Why Children Understand and Misunderstand Sentences: An Eye-tracking Study of Passive Sentences*

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ABSTRACT. Although by 3- or 4-years of age, children are remarkably good at understanding most sentences, many studies have shown that even 5- and 6-year old children have difficulty understanding some types of sentences. The reason(s) why are unclear in large part because we know little about how children process sentences. To investigate how children process the sentences, we collected accuracy, reaction time, and eye-gaze data while 3- to 6-year old English-speaking children listened to active and passive sentences and performed a picture-matching comprehension task. Consistent with previous work, children were faster and more accurate on active than passive sentences. Our data suggest that, although 3-year old children have (at least some of) the linguistic machinery that underlies passives, they cannot interpret them, and even 6-year old children's processing of passives is not yet adult-like insomuch as it is off-line. Our data further suggest that at age 5, children still rely on a 1st NP = Agent heuristic to process active and passive sentences, but that by age 6, children only use the 1st NP = Agent heuristic when they misinterpret passives. Thus, we argue that children misinterpret passives, not because of syntactic limitations, but rather because of sentence processing limitations. More generally, we argue that children's sentence processing is still developing at age 6.

Key words: sentence processing, language development, eye-gaze, syntax, passive sentences

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1. Introduction

1.1 The development of sentence comprehension

Many studies have documented that very young children understand the meaning of simple active sentences. For example, 18-month old English-speaking children distinguish between syntactically minimal active sentences such as *Cookie Monster is washing Big Bird* and *Big Bird is washing Cookie Monster* (Hirsh-Pasek & Golinkoff, 1991), and 28-month old children can understand the subtly different meanings of sentences such as *Cookie Monster and Big Bird are turning* and *Cookie Monster is turning Big Bird* (Hirsh-Pasek, Golinkoff, & Naigles, 1996). By 4-years of age, although children understand simple active sentences, they frequently misunderstand some types of sentences (e.g., passive sentences, center embedded relative clause sentences, etc.). Many studies have investigated the frequency with which children misunderstand these sentences, and the semantic and syntactic characteristics sentences that make children more or less likely to misunderstand them. However, despite an extensive body of empirical data and much fruitful theorizing, we do not know *why* children misunderstand the sentences they do. Are children's misunderstandings a reflection of their immature grammars and, if so, how are their grammars different from adults' grammars? Or are these misunderstandings a reflection of children's immature language processors and, if so, how are children's language processors different from adults' language processors? Do children process sentences in fundamentally different ways than adults or do they just do so more slowly or with less accuracy? Perhaps children's misunderstandings are not due to linguistic limitations but rather to nonlinguistic limitations such as their ability to attend to, remember, and process information.

For several reasons, passive sentences are an ideal test case for investigating how children's grammars and language processors develop. First, we know a great deal about what features makes passives easier and harder for children to understand. Second, because 6-year old children continue to have difficulty understanding passives, we can study how children's sentence processing develops over a relatively long period of time. Third, it is easy to tell when children misunderstand passives because the meanings of active and passive sentences are very different. Fourth, passives are well studied linguistically. Fifth, although passive are rarer than actives, passives are not a fringe part of language cross-linguistically or within English (i.e., they aren't like English's "respectively" construction, e.g., *John and Mary got a B and an A, respectively*). Lastly, the structural characteristics of passives differ from language to language and this means children must learn how passives are formed in their language. For example, in English, full (or *by*) passive sentences differ from active sentences in 4 ways. First, passive sentences must include a passive auxiliary (*be* or *get*). Second, a passive suffix is attached to the verb to form a passive participle. Third, the preposition *by* precedes the grammatical object of the sentence. Finally, the canonical mapping of thematic roles to grammatical roles is switched such that the subject NP is the patient or theme of the sentence and the object NP is the agent of the sentence.

