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Sensitivity to discontinuous dependencies in language learners: evidence for limitations in processing space

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Abstract

Five experiments using the Headturn Preference Procedure examined 15- and 18-month-old children's sensitivity to morphosyntactic dependencies in English. In each experiment, the children were exposed to two types of passages. Passages in the experimental condition contained a well-formed English dependency between the auxiliary verb *is* and a main verb with the ending *-ing*. Passages in the control condition contained an ungrammatical combination of the modal auxiliary *can* and a main verb with the ending *-ing*. In the experiments, the distance between the dependent morphemes was systematically varied by inserting an adverbial of a specified length between the auxiliary and main verbs. The results indicated that 18-month-olds are sensitive to the basic relationship between *is* and *-ing*, but that 15-month-olds are not. The 18-month-olds, but not the 15-month-olds, listened significantly longer to the passages with the well-formed English dependency. In addition, the 18-month-olds showed this preference for the well-formed dependency only over a limited domain of 1–3 syllables. Over domains of 4–5 syllables, they showed no significant preference for the experimental over the control passages. These findings indicate that 18-month-olds can track relationships between functor morphemes. Additionally, these findings are consistent with the hypothesis that 18-month-olds are working with a limited processing window, and that they are only picking up relevant dependencies that fall within this window.

Keywords: Headturn preference procedure; Morphosyntactic dependencies; English

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One of the most striking features of child language is that it seems to be characterized by deficits. Children's first utterances are shorter, and they are often missing subjects, functors or other obligatory parts of a sentence. In addition, infants and children seem to possess deficits in comprehension as well. The nature of these deficits in early language has long been the subject of debate in language acquisition research. Some researchers have attributed these deficits to the development of grammar (e.g. Borer and Wexler, 1987; Radford, 1990; Vainikka, 1992), while others have attributed them to a limited processing capacity (e.g. Bloom, 1970, 1989; Brown, 1973; Valian et al., 1996). Although there has been considerable research in recent years exploring grammatical development, less is known about early processing. This paper seeks to address this gap and to explore the nature of the processing space in early language acquisition.

Processing limitations have often been proposed as a factor contributing to deficits in early language acquisition and language production. For example, many researchers have proposed that infants' early sentences are shorter and less complex than adult sentences because of a limited processing capacity (e.g. Bloom, 1970; Brown, 1973; Bloom and Lahey, 1978; Blake et al., 1994; Adams and Gathercole, 1995). In addition, limitations in working memory or in phonological processing space are often proposed as a factor contributing to language disorders for children with language impairment (e.g. Kirchner and Klatzky, 1985; Gathercole and Baddeley, 1990; Curtiss and Tallal, 1991; Montgomery, 1995; Ellis Weismer, 1996). Limited processing capacity has also been invoked in models of adult language processing, to explain differences among groups in performance on language tasks, breakdowns in adult language performance with disorders such as aphasia and in slips-of-the-tongue errors in production (e.g. Bock, 1982; Baddeley, 1986; Bock and Miller, 1991; King and Just, 1991; Just and Carpenter, 1992; Carpenter et al., 1994).

In terms of language learning, processing limitations are often viewed as limitations on length, either in terms of number of constituents or semantic relations, that a child can comprehend or produce at one time (e.g., Bloom, 1970; Brown, 1973; Montgomery, 1995). In addition, processing limitations may constrain not only length, but also the ability to relate constituents or propositions to each other. One way that languages relate the elements of a sentence is through relationships between morphemes, called morphosyntactic dependency relationships. For example, English exhibits a number of dependency relations between morphemes, e.g., the relationships between subject and verb, *the child always runs*; *the children always run*, the relationships among verb forms, *the child has always run*; *the child is always running*, or the relationships between determiners and nouns, *these big green boats*; *this big green boat*.

Acquiring these relationships is a step crucial for learners to be able to structure and decode the language. At the same time, these relationships often appear on discontinuous constituents in the sentence requiring the language learner to access several non-adjacent morphemes or words. In order to detect and decode these relationships, the learner must have sufficient processing capacity to access all of the elements involved in the relationship. If processing

capacity is limited, this might interfere with the ability to understand or create these dependency relationships, especially if other constituents intervene. Indeed, for adults, Bock and Miller (1991) report that a conflicting noun phrase intervening between two parts of a subject-verb dependency relationship can often lead to errors in production, such as **The time for fun and games are over* (Bock and Miller, 1991, p. 46).

As outlined above, the traditional view of processing limitations in language, has been that they lead to deficits in language comprehension and production for both children and adults. However, there is an alternative view of processing limitations in language acquisition that has recently been proposed. Under this view, proposed by Newport (1988, 1991) and Elman (1993), limits in processing space are not necessarily a detriment to language learning, but may actually instead facilitate the learning of complex systems. According to these models, early limits in processing space promote language learning by creating a restrictive filter for the input data. While this filter does lose some of the input data, it has an advantage in that it focuses the data the child receives. According to Newport (1991), this focusing of the data has the advantage of reducing the number of possible form-meaning co-occurrences. With fewer possible form-meaning correspondences to consider, the learner can easily acquire the basic dependencies in the language. For example, the English-learner needs to acquire the fact that the determiner 'these' is used with plural nouns, or that the verbal suffix *-s* goes with third person subjects.

These dog*s* **These* dog
She go*es* *We go*es*

According to this model, once these basic dependencies between morphemes are acquired, then the learner can apply this knowledge to help decode longer, more complex structures.

A further example might help clarify this point. In his computer simulations of language learning using a connectionist model, Elman (1993) implemented one possible way of reducing the processing space, namely reducing the size of the processing window. Elman presented complex sentences with a number of long distance dependencies to his network models, similar to the following: *The girl who the dogs that he chases down the block frighten, runs away*[1]. When the input to the network consisted of whole sentences like this, the model failed to capture the dependencies between the nouns, verbs and relative clauses. When Elman restricted the network so that it could only process every three words or so, the network took longer to learn the initial generalizations, but it was much better at acquiring the long-distance dependencies once the processing window was expanded.

This seems to raise a paradox. Why would restricting the processing window make learning long-distance dependencies better? The answer may lie in the type

[1]The actual sentences that the model was trained on lacked functors, e.g. *boys who chase dogs see girls*. It is not clear what the consequences of adding functors would have been. It could be that adding functors would have made the task easier since they provide more information. On the other hand, they may make the task harder for the model to learn, since the additional information must be assimilated into the overall set of data.

of information that can be gleaned from a narrow processing window. If we break down the example sentence into 3 word bits, we get the following: [*The girl who*] [*the dogs that*] [*he chases down*] [*the block frighten*], [*runs away*][2]. When chunked like this, the sentence does lose information. For example, all of the long distance dependencies, such as the relationship between *the girl who* and *runs away* are lost. In addition, it creates noise. The chunks such as *the block frighten* are not complete constituents and are unable to be related to anything else in the sentence. At the same time, the number of possible relationships among elements is drastically reduced. Because the total number of possible co-occurrences is reduced, a number of simple, but regular co-occurrences can be extracted: *the* is always followed by a noun, and the subject-verb relationship in *he chases* is maintained. Over repeated exposure to data like this, these types of basic dependencies will keep recurring. Thus the learner should be able to extract a few basic regularities. Once these regularities are acquired, the learner can then apply them to longer distance dependencies. For instance, once the child has learned that third-person singular subjects require the ending *-s* on the verb, the possibility that the plural noun phrase *the dogs* could be the subject of the singular verb *runs away* is excluded. This means that when the child's processing space has expanded enough to encompass both *the dogs* and *runs away*, the child will not expect a dependency between these two elements, but will look elsewhere for an appropriate subject (e.g. *the girl*). Thus, restricting the processing window has the effect of (1) reducing the number of possible dependencies the learner encounters and (2) enabling the learner to focus on the basic dependencies of the language.

These models of language learning proposed by Newport (1988, 1991) and Elman (1993) are intriguing, because they can be made to simulate the incremental nature of childhood language acquisition. However, these models are as yet empirically untested with infant language learners. The models make specific predictions of infants' acquisition of dependencies in the language, yet we know little or nothing about early sensitivity to these relationships[3]. Furthermore, very little is known about the nature of processing space in infants and very young children. This study presents a first pass at examining these issues. First, it examines the age at which infants/toddlers begin to recognize some of the basic morphosyntactic dependencies in English. Second, it uses discontinuous dependencies as a window into investigating some of the basic properties of the processing space.

