same was observed for children with NH (and for
Therefore, it is unlikely that boundary salience alone was a factor in how prosodic boundaries influenced attachment in children with CIs, as these children did not differ from their NH peers how relative boundary size influenced syntactic disambiguation in Brazilian Portuguese. However, children with CIs did not exhibit an overall prosody effect (unlike NH children and adults) and they differed from their NH peers in how well the ABH predicted attachment.

**Absolute Boundary Hypothesis**

Two predictions of the ABH were confirmed for adults, whereas only one of the five predictions was confirmed for children with NH. None of the predictions of the ABH was confirmed in children with CIs. For adults, both predictions involving a larger low boundary were confirmed - regardless of whether the high boundary was an ip or a null boundary. This contrasts with previous findings for English-speaking adults (Snedeker & Casserly, 2010; Carlson et al., 2001; Clifton et al., 2002) that failed to confirm these predictions of the ABH. The contrast between two boundary types and the position of boundaries may have different weights cross-linguistically. When the high boundary was bigger than the low boundary (A > B), the contrast between intermediate phrases (ip) and null boundaries (0) was relevant only in English; the predictions IPh, 0 < IPh, ip and ip, 0 < IPh, ip were confirmed only for English (Snedeker and Casserly, 2010). When the low boundary was bigger than the high boundary (B > A), the contrast between Intonational phrases (IPh) and ip was relevant only in Brazilian Portuguese; the predictions 0, ip < 0, IPh and 0, ip < ip, IPh were confirmed only in the current study. It is possible that for Brazilian Portuguese, boundaries in B are more relevant than boundaries in A and also that IPhs are more relevant than ips. For children with NH, however, the absolute value of the low boundary affected interpretation as predicted by the ABH only when there was no high boundary, providing less strong support to the ABH in general.

No prediction of ABH involved strong acoustic contrasts that were more likely to be confirmed based on the influence of boundary salience (Figure 1) and no prediction of the ABH was confirmed for children with CIs. Furthermore, for NH children and adults, no predictions involving weak (ip and 0) acoustic contrasts were confirmed. Together, these findings suggest an influence of boundary salience on
predictions of ABH for children with CIs, which is also possibly true for NH individuals. However, as previously mentioned, the findings of the RBH do not hold such hypothesis (one prediction involving weak acoustic contrast (ip, 0 < 0, 0) was confirmed for the three groups). The joint operation of acoustic salience and the hypotheses that aim to explain how prosodic boundaries govern syntactic disambiguation are not as straightforward as predicted. Additional components, such as processing and executive function limitations might interfere with this process not only in children with CIs, but also with NH.

When there was a larger high boundary (A was bigger than B), the absolute size of the low boundary did not influence attachment in the way predicted by ABH in Brazilian-speaking adults or in children with NH and with CIs. For English-speaking adults in previous studies, the results were inconsistent. The absolute size of a low boundary guided attachment when there was a larger high boundary in the study by Snedeker and Casserly (2010). However, Carlson and colleagues (2001) did not find such effect. Several factors could explain such differences observed across these studies. Although the sentences tested throughout the three studies were globally ambiguous, a manipulated version is being compared to a “baseline” sentence. For sentences that have a low attachment preference, there should be few low attachment responses on the 0, 0 conditions - the reverse is also true for sentences that have a high attachment preference. The study by Snedeker and Casserly (2010) and the current study found that sentences with a preference for high attachment, the 0, 0 condition lead to more high than low attachment. In Carlson, Cliffton and Frazier’s (2001) study there was a preference for low attachment. Although this alone does not provide an explanation for the cross-linguistically contrasting findings, it might explain the differences observed between the two studies with English-speaking individuals. The proportion of high attachment in the study by Carlson and colleagues (2001) on the two prosodic forms (IPh, 0, IPh, ip) were both .15, whereas in the study by Snedeker and Casserly (2010) they were around .45 and .70, respectively. The low attachment preference for the sentences in the study by Carlson and colleagues created a floor effect that concealed differences.