1.2 The acquisition of English passives

Although children master the passive construction early in some languages (e. g., Aksu-Koç & Slobin, 1985; Allen & Crago, 1996; Demuth, 1989), English-speaking children do not master certain types of passives until they are 6 or 7 years old. That said, analyses of spontaneous speech corpora indicate that English-speaking children begin to produce passives before their third birthday, with most children producing occasional passives before they are 2.5 years old (Snyder & Stromswold, 1997; Stromswold & Snyder, 1995). In addition, passives with novel verbs can be elicited from some 2-year old children (Brooks & Tomasello, 1999; Tomasello, Brooks, & Stern, 1998). Morphosyntactic factors affect the types of passives children produce. Children's early passives are usually truncated (Budwig, 2001; Harris & Flora, 1982; Horgan, 1978), and our analyses of 13 children's CHILDES corpora suggest that, on average, children don't begin to use full *by* passives until at least 9 months after they begin to use truncated passives (see Table). When passives are elicited or imitated, children frequently omit the passive suffix (e.g., *The girl has been lift up by the boy*) or the auxiliary (e.g., *the man helped by the boy*, Baldie, 1977). Lastly, children's spontaneous passives (Budwig, 2001) and elicited passives (Harris & Flora, 1982) almost always contain the auxiliary *get* rather than *be*. Semantic factors also affect the types of passives children produce. Young children have greater difficulty producing semantically reversible passives than semantically irreversible passives (Turner & Rommetveit, 1967).[1] Children also have more difficulty producing passives with nonactional verbs (e. g., *like*, *hate*, *see*) than actional verbs (e.g., *hit, kick, kiss, Pinker, Lebeaux, & Frost, 1987)*.

Child	Age (year;month)	Age of 1st truncated passive	Age of 1st *by* passive	Frequency of Adult *by* passives
Abe (Kuczaj, 1976)	2;5-5;0	2;8.2	3;0.2	1×10^{-4}
Adam (Brown, 1973)	2;3-5;2	2;8.5	none	4×10^{-5}
Allison (Bloom, 1973)	1;4-2;10	2;10.0	none	0
April (Higginson, 1985)	1;10-2;11	2;9.6	none	3×10^{-4}
Eve (Brown, 1973)	1;6-2;3	1;9.4	none	6×10^{-5}
Mark (MacWhinney, nd)	1;5-6;0	2;9.2	4;2.1	4×10^{-4}
Naomi (Sachs, 1983)	1;2-4;9	1;10.6	none	3×10^{-4}
Nathaniel (Snow, nd)	2;6-3;9	2;6.0	3;4.3	3×10^{-4}
Nina (Suppes, 1973)	2;0-3;3	2;0.8	none	1×10^{-4}
Peter (Bloom, 1973)	1;10-3;2	2;3.7	none	0
Ross (MacWhinney, nd)	2;7-7;10	2;9.0	2;10.3	4×10^{-4}
Sarah (Brown, 1973)	2;3-5;1	2;4.4	3;9.9	2×10^{-4}
Shem (Clark, 1978)	2;3-3;2	2;2.8	none	4×10^{-5}
Mean		2;5.2	3;2.3*	$1.7 \times 10^{-4\dagger}$

Table: Age of First Passive Sentences in the CHILDES Corpora

* For children who did not produce a *by* passive in their corpora, we used the children's ages one month after their last speech sample in calculating the mean age of first *by* passives.
† The frequency of adult *by* passives = number of adult *by* passives/number of adult lines.

English-speaking children's comprehension of certain types of passives is also delayed. In his seminal study, Bever (1970) found that 3.5 year-old children's comprehension of semantically reversible and non-reversible active sentences was almost perfect and their comprehension of semantically non-reversible *by* passives was above chance, but their comprehension of semantically reversible *by* passives

[1] A semantically reversible sentence is one in which the agent and the patient can be switched, and the resulting sentence is still semantically plausible (e.g., *The girl was pushed by the boy* and *The girl was pushed by the boy*). In a semantically non-reversible sentence, the agent and patient are not interchangeable because of the animacy of the agent and the patient (e.g. *The girl was opened by the book*) or the real-life implausibility of the event (e.g., *The man was carried by the baby*).