We chose to focus on the acquisition of a morphosyntactic dependent relationship in 15-to 18-month-old infants, because there is evidence that by this age, infants

[2]This particular division of this sentence into strict three word chunks is only for the purposes of illustration. We acknowledge that this sentence is not realistically 'chunked', but we chose this method because the model of Elman (1993) eliminated recurrent feedback randomly after every third or fourth word. Presumably, by 18 months infants will have more precise methods for breaking up the speech stream, given their demonstrated sensitivity to the functional elements of English that help to demarcate phrases (Shipley et al., 1969; Petretic and Tweney, 1977; Gelman and Taylor, 1984; Gerken et al., 1990; Gerken and McIntosh, 1993; Shady, 1996; Shafer et al., 1996).

[3]We know that adults can use morphological marking to learn the structure of an artificial language, e.g. Morgan and Newport (1981) and Morgan et al. (1987), but less is known about childhood acquisition of natural language.

have developed both the perceptual sensitivity to and the prerequisite knowledge about function morphemes necessary for acquiring such relationships. Infants as young as 2-months of age show some capacity to retain information about the serial order of words within a clause (Mandel et al., 1996). Moreover, by 9 months, infants are sensitive to the order of phonetic elements in the speech stream (Jusczyk et al., 1993, 1994; Friederici and Wessels, 1994), and they can use regularities in the speech stream to identify words (Jusczyk and Aslin, 1995; Newsome and Jusczyk, 1995; Saffran et al., 1996). By the age of 12 months, there is evidence that infants show sensitivity to these distributional properties in artificial as well as natural language (Gomez and Gerken, 1997). Moreover, 10-month-old infants are sensitive to the phonetic properties of functor words (Shady, 1996; Shafer et al., 1996). Furthermore, Shady (1996) demonstrated that by 16 months infants respond to the order and distributional properties of function items that are often involved in dependency relationships. Specifically, 16-month-old infants presented with matched passages in which the functors were properly (*the kitten was hiding*) or improperly ordered (*was kitten the hiding*), preferred the passages where the English order was maintained. Neither 12- nor 14-month old infants exhibited this pattern, indicating that between the ages of 14 and 16 months, sensitivity to the order and distributional properties of functor words in English is developing. This raises the possibility that infants may become sensitive to the co-occurrence relationships among morphemes at about the same age.

The present study explored 15- to 18-month-old infants' sensitivity to morpho-syntactic dependencies by examining how they respond to well-formed English dependencies. For each experiment, passages were constructed so that the experimental or 'natural' passages contained a dependent relationship between the auxiliary verb *is* and the verb ending *-ing*, as in *grandma is singing*. The control or 'unnatural' passages were constructed using the modal *can* and the morpheme *-ing*, *grandma can singing*, two morphemes which cannot form a relationship in English. Previous experiments using passages in our laboratory (Hirsh-Pasek et al., 1987; Jusczyk et al., 1992; Gerken et al., 1994; Shady et al., 1994) led us to hypothesize that if infants are sensitive to the natural relationship in the experimental passages, then they would listen longer to these passages than they would to the unnatural control passages.

This particular dependency was chosen because the main verb ending *-ing* must co-occur with a form of the auxiliary verb *to be* (e.g. *is, are, am*), but these two morphemes are not adjacent to one another in the speech stream[4]. Thus, in order to recognize this type of dependency, the infant must have a large enough processing window to be able to compute the co-occurrence of morphemes over several words or syllables. In addition, the *-ing* morpheme is common in spoken English, and is one of the earliest acquired morphemes (Brown, 1973; de Villiers and de Villiers,

[4]When *-ing* is used as a verbal ending on the main verb, then it must co-occur with a form of *be*, e.g. *The dog is barking*. However, in other contexts *-ing* need not co-occur with a form of the auxiliary verb *be*, e.g. *Let sleeping dogs lie*. Nevertheless, since verbal uses of *-ing* are more common than this adjectival use of *-ing*, there is a regular and consistent relationship between the ending *-ing* and the auxiliary *be* (*is, am, are*) that occurs in English.

1973), so the average English-learning infant has most likely had significant exposure to it. Finally, the dependent morphemes in this relationship can be systematically pushed apart, by inserting adverbials of differing lengths, as seen in the examples.

grandma *is* singing
grandma *is* always singing
grandma *is* almost always sing*ing*

The rationale was that if infants do indeed have a limited processing space, then increasing the distance over which they must compute this dependency may interfere with their ability to detect it. Thus, this particular dependency makes it possible both to assess sensitivity to a basic morphosyntactic relationship in English and to investigate processing space by systematically varying the distance across which this dependence must be computed. Experiments 1 and 2 investigated the age at which infants/toddlers demonstrate sensitivity to the basic relationship between *is* and *-ing*. Experiments 3–5 examined more closely the distances over which infants can compute this relationship.

One caveat before we introduce the studies: We use 'number of syllables' as a working definition of distance for measuring processing space. In doing so, we have attempted to provide a relatively neutral, easily measurable definition of distance. We acknowledge however, that 'distance' between two morphemes can be measured in many ways, e.g. number of words, number of syntactic or prosodic constituents or temporal duration. We will return to the issue of defining 'distance' for computing relationships in the discussion.

1. Experiment 1

This first study was designed to determine whether infants are sensitive to the basic relationship between the morphemes *is* and *-ing*. As noted earlier, by 16 months, English-learners are sensitive to both the phonetic and distributional properties of functor morphemes (Shady et al., 1994; Shady, 1996; Shafer et al., 1996). However, little is known about when infants learn about relationships among these functor morphemes. To explore this question, we used the Headturn Preference Paradigm (HPP) to test infants with passages containing the morpheme *-ing*. Eighteen-month-olds were chosen because previous research had shown that they should be sensitive to the distributional patterns of functor morphemes (Shady, 1996). Nevertheless, developmental scales indicate that infants of this age generally have not begun to produce forms marking morphosyntactic relationships in their own speech (e.g. Fenson et al., 1993).

We hypothesized that if infants are sensitive to the relationship between *is* and the ending *-ing*, they would listen longer to the natural passages with this dependency than to the unnatural control passages. Note that none of the individual words was out of order in the unnatural passages. All the words were in their legitimate sentential slots. Only the particular combination of words was strange. Consequently,

any infant who does not track the dependencies between morphemes should not have reacted differently to the unnatural passages than to ones in which the proper English-like dependency was maintained.

1.1. Method

1.1.1. Participants

The participants were 24 American infants (15 males and nine females) from monolingual English-speaking homes. The infants were approximately 18 months old, with a mean age of 78 weeks, 4 days (range 75 weeks, 2 days to 82 weeks, 1 day). The data from an additional eight infants were excluded for the following reasons: three for crying, four for unresponsiveness or falling asleep and one for parental interference.

1.1.2. Stimuli

Eight sets of matched passages (16 total) with six sentences each were created. Two of these matched sets (four passages) were used as practice passages, and the remaining six matched passages (12 total) were used as test trials. In the 'natural' set of passages, every sentence used the auxiliary verb *is* together with a main verb ending in *-ing* on the main verb. In the matched 'unnatural' passages, each sentence contained the modal auxiliary *can* and the main verb ending with *-ing*, a combination which is ungrammatical in English. The natural and unnatural passages were exactly matched except for the substitution of *can* for *is* in the unnatural passages. In each sentence, the auxiliary verb (*is* or *can*) and the ending *-ing* were as close as they can be in English: separated only by the single monosyllabic verb root. The subject in each sentence was a full noun phrase in the third person singular (e.g. *my neighbor*), so that the auxiliary verb would always take the form *is*. Examples of typical Natural and Unnatural passages are shown in Table 1.

The stimuli were produced using synthetic speech (DECTalk model DTC01) so that both the natural and the unnatural passages would use the same prosody and stress on the morphemes under investigation. For the single syllable passages, the average distance between the auxiliary and *-ing* morphemes was 259 ms (SD 25.57), with a range 263–298 ms. We also determined the mean fundamental frequency for the syllable of the material intervening between the auxiliary and -

Table 1
Examples of Natural and Unnatural passages over a single syllable verb root

Natural passage	Unnatural passage
At the bakery, everybody is baking bread. One person is mixing the flour and water together. Someone else is adding salt and yeast. In the next room, a big machine is kneading the dough. Another is shaping the loaves for the oven. The whole place is starting to smell great!	At the bakery, everybody can baking bread. One person can mixing the flour and water together. Someone else can adding salt and yeast. In the next room, a big machine can kneading the dough. Another can shaping the loaves for the oven. The whole place can starting to smell great!

ing for each sentence. The mean fundamental frequency between the auxiliary and *-ing* for the single syllable condition was 181 Hz (SD 6.69), with a range of 176–192 Hz.