The type of task could also clarify some of the observed differences among studies. Carlson and
colleagues (2001) used a timed unacceptability judgment task, in which participants were asked questions only when the sentence was identified as acceptable. This method could have created and increased awareness of manipulations within task stimuli, in comparison to other studies. Snedeker and Casserly (2010), as well as the current study, used a sentence comprehension task with visual stimuli as responses. The lack of unambiguous sentences that forced response to each of the two target pictures (high and low attachment) could have created an overall bias in both studies. Furthermore, the type of instruction provided could also have played a role on findings. In Snedeker and Casserly (2010) and in the current study, the participants were told that interpretation of the sentence could change based on how the sentence was said, so the participant had to pay attention to the prosodic form. That was not clearly stated to the participants in previous studies.

Inverse ABH attachment predictions when comparing 0, 0 and ip, ip were observed in Brazilian Portuguese for adults and children with NH. In Snedeker and Casserly’s (2010) study, this specific ABH prediction (0, 0 < ip, ip) was confirmed for adults who speak English. It is possible that the participants in the current study treated a 0, 0 sentence as natural and the ip, ip sentence as an unnatural manipulated version in which the presence of a high boundary discouraged high attachment regardless of the presence of a low boundary (the reverse of the ABH). However, this rule of discouragement did not completely apply to adults in the current study. The presence of a high ip did not discourage high attachment when the low boundary was larger (i.e., ip, IP lead to more high attachments than 0, ip). Another possibility is that in sentences with two identical boundaries (ip, ip) the relevance of the high boundary was considered stronger. This holds true when considering that 0, 0 had more high attachment responses than ip, ip: the absence of a high boundary joined the two constituents favoring high attachment. However, this possibility of a “more important role” of the high boundary does not hold true for sentences with two different boundaries; under this rationale sentences with 0, ip would have more high attachment responses than sentences with ip, 0 or ip, ip for example, which was not the case. The reason for more high attachment in the unmanipulated version could also be that sentences tested in our study could have a high attachment preference in Brazilian Portuguese besides being syntactically
ambiguous.

Clifton and colleagues (2002) suggested that parallel analysis could explain the high number of high attachment on the *prosodically uninformative* sentences (0, 0 and ip, ip). Two relatively simple noun phrases (NPs) would be adjoined, leading to a high attachment interpretation. However, in a low attachment interpretation, one constituent might be substantially more complex than the other, breaking the parallelism between NPs. Parallel analysis could be an explanation to the attachment preference under the neutral boundaries condition of the current study. Parallel analysis may also explain the overall high attachment preference for adults, as a low attachment would create an unbalanced distribution of constituents. However, Clifton and colleagues (2002) also expected this to interfere in attachment in ip,ip sentences in the same way as 0, 0 sentences. This was not the case in the current study. Children with NH and children with CIs did not exhibit a high attachment preference under the ip, ip prosody condition and the preference for high attachment in this specific condition for adults was not remarkable. In Brazilian Portuguese, these conditions had an outcome that was the reverse of what has been found in English: in Brazilian Portuguese, ip, ip led to less high attachment than 0, 0 sentences. How the parallel analysis proposal would interchange with prosodic boundary information warrants further consideration of why, when, and whether one would overcome the other.

The 0, 0 < ip, ip was the only prediction in which both prosodic forms (0, 0 and ip, ip) were tested in the same block and a reverse outcome compared to English (ip, ip < 0, 0) was found for both children and adults with NH. This reversion may have been caused by the executive function demands of the within subject design applied, as suggested by Snedeker and Yuan (2008). In a within subject design, the response of the current trial is affected by the response of the previous trial. However, in the current study, the possible extra demands in executive functions did not reverse the predictions in all prosodic forms, indicating that some conditions were more challenging than others. Furthermore, one of the RBH predictions also leads to the reverse outcome for adults (more high attachment was applied to IPh, ip than to 0, ip) and these two prosodic forms were not tested in the same block. Nonetheless, the hypothesis that executive functions influenced attachment should not be completely discarded, especially
for children with CIs. Children with CIs of the current study exhibited lower nonverbal IQ scores than children with NH (albeit all children had normal IQ scores and no age or expressive vocabulary difference). The visuo-spatial processing required on the nonverbal IQ task applied (TONI-4; Brown, Sherbenou & Johnsen, 2010) could be related to attention control and inhibition as children have to generate hypotheses and change from one hypotheses to another to arrive at a response, possibly reflecting the previously reported poorer executive functions of children with CIs (Beer et al., 2014; Beer, Kronenberger & Pisoni, 2011).