was at chance level. If children cannot distinguish between active and passive sentences and treat all semantically reversible sentences as if they were active, they should correctly comprehend 100% of active sentences and 0% of passive sentences. Therefore, Bever (1970) proposed that by 3.5 years of age, children are sensitive to the morphological cues that distinguish passives from actives, but they cannot consistently use this information in interpreting passives. Bever (1970) also found that 4-year old children interpret passives as if they were active. Rather than claiming that as children get older they unlearn their early sensitivity to passive cues, Bever (1970) argued that 4-year olds interpret passive sentences as if they were active because they have extracted the canonical sentence structure of English and (erroneously) generalize this Agent-Action-Patient pattern to all NVN sentences. Although the "getting worse on passives" developmental pattern is most striking in Bever's (1970) study, a few other studies have also found that older preschoolers do worse than younger preschoolers (e.g., deVilliers & deVilliers, 1973; Maratsos, 1974). Furthermore, Bever's two basic findings -- that English-speaking children have greater difficulty comprehending semantically reversible passives than semantically reversible actives and that they sometimes interpret passives as if they were active – have been replicated over a dozen times by researchers using a variety of methodologies (e.g., Aschermann, Gulzow, & Wendt, 2004; Baldie, 1977; Bowey, 1982; Brooks & Tomasello, 1999; deVilliers & deVilliers, 1973; Gordon & Chafetz, 1990; Harris & Flora, 1982; Harris, 1976; Horgan, 1978; Lempert, 1978, 1985, 1990; Lempert & Kinsbourne, 1978, 1980; Maratsos, 1974; Maratsos & Abramovitch, 1975; Maratsos, Fox, Becker, & Chalkley, 1985; Pinker et al., 1987; Shorr & Dale, 1981; Stromswold, Pinker, & Kaplan, 1985; Sudhalter & Braine, 1985; Turner & Rommetveit, 1967).

Morphosyntactic features also affect children's ability to comprehend passive sentences. Most studies have shown that children have less difficulty comprehending truncated passives than *by* passives (Fox & Grodzinsky, 1998; Harris, 1976 and references therein). Children's greater difficulty with *by* passives may, however, simply reflect the relative frequency of the two types of passives and not limitations of children's grammars or language processors. Two findings are consistent with the explanation. First, if the number of full passives children hear is artificially increased, 2.5 year olds will produce full passives with known verbs (Alcock, Rimba, Tellaie, & Newton, 2005) and 3 year olds will produce full passives with novel verbs (Brooks & Tomasello, 1999; Tomasello et al., 1998). Second, our CHILDES analyses reveal that adults rarely say full passives when speaking to children (see Table 1), with the adults who spoke to Adam (Brown, 1973) using 15 times more truncated passives than full passives. Harris and Flora (1982) found that preschool children and school age children had less difficulty understanding *get* passives than *be* passives. However, our analyses of Adam's corpora reveal that the adults who spoke to Adam used 7 times as many *get* passives as *be* passives which means that children's greater ease with *get* passives may simply reflect their higher frequency in the input, and not limitations on the children's part.

Semantic features also affect children's ability to comprehend passives. Although children do not use the animacy of NPs to interpret active sentences (Bever, 1970; Lempert, 1978), the finding that children have less difficulty understanding semantically non-reversible passives than semantically reversible passives shows that children do use the animacy of NPs to interpret passives. In addition, most studies (e.g., Fox & Grodzinsky, 1998; Gordon & Chafetz, 1990; Harris & Flora, 1982; Hirsch & Wexler, 2005; Maratsos et al., 1985; Paul, 1985; Sudhalter & Braine, 1985; Turner & Rommetveit, 1967) have shown that children have less difficulty understanding actional passives than nonactional passives. Because 90% of the passives adults produce when they speak to children have actional verbs (Gordon & Chafetz, 1990), children may simply understand actional passives better than nonactional passives because they hear more of them.