The stimuli were recorded onto a DAT player (model DTC 690) and then digitized on a VAXStation Model 3176 computer at a sampling rate of 20 via a 16-bit analog-to-digital converter. The average duration of the 12 passages in the test stimuli was 24510 ms (the passages ranged from 24269 ms to 24697 ms) and the stimuli were played at 72 + 2 dB SPL as measured by a Quest Model 215 Sound Level Meter at the location of the infant's head. After editing the passages were transferred to a Macintosh Quadra 650 computer and prepared for presentation.

1.1.3. Design

Each infant was seen for one experimental session. All infants heard the same set of four passages during the practice phase. The order and side of presentation for the test passages was randomized for each participant. The complete session occurred after the infants had received all 12 test trials.

1.1.4. Apparatus

A Macintosh Quadra 650 controlled the presentation of the stimuli and recorded observers' coding of the infant's responses. A 16-bit D/A converter (at a 20 kHz sampling rate, and low-pass filtered at 9.5 kHz) was used to recreate the audio signal. The output was fed through anti-aliasing filters and a Kenwood audio amplifier (KA 5700) to one of two 7-inch Advent loudspeakers mounted on the side walls of the testing booth.

The experiment was conducted in a three-sided test booth constructed out of pegboard panels (4 × 6 ft). An experimenter, located behind the front wall of the booth, looked through one of the existing pegboard holes in the front panel to monitor the infant's head turns. Except for a small section for viewing the infant, the remainder of the pegboard panels was backed with white cardboard so that the infant could not see movements behind the panels. There was a green light mounted on the center panel and a 5-cm hole for the lens of a video camera directly below this light, used to record each session. A white curtain was suspended from the ceiling and prevented the infant from seeing over the top of the booth. A red light was mounted on each side panel, and a loudspeaker was mounted at the infant's ear level behind each of these panels. A computer terminal and a six-button response box were located behind the front wall of the booth. The response box, which was connected to a Macintosh Quadra 650, was equipped with a series of buttons that started and stopped the flashing center and sidelights, recorded the direction and duration of headturns, and terminated a trial when the infant looked away for more than 2 s. Information about the direction and duration of headturns and the total trial duration were stored in a data file on the computer. Computer software was responsible for the selection and randomization of the stimuli and for the termination of test trials. The average looking times to each of the passages were calculated by the computer following the completion of each session.

1.1.5. Procedure

A version of the Head Turn Preference Procedure was used (Kemler Nelson et al., 1995). Each infant was held on a caregiver's lab. The caregiver was seated on a chair in the center of the test booth. Each trial began by blinking the green light on the center panel until the infant had oriented in that direction. Then, the center light was extinguished and the red light above the loudspeaker on one of the side panels began to flash. When the infant made a head turn of at least 30 degrees in the direction of the loudspeaker, the stimulus for that trial began to play and continued until its completion or until the infant failed to maintain a 30 degree headturn for 2 consecutive s, whichever came first. Any time the infant spent looking away from the target (e.g. looking back to the center or other side light, looking at the caregiver, or at the floor) was not included in the orientation time. The maximum time for orientation was thus the duration of the entire sample. The red light flashed for the entire duration of the trial.

Each experimental session began with four practice trials, two from each blinking light. The practice trials were used only to get the infants comfortable with responding to the lights, and responses during the practice trials were not recorded or analyzed. The same four stimulus passages were used as practice trials for all participants, and had the same structure as the test trials. These practice trials were conducted using two sets of matched passages (four total): two 'natural' passages, where the six sentences contained the auxiliary verb *is* together with the ending *-ing*, and two matched 'unnatural' passages, where the six sentences contained the modal auxiliary *can* and the ending *-ing*. The test phase began immediately following the four practice trials, and consisted of the presentation of the 12 passages. An observer hidden behind the center panel looked through the peephole and recorded the direction and duration of the infant's Headturns using the six-button response box. The observer was blind to the type of sample that the infant was listening to on a given trial. Both the observer and the infant's caregiver wore foam earplugs and listened to masking music over tight-fitting closed headphones (Sony MDR-V600). The masking music consisted of loud instrumental music, which had been recorded with very few silent periods. Kemler Nelson et al. (1995) have shown that for the procedure in general, reliability between the experimenter and observers of the video tapes for each session is high, with correlations ranging from 0.92 to 0.96.

In addition, to determine whether the masking was sufficient, we tested two naive adult observers to determine whether they could identify the type of sample being played on a given trial. For this task, the adult observers sat in the caregiver's chair and were wearing the ear plugs and were listening to the masking music over the closed earphones. The adults were instructed about the differences in the natural and unnatural passages. These observers heard all 12 test trials randomly presented. They were told that when the red light began to flash on a given side, they should identify whether the passage was either 'natural' or 'unnatural'. The observers had a 50% and 48% accuracy respectively in correctly identifying the natural passages. Thus the ear plugs and music were sufficient to prevent either the caregiver or the observer from identifying the type of trial.

1.2. Results and discussion

Mean looking times to the Natural and Unnatural passages were calculated for each of the 24 participants. The mean looking times were averaged for the Natural and Unnatural passages. Across all participants, the averaged looking times, displayed in Fig. 1, were 10.51 s. (SEM = 0.69) for the Natural passages and 8.92 (SEM = 0.90) for the Unnatural passages. A paired *t*-test indicated that this difference in average looking times was significant, $t(23) = 2.43$, $P = 0.023$. Inspection of the data for individual subjects indicated that 16 of the 24 infants listened longer to the natural passages.

These results indicate that 18-month-olds are indeed sensitive to the dependency between the morphemes *is* and *-ing*. This finding suggests that by 18 months, infants are able to track the co-occurrence of English morphemes and that they have begun to develop some detailed knowledge about the type of dependencies between morphemes that occur in English. However, although we have determined that 18-month-olds are sensitive to this relationship in English, we still do not know when this sensitivity develops. To explore this question, we decided to investigate infants' sensitivity to this dependency at an earlier age.

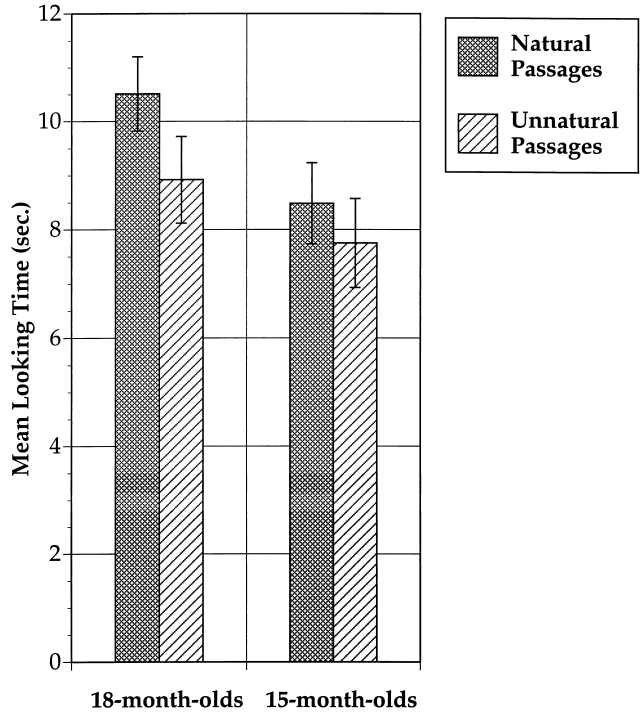

Fig. 1. 18-month-olds' (Experiment 1) and 15-month-olds' (Experiment 2) average looking times (and standard error) for passages with Natural and Unnatural dependencies across a single syllable.

2. Experiment 2

As we noted earlier, sensitivity to the distribution and order of functor morphemes in English develops between 14- and 16-months (Shady, 1996). Thus, it is possible that at this age, sensitivity to the basic relationships among morphemes also develops. Consequently, we decided to investigate whether 15-month-old infants would show sensitivity to the basic dependency between *is* and *-ing*. Again, we hypothesized that if infants are sensitive to the relationship between *is* and the ending *-ing*, then they would listen longer to the natural passages that contained this dependency than they would to the unnatural control passages. If they are not sensitive to this dependency, then they should show no preference for either type of passage.