**Acoustic correlates**

Gap detection thresholds and frequency limens for the nonlinguistic stimuli were not related to the attachment of syntactically ambiguous sentences with different prosodic boundaries on NH individuals regardless of their age (children or adults). This suggests that the relation between linguistic and nonlinguistic thresholds of acoustic differences are to some extent independent, possibly because nonlinguistic thresholds of NH individuals in this study were in general below the acoustic differences observed between the prosodic boundaries tested here. Children with CIs were expected to exhibit a decreased ability to perceive these nonlinguistic acoustic changes related to prosodic boundaries (when compared to their NH peers), which was confirmed. Children with CIs were also expected to exhibit thresholds lower than the acoustic changes observed on IPh and ip boundaries. Although this was true for the group, some children with CIs exhibited gap detection and frequency discrimination thresholds on nonlinguistic stimuli that exceeded the changes in pause and F₀ observed when comparing ip and null boundaries. Given that nonlinguistic acoustic thresholds may overestimate identification and discrimination of acoustic changes in linguistic stimuli (Heeren et al. 2012), the effect of lower perception could be stronger than expected in the sentences. Nonetheless, a significant relationship was found only between gap detection and responses to sentences with strong prosodic contrast (IPh, 0 and 0, IPh) for children with CIs. It is possible that children with CIs mainly relied on pause differences between intonational phrases and null breaks, which became evident on the correlational analysis. Online studies with fine-grained time analysis would allow the investigation of which acoustic characteristic(s) of the
boundary (the $F_0$ change on the noun preceding the intonational phrase or the pause after the intonational phrase) are used to perceive and apply prosodic boundaries on comprehension.

Although CIs provide poor $F_0$ resolution in general, which hampers the perception of some prosodic cues, including prosodic boundaries, no correlation was found between frequency limen and the proportions of high attachment for different prosodic boundaries. While the longstanding general agreement that bimodal stimulation provides improved frequency discrimination (e.g., Gantz, Turner, & Gfeller, 2004; Straatman et al., 2010), evidence that this does not holds true for all individuals is increasingly accumulating. Hegarty & Faulkner (2013) found that not all children with CIs showed a bimodal (hearing aid contralateral to the CI) advantage in frequency discrimination and stress identification on linguistic stimuli. Their results suggest that in the absence of $F_0$ cues, amplitude and duration cues are used to perceive stress and intonation in children with CIs. Similarly, Mulhern and Cullington (2014) found no acoustic advantage on a speech intelligibility test where sentences were masked with an additional (longer and more complex) sentence. In the current study, only one child had a hearing aid contralateral to the CI and, although his mean frequency discrimination was lower (24 Hz) than the group average (73 Hz), it was still higher than some of the other children with CIs only.

**Developmental considerations**

The results of the present study confirm that NH children from eight to 12 years of age who are speakers of Brazilian Portuguese do use prosodic information to disambiguate sentences. However, they differ subtly from adults in the way they use prosodic boundaries to aid in the resolution of global syntactically ambiguous sentences. For children, only predictions of RBH and ABH that involved sentences with no low or no high boundaries were confirmed. When predictions involved two boundaries, children, regardless of their hearing status, were not able to benefit from prosodic boundary information to choose the attachment site. The findings for the RBH predictions involving low intermediate phrases (ip) support the hypothesis that only one boundary is relevant for children. When the low boundary is an ip, the high boundaries were treated similarly, independently of being a null boundary (0), an ip, or an intonational phrase (IPh). Neither the category nor dimension of acoustic characteristics were sufficient as
standalone features of prosodic boundaries for children to use prosodic boundaries to disambiguate sentences. It is unlikely that the size of boundary alone was the reason for these findings, as intonational phrase and intermediate phrase involve more extreme acoustical changes than intermediate phrase and null boundary. The findings for the specific predictions of ABH also support the one-boundary explanation for children with NH, as only the 0, ip < 0, IPh prediction was confirmed.

The fact that only predictions of a unique boundary were confirmed for children with NH and with CIs might suggest that children are unable to benefit from multiple sources of prosodic boundary information at once, regardless of hearing status. Working memory may be involved, as it is more demanding to hold the information of two different boundaries and to compare these boundaries than to consider the presence of only one boundary. The process of binding (between boundaries and phrase structure) and release from binding described in recent models of working memory (Lewandosky & Oberauer, 2009; Oberauer, 2010) may well be involved. In the current study, no measures of working memory or executive functions were included. However, the increase in memory capacity across development is accompanied by an increase in processing speed across a wide range of tasks (Kail, 1991; Kail & Park, 1994). Therefore, response time analyses could aid explaining some of the developmental differences.