Let us return to the three morphological cues that distinguish actives from passives. Notice that each of these cues appears in certain types of active sentences: passive *be* is homophonous with progressive *be* (e.g., *The horse is kicking*) and copula *be* (e.g., *The horse is brown*); passive *get* is homophonous with semi-modal *get* (e.g., *I get to drink coffee*) and lexical verb *get* (e.g., *I get a cookie*); and passive participles are homophonous with past participles (e.g., *The horse kicked/hit the cow*), aspectual participles (e.g., *The horse has kicked/hit/shaken the cow*), and predicate adjectives (e.g., *the horse was tired*). Lastly, in addition to *by* assigning an agentive thematic role to object NPs in passive sentences, the preposition *by* can assign a locative thematic role (e.g., *The book was by the window*) or an instrumental or agentive-like thematic role (e.g., *I did the dishes by hand*, *I did it by myself*, *the painting is by Monet*). Thus, in order to correctly interpret a passive sentence, children must distinguish the three passive morphemes from their non-passive homophones. Furthermore, because none of the three passive morphemes is sufficient for a sentence to be passive, children must understand that, for a sentence to be passive, the three morphemes must co-occur.

That said, some of the passive cues appear to be more important in children's comprehension of passive sentences. If a sentence has a second NP, *by* plays a crucial role in determining whether children interpret the sentence as passive or active. Maratsos and Abramovitch (1975) found that children interpreted sentences that lack *be* (e.g., *the cow pushed by the pig*) as passive, whereas they interpreted sentences that lacked *by* (e.g., *the cow is pushed the pig*) as active. Expanding on Maratsos and Abramovitch's (1975) study, Stromswold, Pinker and Kaplan (1985) had children act out sentences that contained zero, one, two, or all three passive cues. The linguistically less advanced children seemed to have a strong Agent-Action-Patient bias. If a sentence didn't match this schema, it was treated as increasingly less active depending on the number of passive cues present, but none of the sentence types were interpreted as passive. The more linguistically advanced children attended to the *by* more than to the other passive cues: they correctly interpreted sentences that had all three passive cues as passive, they interpreted sentences that lacked a *by* phrase as active, and they performed randomly on sentences that contained a *by* phrase but weren't full passives. It is unclear how the presence of an auxiliary affects children's interpretation of a sentence. Maratsos and Abramovitch (1975) found that children interpreted sentences that lack a passive auxiliary (but contain a passive participle and *by*) as passive, whereas Stromswold et al. (1985) found that children interpreted these sentences randomly. It is also unclear how the passive participle affects children's interpretation of sentences. Stromswold et al. (1985) found that the mere presence of a passive participle had relatively little effect on whether children interpreted a sentence as active or passive, whereas the type of passive participle did have an effect: children only "got worse" on passives with *–ed* participles (e.g., *kicked*), and not passives with *-en* participles (e.g., *beaten*), suggesting that preschool children have some (limited) awareness that *–en* is a cue that a sentence may be passive.

1.4 Theories of children's acquisition of passive sentences

Researchers disagree about why children acquire certain types of passives late, why they rarely produce certain types of passives, and why they sometimes misunderstand certain types of passives. Let us review some of the more prominent theories. Tomasello and colleagues (e.g., Savage, Lieven, Theakston, & Tomasello, 2003; Tomasello, 2000a, 2000b; Tomasello et al., 1998) argue that young children learn language on an item-by-item basis. According to them, children acquire passives late because adults rarely say them. Whether a child produces or understands a particular passive sentence depends on the frequency with which s/he has heard that verb used in a passive sentence. The child does not create a general passive 'rule' until s/he has heard and said passive sentences with many different verbs. Pinker (1989) agrees with Tomasello and his colleagues insomuch as Pinker believes that children do not initially passivize all verbs. However, in striking contrast, Pinker argues that even very young children have a productive rule for producing passives, but that this rule is restricted to transitive verbs in which the theme is affected by the agent's action.