2.1. Method

2.1.1. Participants

The participants were 24 American infants (nine males, 15 females), from monolingual English-speaking homes. The infants were approximately 15 months of age, with a mean age of 63 weeks, 3 days (range = 60 weeks, 4 days to 66 weeks, 6 days). The data from an additional four infants were excluded for the following reasons: two for crying, one for unresponsiveness or falling asleep, and one for looking times less than 3 s (long enough to listen to at least one full sentence in the passages).

2.1.2. Stimuli

The same stimuli as in Experiment 1 were used.

2.1.3. Design, apparatus and procedure

These were identical to Experiment 1.

2.2. Results and discussion

As in Experiment 1, mean looking times to the Natural and Unnatural passages were calculated and averaged for each of the 24 participants. Across all participants, the mean looking times, displayed in Fig. 1, were 8.48 s (SEM) = 0.75 for the Natural passages and 7.75 (SEM = 0.82) for the Unnatural passages. A paired *t*-test indicated that this difference in mean looking times was not significant, $t(23) = 1.48$, $P = 0.151$. Inspection of the data for individual subjects indicated that 16 of the 24 infants listened longer to the natural passages.

These results provide no evidence that 15-month-olds are sensitive to the dependency between the morphemes *is* and *-ing*. Although infants of this age have developed some detailed knowledge about the phonetic characteristics and distributional properties of functor morphemes, they do not appear to track the co-occurrence of English morphemes. Together with the results from Experiment 1, these results suggest that sensitivity to co-occurrence relationships and knowledge about the type of dependencies between morphemes develops sometime between 15 and 18 months.

Although we know that 18-month-olds are sensitive to the basic relationship between *is* and *-ing*, we do not know whether there are limits to 18-month-olds' ability to detect this dependency. In Experiment 1, the infants only had to compute the dependency over a relatively short distance. On the one hand, owing to processing limitations affecting working memory, it is possible that infants' sensitivity is restricted to a relatively limited domain, such as the one tested. On the other hand, it may be that once infants have worked out the dependencies, they can then apply this knowledge over a range of domains, both large and small. In the next series of experiments, we examined whether systematically altering the distance between the dependent morphemes would disrupt 18-month-olds' sensitivity to the relationship between the morphemes *is* and *-ing*.

3. Experiment 3

As noted earlier, processing limitations at earlier stages of language acquisition may actually be helpful, rather than detrimental, for learning about certain kinds of grammatical relations (Newport, 1988, 1991; Elman, 1993). However, such limitations are usually inferred from data regarding the kinds of utterances that language learners are producing at various points in development. Little is known about whether the same kinds of processing limitations apply to language learners' perception of linguistic input. For example, processing limitations may occur in production not because of some constraint on working memory, but rather because of the difficulty involved in planning, sequencing, and coordinating the articulatory gestures required to convey utterances longer than a few words. If so, then learners might well be capable of tracking dependencies over long distances well before what might be predicted from their productions of utterances. To evaluate the plausibility of the hypothesis that processing limitations aid in the acquisition of certain kinds of grammatical relations, it is crucial to derive some estimate of these processing limitations and how they change at various points in development.

The present experiment was designed to determine whether there is a limit to the domain over which 18-month-olds can detect the dependency between *is* and *-ing*. The specific question addressed was whether increasing the distance between the dependent morphemes will interfere with the toddlers' ability to detect the dependency. The objective of this experiment was to find an outermost limit to 18-month-olds' sensitivity to the discontinuous dependency. To examine this issue we modified the set of passages used in Experiments 1 and 2. In these passages four syllable adverbials were inserted between the auxiliary and main verbs. Each passage contained a range of adverbials, such as *diligently* or *almost always*. Thus, the dependent morphemes were separated by five syllables: the four syllable adverbial and the single syllable verb root. A typical pair of passages is shown in Table 2. We hypothesized that if infants are sensitive to the relationship between *is* and the ending *-ing* over the four syllable adverbs, they would listen longer to the natural passages that contained this dependency than to the unnatural control passages.

3.1. Method

3.1.1. Participants

The participants were 24 American infants (12 males and 12 females) from monolingual English-speaking homes. The infants were approximately 18 months old, with a mean age of 78 weeks (range 76 weeks, 1 day to 80 weeks, 0 days). The data from an additional 10 infants were excluded for the following reasons: five for crying, three for unresponsiveness or falling asleep and 2 for having mean looking times of less than 3 s (long enough to listen to at least one full sentence in the passages).

3.1.2. Stimuli

Once again, eight sets of matched passages with six sentences each were used (16 total: four practice passages and 12 test passages). The natural passages contained the auxiliary verb *is* together with verb ending *-ing* on the main verb in every sentence. In the matched 'unnatural' passages, each sentence contained the modal auxiliary *can* and the verb ending *-ing*. In each sentence, a four-syllable adverbial was inserted in between the auxiliary verb (*is* or *can*) and the main verb. Thus the dependent morphemes were always separated by five syllables: the single syllable verb root plus a four-syllable adverbial.

Again, the stimuli were produced using synthetic speech (DECTalk) so that both the natural and the unnatural passages would use the same prosody and stress on the morphemes under investigation. For these passages with a five syllable difference, the average distance between the auxiliary and *-ing* morphemes was 1125 ms (SD 29.96) with a range 1093–1162 ms. We also determined the mean fundamental frequency for each syllable of the material intervening between the auxiliary and *-ing* for each sentence. The mean fundamental frequency of the syllables in the five syllable condition was: 170 Hz (SD 2.46) with a range of 166–173 Hz for the first syllable, 178 Hz (SD 8.07) with a range of 167–187 Hz for the second syllable, 169 Hz (SD 2.60) with a range of 164–173 Hz for the third syllable, 169 Hz (SD 10.93) with a range of 162–189 Hz for the fourth syllable and 175 Hz (SD 6.29) with a range of 168–187 Hz for the fifth syllable.

Table 2
Examples of Natural and Unnatural passages over five syllables (four-syllable adverb and single syllable verb root)

Natural passage	Unnatural passage
At the bakery, everybody is effectively baking bread. One person is impatiently mixing the flour and water together. Someone else is quite skillfully adding salt and yeast. In the next room, a big machine is ponderously kneading the dough. Another is adequately shaping the loaves for the oven. The whole place is undoubtedly starting to smell great!	At the bakery, everybody can effectively baking bread. One person can impatiently mixing the flour and water together. Someone else can quite skillfully adding salt and yeast. In the next room, a big machine can ponderously kneading the dough. Another can adequately shaping the loaves for the oven. The whole place can undoubtedly starting to smell great!

The stimuli were recorded onto a DAT tape and digitized as described in Experiment 1. The average duration of the 12 stimulus passages was 28 999 ms (range 28 990 ms to 29 010 ms) and the stimuli were played at 72 ± 2 dB SPL as measured by a Quest Model 215 Sound Level Meter at the location of the infant's head. After editing the passages were transferred to a Macintosh Quadra 650 computer for presentation to the infants during the test sessions.

3.1.3. Design, apparatus and procedure

These were identical to Experiments 1 and 2.

3.2. Results and discussion

Once again, mean looking times to the Natural and Unnatural passages were calculated and averaged for each of the 24 participants. Across all participants, the mean looking times, displayed in Fig. 2, were 8.15 s (SEM = 0.80) for the Natural passages and 8.90 (SEM = 1.09) for the Unnatural passages. A paired *t*-test indicated that this difference in average looking times was not significant, $t(23) = -1.06$, $P = 0.301$. Inspection of the data for individual subjects indicated that 10 of the 24 infants listened longer to the natural passages.

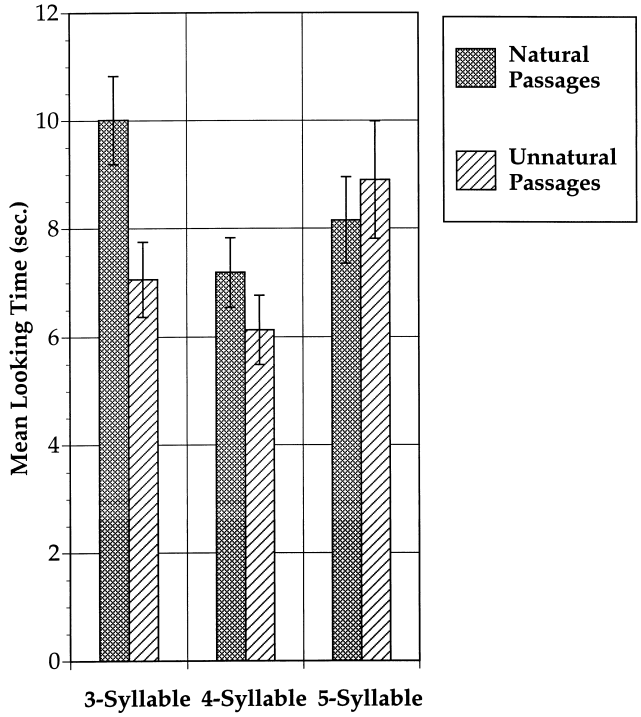

Fig. 2. 18-month-olds' average looking times (and standard error) for passages with Natural and Unnatural dependencies across three syllables (Experiment 4), four syllables (Experiment 5) and five syllables (Experiment 3).