Although only a few differences were observed in how prosodic boundaries influenced attachment of globally ambiguous sentences in children and adults with NH, processing speed revealed substantial developmental differences, possibly as a reflection of different timings of the effect of prosody (in addition to other processing limitations, such as working memory). Adults were systematically and considerably faster than children in arriving at a high attachment response. Outside of limitations in working memory, this difference may reflect children’s need to create and use strategies to resolve ambiguity. They might not be able to automatically resolve syntactically ambiguous sentences, which may be related to poor cognitive control, an executive function ability that is related to the capacity to detect and resolve conflicts between differing representations (Novick et al., 2005). This aspect of executive function seems to emerge between the ages of five and 11 years (Weighall, 2008), which includes the ages of many of the
participants in this study. Hearing status did not influence the processing speed of these sentences (children with CIs were as fast as children with NH), suggesting that children with CIs might have faced the same challenge. Eye tracking studies corroborate to the conclusion that the effect of prosody on syntactic disambiguation emerges at different time frames in children, adolescents and adults (Diehl et al., 2014; Snedeker & Yuan, 2008). This effect seems to emerge early in adults, at approximately 200 ms, later in adolescents (after 200 ms), while children are delayed by approximately 500 ms (Diehl et al., 2014; Snedeker & Yuan, 2008).

In conclusion, this study revealed that neither the ABH or the RBH explain how prosodic boundaries influence attachment in Brazilian Portuguese speaking children with CIs and in NH children and adults. The relationship between position and size of boundaries and resolution of syntactic ambiguities is not as straightforward and cannot be explained by the predictions of these two hypotheses. Although not considered by the ABH and the RBH, factors such as attachment preferences, cross-linguistic differences and working memory demands might influence this relationship. This study also revealed that ABH and RBH are not consistent cross-linguistically, as different predictions were confirmed for Brazilian Portuguese and English. Nonetheless, the literature also shows inconsistent findings for English. Furthermore, although children with NH subtly differ from adults in the way they use prosodic boundaries to disambiguate sentences, there are remarkable developmental differences regarding processing speed of these structures as adults were significantly and systematically faster than children. The current study also showed that children with CIs do have deficient prosodic input that affects their linguistic comprehension. Overall, children with CIs did not use prosodic information to disambiguate sentences or to facilitate comprehension of unambiguous sentences in the same way as children with NH. It also revealed that the acoustic parameters that reflected such prosodic characteristics at a nonlinguistic level did not explain performance at a linguistic level. Therefore, it is important to include a comprehensive assessment of prosody at a linguistic level in children with CIs. Furthermore, language intervention should not focus on potential prosodic or syntactic deficits of children with CIs in isolation, but examine the interaction between syntax and prosody.
Future Directions

It is clear that the role of prosodic boundaries on syntactic disambiguation within and across languages is far from being completely understood. Future studies should include adolescents to provide a more complete developmental picture and include additional syntactic structures. The manipulation of working memory and other executive functions demands on sentences, especially in experiments with children, would provide the means to determine the potential roles of these factors in listener’s abilities to process both syntax and prosody simultaneously.

Moreover, the use of online measures, such as ERPs or eye tracking, is urgent to allow a fine-grained time-frame picture of the interface between prosodic boundaries and syntactic disambiguation. Online studies would permit an examination of which specific information aids in disambiguation and when that information becomes available. Furthermore, the role of prosodic boundaries on syntactic disambiguation in children with CIs still deserves more attention. Future studies should attend to the possible effect of bimodal, unilateral and bilateral CI use on the perception of these boundaries. Additionally, studies with adolescents and adults with CIs would help teasing apart developmental influences from the effects of hearing status on syntactic disambiguation when prosodic information is available.
Appendices

Appendix A: Target Sentences

The eight target sentences used on the prosody task are displayed below. Please note that each sentence was recorded in eight different prosodic forms, varying the prosodic boundary pairs after the first and second nouns, respectively (0, 0; 0, ip; 0, IPh; ip, 0; ip, ip; IPh, 0; IPh, ip; where 0 = null boundary, ip = intermediate phrase and IPh = intonational phrase).