Some theorists argue that children acquire passives late because they must first acquire some aspect of English necessary to form passives. According to Chomsky's Government and Binding Theory (1981), in a verbal passive sentence such as *the girl was pushed by the boy*, *the girl* starts as the complement of the verb which gives it an agentive thematic role. However, the verb cannot assign case and so *the girl* moves to the specifier of the Inflectional Phrase position where it gets case from the passive auxiliary. A trace of *the girl* remains in post-verbal position, and an A-chain is formed between *the girl* and its trace. This A-chain allows the trace to transmit its theta role to *the girl*. Borer and Wexler (1987) propose that prior to about 6 years of age, children cannot understand verbal passives because they cannot form A-chains. Fox and Grodzinsky (1998), on the other hand, argue that young children have no difficulty forming A-chains, but rather their difficulty with passives stems from their inability to transmit an external theta role to a *by* phrase. They account for children's better performance on actional than nonactional passives by arguing that *by* transmits an affector role and this is the correct theta role for actional passives but not nonactional passives.

1.5 Theories of children's sentence processing

Of the theories discussed above, only Bever (1970) attempts to explain how young children process sentences. However, as previously discussed, if preschoolers apply the 1st NP = Agent heuristic to all sentences, they should misinterpret <u>all</u> semantically reversible passives, not half. Townsend and Bever (2001) have proposed the Late Assignment of Syntax Theory (LAST) which may account for this discrepancy. According to the LAST, people process sentences twice. They use heuristics to pseudo-parse a sentence and arrive at a 'quick and dirty' interpretation of its meaning, with the critical structural heuristic for sentences being the 1st NP = Agent heuristic. Simultaneously, every sentence is syntactically parsed. If the syntactic parser finishes its analysis, a sentence is understood correctly. If the syntactic parser doesn't finish and the pseudo-parser produces the wrong interpretation of a sentence (as it would with reversible passives), the sentence is misunderstood. Thus, according to the LAST, the reason children frequently misinterpret passives but not actives is that passives will only be correctly understood when they are syntactically parsed, whereas actives will be correctly understood regardless of whether they are syntactically parsed or not. According to the LAST, how frequently people misinterpret passives depends largely on how often pseudo-parsing is faster than syntactic parsing. If children syntactically parse more slowly than adults, this would explain why children misinterpret passives more often than adults. Additionally, the frequency with which children misinterpret passives should correspond to how often they complete pseudo-parsing before syntactic parsing.

In the experiments reported in this paper, we collected eye gaze, reaction time and accuracy data from English-speaking children while they listened to active and passive sentences and performed a picture-matching comprehension task. Our goals in doing so were two-fold. First, we sought to answer the 40-year old question of why English-speaking children misunderstand passives. Specifically, we sought to determine what cues children use to distinguish active and passives sentences; how children use these cues to interpret active and passive sentences; and whether children process active and passive sentences in the same way. Our second, more general, goal was to investigate how children of different ages process sentences. The first major question has to do with the time course of sentence processing. Do children process sentences as they unfold (i.e., heuristic on-line processing), do they delay processing sentences until they are syntactically unambiguous (i.e., syntactic on-line processing), or do they only begin to process sentences once the sentences are over (i.e., off-line processing)? The second major question is whether and how children use word order and morphological cues to guide sentence processing. The third major question is whether and how sentence processing changes during early childhood.

2. Children's Accuracy and Processing Speed for Active and Passive Sentences

2.1 Participants

Preschool children. Accuracy and reaction time (RT) data were collected from 19 preschool-aged children who were typically developing, monolingual English speakers with normal hearing and vision. Data from two preschool children were subsequently eliminated because they always chose the picture on the same side of the computer screen. The remaining 17 children ranged in age from 3;1 (years; months) to 4;8, with a mean age 3;10 (SD = 6.0 months). These children were divided into two age groups. The mean age of the 8 preschool children in the younger group was 3;4 (SD = 2.8 months) and the mean age of the 9 preschool children in the older group was 4;3 (SD = 3.4 months). Nine children were male and 8 were female.