These results indicate that the 18-month-olds did not show sensitivity to the target dependency under these conditions. The insertion of a four-syllable adverbial apparently interfered with their ability to detect the dependency between *is* and the morpheme *-ing*. This finding suggests that the 18-month-olds' ability to detect morphosyntactic dependencies is not unlimited, but is restricted to a relatively small domain. This also indicates that the effect found in Study 1 was not due solely for a preference for *is* over *can*, since these remained constant in this study.

Experiments 1 and 3 have shown several things: The first experiment provided evidence that 18-month-old infants are sensitive to the relationship between the auxiliary verb *is* and the verb ending *-ing*. This indicates that they have acquired some of the basic knowledge of the relationships between word endings in English. At the same time, the third experiment provided evidence however that 18-month-old infants' ability to detect this relationship is limited: they were not able to detect this dependency between *is* and the ending *-ing* when a 4-syllable adverb was inserted. At this point, we have found an inner domain where they show sensitivity to this relationship and an outer limit where they do not.

The next issue to be addressed concerns the nature of the limits found in the present experiment. Although the present experiment demonstrated that it is possible to interfere with 18-month-olds' sensitivity to dependency relationship between *is* and *-ing*, it leaves open what the source of the interference was. On the one hand, the interference may be attributable to the sheer distance between the dependent morphemes (i.e. five syllables separating the relevant elements). On the other hand, it is possible that it is not simply the distance between the elements, but rather the nature of the intervening material (i.e. the presence of an adverb between the two elements) that was responsible for producing the interference. Experiments with adults, e.g. Bock and Miller (1991), have suggested errors in dependency relationships are more affected by the nature of the intervening material rather than the length or semantics of that material. Thus, inserting any adverbial, regardless of length, between the auxiliary verb *is* and the main verb with *-ing* may actually affect 18-month-olds' ability to detect this relationship.

4. Experiment 4

To address the question of the nature of the interference, we created an additional set of passages where the dependency is separated by two syllable adverbs, as in *grandma is always singing*. We modified the eight sets of matched passages from Experiment 1 so that each sentence contained a 2-Syllable adverbial in between the auxiliary and main verbs. Each passage again contained a range of adverbials. Thus in these passages, the dependent morphemes were separated by three syllables: the 2-syllable adverbial and the single syllable verb root. A typical pair of passages used is given in Table 3. If infants are sensitive to the relationship between *is* and the ending *-ing* over the 2-syllable adverbs, they should listen longer to the natural passages that contained this dependency than to the unnatural control passages.

Table 3
Examples of Natural and Unnatural passages over three-syllables (two-syllable adverb and single syllable verb root)

Natural passage	Unnatural passage
At the bakery, everybody is often baking bread. One person is neatly mixing the flour and water together. Someone else is quickly adding salt and yeast. In the next room, a big machine is firmly kneading the dough. Another is deftly shaping the loaves for the oven. The whole place is really starting to smell great!	At the bakery, everybody can often baking bread. One person can neatly mixing the flour and water together. Someone else can quickly adding salt and yeast. In the next room, a big machine can firmly kneading the dough. Another can deftly shaping the loaves for the oven. The whole place can really starting to smell great!

4.1. Method

4.1.1. Participants

The participants were 24 American infants (13 males and 11 females) from monolingual English-speaking homes. The infants were approximately 18 months old, with a mean age of 80 weeks, 6 days (range 73 weeks, 4 days to 83 weeks, 4 days). The data from an additional six infants were excluded for the following reasons: four for crying or restlessness, one for unresponsiveness or falling asleep, and one for having mean looking times of less than 3 s (long enough to listen to at least one full sentence in the passages).

4.1.2. Stimuli

Once again, eight sets of matched passages (16 total: four practice and 12 test) with six sentences each were used. The natural passages contained the auxiliary verb *is* together with verb ending *-ing* on the main verb in every sentence. In the matched 'unnatural' passages, each sentence contained the modal auxiliary *can* and the verb ending *-ing*. A 2-syllable adverbial was inserted in each sentence between the auxiliary verb (*is* or *can*) and the main verb. Thus the dependent morphemes were always separated by three syllables: the single syllable verb root plus a two-syllable adverbial.

Again, the stimuli were produced using synthetic speech (DECTalk) and were recorded onto a DAT player, and digitized as in Experiment 1. For these passages, the average distance between the auxiliary and *-ing* morphemes was 777 ms (SD 36.17), with range 718–817 ms. We also determined the mean fundamental frequency for each syllable of the material intervening between the auxiliary and *-ing* for each sentence. The mean fundamental frequency for the syllables in the 3-syllable condition, was 181 Hz (SD 4.61), with a range of 175–188 Hz for the first syllable, 167 Hz (SD 2.67) with a range of 164–171 Hz for the second syllable and 174 Hz (SD 4.34) with a range of 171–182 Hz for the third syllable.

The average duration of the stimulus passages was 26 507 ms (range 26 483–26 549 ms) and the stimuli were played at 72 ± 2 dB SPL as measured by a Quest Model 215 Sound Level Meter at the location of the infant's head. After editing the passages were transferred to a Macintosh Quadra 650 computer and prepared for presentation.

4.1.3. Design, apparatus and procedure

These were identical to the previous experiments.

4.2. Results and discussion

As in the previous experiments, mean looking times to the Natural and Unnatural passages were calculated and averaged for each of the 24 participants. Across all participants, the mean looking times, displayed in Fig. 2, were 10.01 s (SEM = 0.82) for the Natural passages and 7.06 s (SEM = 0.69) for the Unnatural passages. A paired *t*-test indicated that this difference in mean looking times was significant, $t(23) = 2.99$, $P = 0.007$. Inspection of the data for individual subjects indicated that 17 of the 24 infants listened longer to the natural passages.

These results indicate that infants' sensitivity to this dependency is not limited to a single syllable verb root; the infants are also sensitive to this dependency over a total of three syllables: the single syllable verb root plus a two syllable adverb. Furthermore, the results indicate that it is not simply the insertion of an adverb that interfered with their ability to detect the dependency in the second study. Rather, it appears that the distance between the related constituents also affects the ease with which the dependency is detected.

We have now narrowed the domain over which 18-month-olds are sensitive to this dependency to a range between three and five syllables. However, to better evaluate claims regarding the processing limitations of infants at this age, it would be useful to have a more precise estimate of the size of the domain. In other words, are 18-month-olds sensitive to the relationship over an intermediate range of four syllables, or is this sensitivity restricted to three or fewer syllables?

5. Experiment 5

In order to estimate the size of the processing domain more precisely, we created an additional set of passages where the dependency is separated by three-syllable adverbs, as in *grandma is quite often singing*. The matched passages from Experiment 1 were modified so that each sentence contained a three-syllable adverbial between the auxiliary and main verbs. Each passage again contained a range of adverbials. In these passages, the dependent morphemes were separated by four syllables: the three-syllable adverbial and the single syllable verb root. A typical pair of passages used is given in Table 4. If infants are sensitive to the relationship between *is* and the ending *-ing* over the three-syllable adverbs, they should listen longer to the natural passages that contained this dependency than to the unnatural control passages.

5.1. Method

5.1.1. Participants

The participants were 24 American infants (12 males and 12 females) from

Table 4
Examples of Natural and Unnatural passages over four syllables (3-syllable adverb and single syllable verb root)

Natural passage	Unnatural passage
At the bakery, everybody is cheerfully baking bread. One person is actively mixing the flour and water together. Someone else is gingerly adding salt and yeast. In the next room, a big machine is constantly kneading the dough. Another is easily shaping the loaves for the oven. The whole place is certainly starting to smell great!	At the bakery, everybody can cheerfully baking bread. One person can actively mixing the flour and water together. Someone else can gingerly adding salt and yeast. In the next room, a big machine can constantly kneading the dough. Another can easily shaping the loaves for the oven. The whole place can certainly starting to smell great!

monolingual English-speaking homes. The infants were approximately 18 months old, with a mean age of 77 weeks, 4 days (range 76 weeks, 0 days to 80 weeks, 2 days). The data from an additional 17 infants were excluded for the following reasons: eight for crying or restlessness, two for unresponsiveness, five for having mean looking times of less than 3 s (long enough to listen to at least one full sentence in the passages) and two for experimental failure.