A1. Tucanos e galinhas com maçãs verdes estão na gaiola.
   *Toucans and chickens with green apples are in the cage.*

A2. Corujas e morcegos com chapéus marrons estão na caverna.
   *Owls and bats with brown hats are in the cavern.*

A3. Aranhas e camelos com copos azuis estão no deserto.
   *Spiders and camels with blue glasses are in the desert.*

A4. Formigas e abelhas com flores roxas estão na árvore.
   *Ants and bees with purple flowers are on the tree.*

A5. Coelhos e cachorros com bolas azuis estão no cercado.
   *Rabbits and dogs with blue balls are inside the fence.*

   *Gorillas and giraffes with brown branches are in the forest.*

A7. Ovelhas e cavalos com capins verdes estão na fazenda.
   *Sheep and horses with green grass are on the farm.*

A8. Baleias e jacarés com laços rosas estão no aquário.
   *Whales and alligators with pink ribbons are in the aquarium.*
Appendix B: Filler Sentences - Predicates

Below is a list of all eight filler sentences containing predicate attachment. Each sentence was presented twice, stress placement varying between the first noun (for example, caixa on sentence B1) or on the second noun (for example, xícara on sentence B1).

   *The box inside the cup is red.*

   *The chicken on the ball is black.*

B3. O coelho na frente do cachorro é cinza.
   *The rabbit in front of the dog is grey.*

B4. O cavalo atrás do celeiro é laranja.
   *The horse behind the barn is orange.*

B5. A caixa dentro da xícara é amarela.
   *The box inside the cup is yellow.*

   *The chicken on the ball is brown.*

B7. O coelho na frente do cachorro é verde.
   *The rabbit in front of the dog is green.*

B8. O cavalo atrás do celeiro é rosa.
   *The horse behind the barn is pink.*
Appendix C: Filler Sentences - Reflexives

Below is a list of all eight filler sentences containing reflexive assignment. Each sentence was presented twice, with stress placement varying between the first (for example, mãe on sentence C1) or on the second (avó on sentence C1) nouns.

C1. A mãe atrás da avó está se trocando.
   *The mom behind the grandma is changing herself.*

C2. A mulher abaixo da menina está se secando.
   *The woman above the girl is drying herself.*

C3. O pai na frente do avô está se coçando.
   *The dad in front of the grandpa is scratching himself.*

C4. A mãe na frente da avó está se lavando.
   *The mom behind the grandma is washing herself.*

C5. A mulher acima da menina está se trocando.
   *The woman above the girl is changing herself.*

C6. O avô atrás do pai está se lavando.
   *The grandpa behind the dad is washing himself.*

C7. A avó atrás da mãe está se olhando.
   *The grandma behind the mom is looking at herself.*

C8. O pintor abaixo do menino está se coçando.
   *The painter below the boy is scratching himself.*
Appendix D: Visual Stimuli for the Target Sentences

The visual stimuli corresponding to each of the eight target sentences are displayed below. The picture on the right reflects a high attachment response. The picture on the left reflects a low attachment response. Please note that position of the pictures (left or right) was randomized by E-Prime (Psychology Software Tools, Pittsburgh, PA) in each trial.

Figure D1. Visual stimuli for the target sentence Tucanos e galinhas com maçãs verdes estão na gaiola (Toucans and chickens with green apples are in the cage).
Figure D2. Visual stimuli for the target sentence Corujas e morcegos com chapéus marrons estão na caverna (Owls and bats with brown hats are in the cavern).

Figure D3. Visual stimuli for the target sentence Aranhas e camelos com copos azuis estão no deserto (Spiders and camels with blue glasses are in the desert).
Figure D4. Visual stimuli for the target sentence *Formigas e abelhas com flores roxas estão na árvore* (Ants and bees with purple flowers are on the tree).

Figure D5. Visual stimuli for the target sentence *Coelhos e cachorros com bolas azuis estão no cercado* (Rabbits and dogs with blue balls are inside the fence).
Figure D6. Visual stimuli for the target sentence *Gorilas e girafas com galhos marrons estão na floresta* (Gorillas and giraffes with brown branches are in the forest).

Figure D7. Visual stimuli for the target sentence *Ovelhas e cavalos com capins verdes estão na fazenda* (Sheeps and horses with green grass are on the farm).
Figure D8. Visual stimuli for the target sentence *Baleias e jacarés com laços rosas estão no aquário* (Whales and alligators with pink ribbons are in the aquarium).
References