School children. Accuracy, RT and eye gaze data were collected from 20 school-aged children. Three children were subsequently eliminated because of poor eye tracking and one child was eliminated because he always chose the picture on the same side of the computer screen. The remaining 16 school children were between 4;9 and 7;4 (mean = 5;8, SD = 8.5 months). Children were divided into 2 equalsized groups according to age. Children in the younger group had a mean age of 5;2 (SD = 3.2 months) and children in the older group had a mean age of 6;2 (SD = 7.4 months). Half of the children were male and half were female. Like the preschool children, all school age children were typically developing, monolingual English speakers with normal hearing and vision.

2.2 *Stimuli*

Each child listened to active sentences with object NPs (e.g., *The girl was pushing the boy*) and passives sentences with agentive *by* phrases (e.g., *The girl was pushed by the boy*) and chose which of two pictures corresponded to the sentence. Because great care was taken in choosing verbs and nouns that resulted in semantically reversible sentences, children could not use semantic cues to interpret the sentences. The verbs *touch*, *tickle*, *push*, *shove*, *kiss*, and *sniff* were used in the sentences because they take the -*ed* passive participle, they are easily depicted, and they are actional verbs that are felicitous as verbal passives with an animate patient and overt animate agent (Levin, 1993; Levin & Rappaport, 1986). In half of the sentences, the agent and patient were a man and a woman, and in other half, the agent and patient were a boy and a girl. Agent and patient NPs were paired in this way in order to make the sentences as semantically reversible as possible. Adult and child male and female NPs appeared as the agent and patient of active and passive sentences equally often, and each of the 6 verbs appeared equally often in active and passive sentences. These 4 factors were varied orthogonally to yield 48 experimental sentences (active/passive x adult/child NPs x male/female agent x 6 verbs = 48 sentences).

Because pilot testing revealed that children were not willing to do 48 trials, we divided the 48 experimental sentences into two lists. In each of the two lists, each verb appeared 4 times (one time each in an active and passive sentence with adult NPs and with child NPs). The sentences on the two lists differed in whether the male or female noun was the first noun in sentences with a particular verb (e.g., List 1 contained the sentences *The girl was pushing the boy* and *The girl was pushed by the boy* and List 2 contained the sentences *The boy was pushing the girl* and *The boy was pushed by the girl*. For each list, if *girl* was the first noun for sentences with a given verb and child NPs, then *man* was the first noun for sentences with that verb and adult NPs. Lastly, for verbs that used the same pair of pictures (e.g., *push* and *shove*, see below), if the first noun for one verb was *girl*, then the first noun for the other verb was *boy*. A female research assistant with a mid-Atlantic United States accent said the sentences using declarative sentence prosody. Sentences were recorded using a Sony DAT tape recorder with a high quality hand-held microphone. The Appendix gives the intonational contours of the experimental sentences in Tones and Breaks Indices (ToBI) notation (Silverman et al., 1992).