5.1.2. Stimuli

Once again, eight sets of matched passages (16 total) with six sentences each were used. The natural passages contained the auxiliary verb *is* together with the ending *-ing* on the main verb in every sentence. In the eight matched 'unnatural' passages, the modal auxiliary *can* was substituted for *is* in every sentence. In each sentence, a three-syllable adverbial was inserted in between the auxiliary verb (*is* or *can*) and the main verb. Thus the dependent morphemes were always separated by four syllables: the single syllable verb root plus a three-syllable adverbial.

Again, the stimuli were produced using synthetic speech (DECTalk) and were recorded onto a DAT player and digitized on the VAXStation as in Experiment 1. For these passages with a four syllable distance, the average distance between the auxiliary and *-ing* morphemes was 891 ms (SD 79.60), range 741 –946 ms. We also determined the mean fundamental frequency for each syllable of the material intervening between the auxiliary and *-ing* for each sentence. The mean fundamental frequency for the syllables in the four syllable condition was: 176 Hz (SD 4.23) with a range of 171–181 Hz for the first syllable, 171 Hz (SD 4.89) with a range of 166–178 Hz for the second syllable, 167 Hz (SD 4.79) with a range of 163–176 Hz for the third syllable and 175 Hz (SD 7.25) with a range of 170–189 Hz. for the fourth syllable.

The average duration of the stimulus passages was 24 511 ms (range 24 280 ms to 24 700 ms) and the stimuli were played at 72 ± 2 dB SPL as measured by a Quest Model 215 Sound Level Meter at the location of the infant's head. After editing the passages were transferred to a Macintosh Quadra 650 computer and for presentation during the test sessions.

5.1.3. Design, apparatus and procedure

These were identical to the previous experiments.

5.2. Results and discussion

As in the previous experiments, mean looking times to the Natural and Unnatural passages were calculated and averaged for each of the 24 participants. Across all participants, the mean looking times, displayed in Fig. 2, were 7.19 s (SEM = 0.64) for the Natural passages and 6.13 (SEM = 0.64) for the Unnatural passages. A paired *t*-test indicated that this difference in mean looking times was not significant, $t(23) = 0.808$, $P = 0.427$. Inspection of the data for individual participants indicated that 13 of the 24 infants listened longer to the natural passages.

These results indicate that the infants did not show sensitivity to the target dependency under these conditions. The insertion of a three-syllable adverbial to create a four syllable total distance also interfered with their ability to detect the dependency between *is* and the morpheme *-ing*. This suggests that the 18-month-olds' ability to detect this particular morphosyntactic dependency is indeed restricted to a small domain. The results from this experiment, combined with the results from the previous experiments, strongly suggest that the domain for detecting the relationship between *is* and *-ing* is restricted to three or fewer syllables. This in turn is consistent with the hypothesis that the processing domain in early language learners is very restricted.

6. Comparison of results of experiments 1, 3, 4 and 5

The *t*-tests from the individual experiments have shown that the infants showed a significant preference for the natural passages over the unnatural ones in the 1- and 3-syllable conditions, but not in the 4- or 5-syllable conditions. As a further check that infants' processing of the dependencies was affected by the distance between the critical syllables, we subjected the data from Experiments 1, 3, 4 and 5 to an omnibus ANOVA.

The ANOVA revealed a significant effect for experiment on the difference between the Natural and Unnatural passage, $F(3,92) = 4.500$, $P = 0.005$. Planned comparisons indicate a significant difference between the experiments for the 3- and 4-syllable conditions, $F(1,47) = 4.816$, $P = 0.030$, but no significant difference between the 1- and 3-syllable conditions, $F(1,47) = 1.327$, $P = 0.255$ or between the 4- and 5-syllable conditions, $F(1,47) = 1.774$, $P = 0.189$. In other words, there is a significant difference between the key experiments in the 'short' and 'long' conditions, but no significant difference between either the two short conditions or the two long conditions.

Although processing limitations are a possible explanation for why infants responded differently to the longer adverbials, another possibility is worth considering. Perhaps, owing to their greater length, the 4- and 5-syllable conditions included some acoustic discontinuity that led the infants to treat the two elements of the

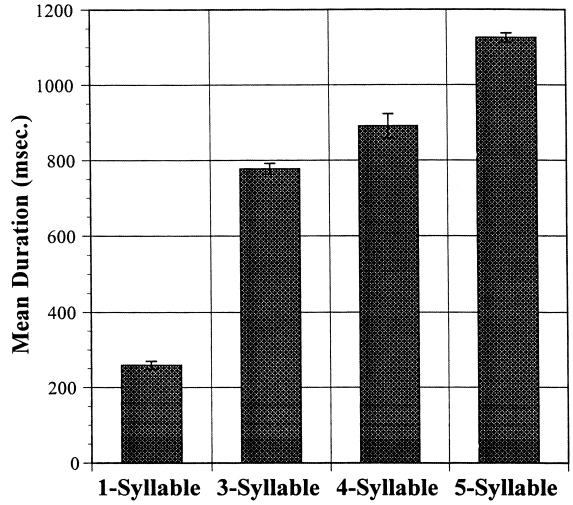

Fig. 3. Mean duration in ms (and SE) between the morphemes *is* and *-ing* across one syllable (Experiment 1), three syllables (Experiment 4), four syllables (Experiment 5) and five syllables (Experiment 3).

dependency as unrelated units. To explore this possibility, we first investigated the possibility that there was some abrupt change in the duration of the syllables across the particular conditions, especially between the 3- and 4-syllable conditions. A plot of the durations is shown in Fig. 3. If anything, the largest change in syllable duration occurs between the conditions in which the infants detected the dependency, namely, the 1- and 3-syllable conditions. In fact, a one-way ANOVA revealed a significant main effect of syllable distance, $F(3,20) = 349.54$, $P < 0.001$. Planned comparisons indicated that there were significant durational differences across all the conditions, range from $F(1,10)$ 10.15, $P < 0.01$ for the difference between the 3- and 4-syllable condition to $F(1,10) = 821.06$, $P < 0.0001$ between the 1- and 3-syllable condition.

We also analyzed the fundamental frequency of the syllables between the elements of the dependency relation to determine whether there was evidence of any abrupt change in the adverbials of the 4-syllable condition, which was the shortest condition in which the infants failed to detect the dependency. In fact, the fundamental frequency contour for the 4-syllable condition was very similar to that of the 3-syllable condition. The average fundamental frequency of the syllables in the 3-syllable condition started out relatively high (181 Hz) on the first syllable, dropped slightly on the second syllable (167 Hz) and rose again on the third syllable (174 Hz). The comparable values for the average fundamental frequency of the syllables in the 4-syllable condition were 176 Hz, 171 Hz, 167 Hz, and 175 Hz for the first, second, third, and fourth syllables respectively. Hence, there was no evidence of any obvious discontinuity in either the durations or the fundamental frequencies of the syllables of the intervening adverbials that could explain the differential pattern of responding to the ‘short’ and ‘long’ conditions. Consequently, the remainder of the

discussion focuses on how processing capacities of the infants may have affected their ability to detect the dependencies in the different conditions.

6.1. Analyses of the relation between productive and receptive capacities

In addition to this perception evidence, we also conducted an additional analysis of the data based on parental reports on the 18-month-olds productions[5]. Specifically, we collected data about whether or not the infants had begun to produce two-word combinations. Parents were given a short written questionnaire and asked whether their children were saying any words and whether they had begun to put words together. Parents were also asked to give examples of the words their children were saying (if any), as well as examples of the word combinations (if any) the children produced. The child was considered to produce two-word combinations if the parents reported one or more combinations of two lexical items, such as *Daddy go* or *more juice*. Compounds, such as *teddy-bear*, and routine phrases or idioms, such as *all gone*, were not considered to be two-word combinations.

The analysis of the production data suggests a possible link between increases in production and sensitivity to morphosyntactic relationships. For Experiment 1, with the short-distance dependency, sensitivity to the dependency and the infants' productions of word combinations appear to have been related[6]. In this study, production reports were available from the parents of 22 of the 24 infants. Seven infants had begun to produce two-word combinations. A paired *t*-test of the mean looking times for these infants, given in Table 5, reveals a significant preference for the natural passages, $t(6) = 3.63$, $P = 0.011$. By comparison, a paired *t*-test of the mean looking times for the 15 infants who did not yet produce word combinations did not show a significant difference between the natural and the unnatural passages, $t(14) = 0.843$, $P = 0.414$. One possible interpretation of these findings is that there is an underlying developmental change that both enables infants to produce longer utterances and to more reliably track discontinuous dependencies.

Note that we are not suggesting that the production of word combinations is a prerequisite for the ability to detect discontinuous dependencies or that infants who are sensitive to this dependency should be able to produce word combinations. Of the 15 infants who did not combine words, nine showed a preference for the natural passages. Some of these infants showed a quite strong preference for the natural passages, up to 4 or 5 s. This indicates that some infants who do not produce word combinations may have been able to track the dependency. But as a group these data are much more variable, and the preference for the natural passages was not significant.

[5]We considered these analyses to be post-hoc for several reasons. First, the studies were not originally designed to control for the 18-month-olds production data; this data began to be collected after the experimenters noticed that the children who were producing two-word combinations seemed to be showing much stronger preferences for the natural passages. Second, the number of children in each group (combines words vs. does not combine words) was not controlled for, leading to different and unequal numbers of children in each group for the different studies.

[6]Only two of the 15-month-olds in Experiment 2 were reported to be combining words, so we did not conduct this post-hoc analysis on the 15-month-old data.

Table 5
Mean looking times (and SE) to Natural and Unnatural passages for 18-month-olds who do and do not combine words in their productions (based on parental report)

Study	Combines words		Does not combine words	
	Natural	Unnatural	Natural	Unnatural
Study 1: single syllable separation	10.59 (0.51)	6.54 (1.21)	9.62 (0.82)	8.97 (0.93)
Study 3: five syllable separation	8.08 (1.35)	8.52 (1.97)	8.20 (1.00)	9.21 (1.21)
Study 4: three syllable separation	10.51 (1.08)	6.41 (0.92)	9.30 (1.30)	7.97 (1.02)
Study 5: four syllable separation	7.55 (0.79)	6.80 (0.77)	5.80 (0.61)	6.47 (1.06)

We find the same pattern of results in Experiment 4, where dependencies were separated by three syllables, that we found in Experiment 1, where the dependency was separated by only a single syllable. According to the parental reports, 14 of the 24 infants in this study had begun to produce two word combinations. As with the infants in Experiment 1, these infants who combined words showed a significant preference for the natural passages in their mean looking times, $t(13) = 3.29$, $P = 0.006$. However, the 10 infants who did not combine words did not show this difference in looking times, $t(9) = 0.876$, $P = 0.404$. The mean looking times are given in Table 5. This result confirms the connection that we found in Experiment 1: over the shorter distances, the infants who combine words are significantly more likely to show sensitivity to the dependency than the infants who have not yet begun to combine words.

A different pattern of results was found in the experiments with the longer distances, where the dependency was separated by four syllables (Experiment 5), or by five syllables (Experiment 3). In the experiment with the 4-syllable separation (Experiment 5), 19 of the 24 infants had begun to produce two-word combinations. However, these infants showed no significant difference in their mean looking times, given in Table 5, between the natural passages and unnatural passages, $t(18) = 1.197$, $P = 0.247$. Similarly, the five infants who were not yet combining words also showed no significant preference for the natural passages, $t(4) = -0.527$, $P = 0.626$.

A similar pattern of results was found for the dependencies separated by five syllables (Experiment 3). In this experiment, production reports were available for 23 of the 24 infants. There were 11 infants who had begun to produce two word combinations, and 12 who had not yet begun to combine words. Mean looking times for each group are given in Table 5. As with the four-syllable distance, the mean looking times for the infants who combined words indicated no significant preference for the natural passages, $t(10) = -0.496$, $P = 0.630$. These data paralleled those of the 12 infants who did not produce word combinations, where the mean looking times revealed no significant preference for the natural passages, $t(11) = -1.04$, $P = 0.320$.

In neither of the studies with the longer distance dependencies was there was an overall preference for the natural passages. No group in either study showed a significant preference for the natural passages. This pattern of results suggests even 18-month-olds whose processing space has increased enough for them to

produce word combinations are not able to detect the discontinuous dependency reliably over a four- or five-syllable adverbial. Their difficulty in detecting these dependencies over the longer distances may be a reflection of their on-line processing capacities.

Hence, there may be at least two important developments that affect the ability to pick up discontinuous dependencies in linguistic input. The first of these is simply learning about relations among words in utterances, which leads to sensitivity to relationships between words and word endings. This sensitivity to relations between words may then facilitate the planning and production of word combinations. The second is a processing limitation on working memory that restricts the distance over which infants can detect these kinds of dependencies in the input. Thus, even the ability to combine words in production does not seem to be a sufficient basis for infants to detect the relationship between *is* and *-ing* over the longer four- and five-syllable distances.

However, in order to understand more fully the nature of the link between processing space, language development and the perception of dependency relations, further research is called for. In particular, more detailed measures of language development (both receptive and productive), are needed to explore the factors that may contribute to this apparent link between language development and perception of dependency relationships.

7. General discussion

This series of experiments was undertaken to explore 15- to 18-month-olds' sensitivity to discontinuous dependencies in English, as well as to begin to explore the nature of the processing space in early language learning. The experiments indicate that sensitivity to the basic dependency between the auxiliary verb *is* and the verbal ending *-ing* develops between 15 and 18 months; 18-month-olds showed a significant listening preference to the passages where this dependency is maintained, while 15-month-olds did not. These results indicate that 18-month-olds have acquired some of the basic knowledge of the relationships between morphemes in English. This knowledge should provide a solid foundation from which they can begin to process longer and more complex strings. These studies add to the growing body of evidence that even infants who do not regularly produce function morphemes such as *is* or *the*, are nonetheless sensitive to the presence of these morphemes in the speech around them (e.g. Shipley et al., 1969; Petretic and Tweney, 1977; Gelman and Taylor, 1984; Gerken et al., 1990; Gerken and McIntosh, 1993). Moreover, we have shown that not only are they sensitive to the presence of these functor morphemes, but that 18-month-olds can also track relationships between them, a necessary prerequisite for being able to structure and decode longer, more complex sentences.

At the same time, the results suggested that 18-month-olds' sensitivity to this dependency is restricted to a relatively short domain; over distances of one- to three-syllables the 18-month-olds showed a significant listening preference to the natural

passages. Over larger distances of four- or five-syllables, however, the 18-month-olds showed no significant listening preference to the passages with the natural dependency. In addition, we presented post-hoc analyses based on a production measure which suggest that there may be limitations that constrain both perception and production at this age. In those studies where the 18-month-olds showed a significant preference for the natural passages, infants who combined words showed a preference for the natural passages while the infants who did not yet combine words did not.

Before we can conclude, however, that these results reflect 18-month-olds' sensitivity to the relationships between the two morphemes under investigation, we must consider a possible alternative explanation for our results. In particular, since previous research has demonstrated that infants are sensitive to distributional information in language, it may be possible that the 18-month-olds are simply responding to the frequency of *is* rather than to the relationships between the morphemes *is* and *-ing*.

There are several reasons why this alternative hypothesis cannot hold. First, there are recent results by Golinkoff et al. (1998) with an intermodal looking procedure. In their experiment, they held *is* constant and varied the ending on the verb among *-ing*, *-ly*, and *-lu*. Their results showed that 18-month-olds looked longer to the correct action with the *-ing* as the ending on the main verb than for the other endings. This indicates that 18-month-olds are sensitive to the ending *-ing*, even with *is* held constant. Second, in our studies, several conditions revealed no significant preference for the passages with *is*. If the 18-month-olds were simply demonstrating a preference for *is*, we would expect them to show this preference in all conditions. However, this is not the case. The preference for the *is* passages occurs only in those conditions where the *is* and the *-ing* are relatively close together.

Another possible alternative explanation for the lack of preference for the natural passages in the four- and five-syllable conditions is that the infants failed to respond because both the Natural and Unnatural conditions included odd, low frequency adverbs which might have masked the preference for *is* over *can*. Under this hypothesis, the preference for *is* over *can* was not 'masked' in the one- and three-syllable conditions because these conditions either lacked the low frequency adverbs altogether or they used more frequent, less 'odd' two-syllable adverbs such as *often*, *really* or *deftly*.

There are several reasons why this alternative possibility cannot hold. First, we used a range of adverbs, 122 over all three conditions, both frequent and infrequent. The adverbs used for each condition are listed in Appendix A. The adverbs used in the three-syllable condition included some relatively common adverbs such as *often* or *firmly*, and some rare adverbs such as *crassly* or *primly*. Likewise, the longer adverb conditions, contained some relatively common adverbs, such as *very calmly*, *almost always* or *suddenly*, as well as some less frequent adverbs such as *haphazardly* or *tenaciously*. We analyzed the adverbs based on their reported log frequency in Kucera and Francis (1968), and we found no significant difference among the experiments for frequency of the adverbs used, $F(1,121) = 1.253$, $P = 0.289$.

Since the Kucera and Francis corpus was based on written English, it is not clear that frequencies from this corpus are directly comparable to what 18-month-olds hear. Because of this, we also analyzed the frequency of the adverbs used in this set of experiments based on their frequency in the CHILDES Wisconsin corpus (Chapman and Miller, 1978; MacWhinney, 1995). This is a corpus of 48 parent-child dyads, recorded when the children were approximately 18-months-old. We found that the vast majority of the 122 adverbs used in the experimental studies did not occur in this corpus at all. Only 10 out of the 122 adverbs we used (8.1%) were present in any of the recordings. The adverbs that did occur were distributed fairly evenly across the three conditions with adverbs. Three adverbs from the three-syllable condition appeared in this corpus: *really*, *sometimes* and *always*. Three adverbs from the four-syllable condition also appeared in this corpus: *usually*, *quite* and *nicely* (as part of *quite nicely* or *quite loudly*). Four adverbs from in the five-syllable condition also appeared in this corpus. These included *very*, *quite*, *too* and *almost*, all used as part of combinations of adverbs in this condition. An ANOVA of the frequency of these adverbs as they appear in the Wisconsin corpus reveals no significant difference among the experiments for frequency of the adverbs used, $F(2,7) = 0.668$, $P = 0.543$.

These results show that the 18-month-olds preference (or lack thereof) for the Natural passages with *is* was not due to the use of low frequency adverbs in the longer adverbial conditions which either masked a possible preference for *is* or created a general dispreference for these passages because they contained more 'odd' or less frequent words. Instead, our findings are consistent with the hypothesis that 18-month-olds are working with a limited processing window, and that they are only picking up relevant dependencies that fall within this window. These findings are also consistent with the view that as the processing space increases, the infants may be better able to track discontinuous dependencies over longer distances. Whether or not the limitations in processing space, such as we have found in this study, facilitate language acquisition, as suggested by Newport (1988, 1991) or Elman (1993), or hamper language acquisition as the traditional views hold is a question that we cannot yet address. They may do both. The literature on specific language impairment suggests that reduced working memory in older children limits both sentence comprehension and the ability to learn novel words and morphemes (e.g. Montgomery, 1995; Ellis Weismer, 1996). For adults, it has been argued that constraints on working memory affect performance on verbal comprehension tasks, (e.g. Just and Carpenter, 1992 and references cited therein). Thus, it is possible that processing limitations could help facilitate language acquisition in the very early stages, but hinder performance later on.

While these studies have found evidence for processing limitations, they still leave many questions about the nature of the processing space in early language learning unanswered. One important question about the nature of the processing space that these studies raise concerns the nature of that material that interferes with the infants' ability to detect the dependency in the conditions with four and five syllables. By characterizing the distance in terms of number of syllables, we have attempted to provide a relatively neutral metric as the relevant measure of inter-

ference. Nevertheless, it is not clear that interference is directly related to the number of syllables intervening between the two parts of the dependency. Although difference in the three- and four-syllable conditions of the present study was not marked by any significant changes in prosodic contours, changes in the prosodic contour could very well interact with the ability to detect this kind of dependency. For example, previous research indicates that prosodic breaks can interfere with infants' ability to remember speech information across clause boundaries (e.g. Mandel et al., 1994, 1996). It is possible that changes in the prosodic pattern could interfere with the infants' ability to form a relationship between the auxiliary verb and the verb ending across longer distances. Another possibility is that the type of material intervening matters. In the present study, only adverbs were inserted between the critical elements of the syntactic dependency. It is possible that we may not find the same type of interference if we separate the dependent morphemes with a multi-syllable verb root rather than adverb + verb root. Alternatively, the measure of interference could be temporal, such that simply increasing the time lag between the two parts of the relationship could interfere with infants' ability to detect it. Further research is indicated to explore more closely the source of the interference in these studies.

Another major issue that arises concerns the cross-linguistic implications of this work. The hypothesis that infants learn the basic relationships and dependencies of the language through a restricted processing window may work well for a language like English, where the majority of basic dependencies are close together. However, for other languages, this model may run into difficulties. For example, German uses auxiliary-main verb constructions similar to those we tested in English. However, while the main verb generally follows the auxiliary verb very closely in English, this is not the case in German. In German, the auxiliary verb must appear in the second position in the clause, but the main verb must be in final position. Thus, the main verb in German will be preceded by both adverbs and objects. For example, in the German sentence *Wir haben diese Bilder schon gesehen*, 'we have already seen these pictures', the dependent morphemes are separated by two constituents, the object noun phrase (*diese Bilder* 'these pictures') and the adverb *schon* 'already'. Together these make up five syllables in length; our English-learning infants were not able to detect a similar dependency over this distance. So the question arises as to how processing interacts with the structure of a specific language, and how similar or how different infants' processing strategies are across languages.

Finally, we note that the Headturn Preference Procedure was successfully adapted for exploring syntactic processing in older infants. Although the preferential looking procedure has been used successfully with infants at this age (e.g. Hirsh-Pasek and Golinkoff, 1996), it is limited in that it requires that the relations tested be picturable. The Headturn Preference Procedure requires only the use of well-controlled contrasting utterances. Hence, it can be useful in exploring the comprehension of grammatical relations that are not amenable to testing with the preferential looking procedure. It provides researchers with an opportunity to explore the comprehension of certain grammatical elements long before these appear in language learners' utterances.

Although there are many issues left to be addressed, the present studies have provided evidence for both sensitivity to relationships among morphemes and evidence for limitations in the domain over which 18-month-olds can detect these relationships. These results indicate that theories of language development must take into account not only the nature of the language to be acquired but also the nature of the processing space and the perceptual mechanisms that infants are working with while acquiring language.

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Appendix A. Adverbs used (numbers in parentheses indicate number of times used in passage)

Two syllables (Experiment 4)
Always (3)
Boldly (2)
Calmly (3)
Crassly
Deftly
Deftly
Firmly
Fondly
Gladly (2)
Grimly (2)
Hardly
Keenly
Kindly (2)
Loudly (2)
Loudly
Meekly
Neatly (2)
Nimbly
Nobly
Often
Pertly
Primly (2)
Quickly (4)
Rashly (2)
Really (3)
Rudely
Sadly
Safely
Softly
Sometimes (2)
Vainly

Three syllables (Experiment 5)
Actively (2)
Adeptly
Affably
Alertly
Ardently
Astutely
Very calmly
Very fondly
Very hotly
Very neatly
Very nimbly
Basically
Brazenly
Callously
Carelessly
Certainly (2)
Cheerfully (2)
Constantly (2)
Eagerly
Earnestly
Easily
Forcefully (2)
Frantically
Furtively
Gingerly
Greedily
Groggily
Joyfully
Merrily
Nervously
Noisily
Openly
Peaceably
Prudently
Quite boldly
Quite kindly
Quite loudly
Quite nicely
Sedately
Serenely
Silently
Skillfully
Suddenly
Timidly
Visibly
Vividly
Warily
Wistfully

Four syllables (Experiment 3)
Adequately
Almost never
Almost always
Contentedly
Deliberately
Dependably
Desperately
Diligently
Dutifully
Effectively (2)
Efficiently
Elegantly
Flamboyantly
Generously
Grumblingly
Habitually
Halfheartedly
Haphazardly
Hardheartedly
Hesitantly
Hospitably
Impatiently (2)
Innocently
Observantly
Painstakingly
Perpetually
Ponderously
Presumably
Quite certainly
Quite frantically
Quite intently
Quite probably
Quite suddenly
Quite skillfully (2)
Reliably
Tenaciously
Tirelessly
Too eagerly
Undoubtedly
Usually