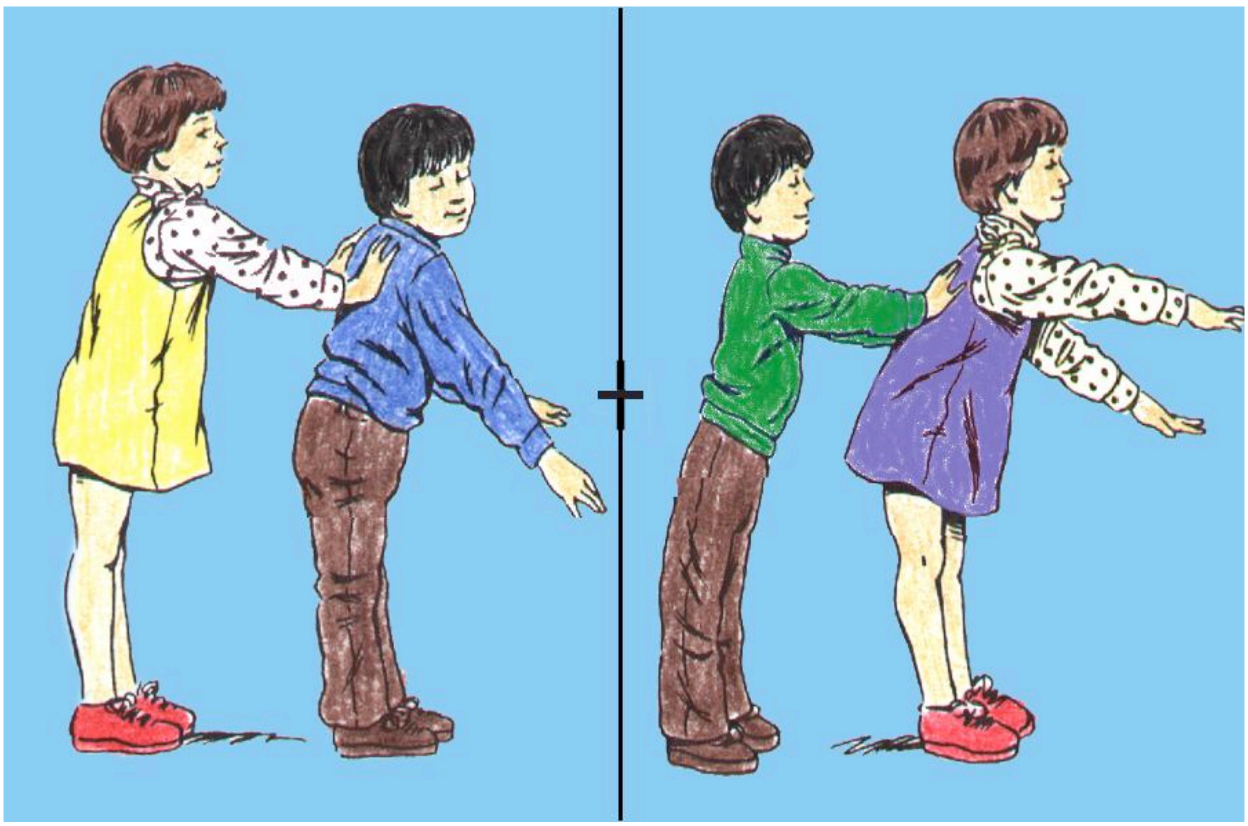

Figure 1: Example of a Pair of Pictures used in the Experiments

This pair of pictures was used for the active sentences *The girl was pushing/shoving the boy* and *The boy was pushing/shoving the girl* and the passive sentences *The girl was pushed/shoved by the boy* and *The boy was pushed/shoved by the girl*.

The pairs of pictures used in the experiment only differed from one another in whether the male or the female NP was the agent of the action and the color of the clothing worn by the people. Thus, the pictures contained no visual cues as to which picture in a pair matched a sentence (see Figure 1). The same pairs of pictures were used for active and passive sentences. In addition, the same pair of pictures was used for the verbs *touch* and *tickle*, the verbs *push* and *shove*, and the verbs *kiss* and *sniff*. Over the course of the experiment, pairs of pictures were balanced such that the left and right picture was the target picture equally often for active and passive sentences. Furthermore, over the course of the experiment, in both left- and right-sided pictures, the agent appeared to the left and the right of the patient equally often, and each of the 4 NPs appeared on the left and right side equally often. Sentences were presented in pseudo-random order with the restrictions being that there were no more than three instances in a row of the same sentence type (active or passive), two instances in a row of the same verb, four instances in a row of adult or child NPs, and three instances in a row of the target picture being on the same side of the screen. For half of the participants, the order of sentences was reversed for a total of four lists. The order of sentences for List 1 and List 2 are given in the Appendix.

2.3 Experimental procedures

Children were tested individually in their daycare center or school, in a quiet room away from other children. Each child was seated in a child-sized chair approximately two feet in front of a laptop computer. The laptop was positioned such that the horizontal mid-point of the screen was at the child's eye level, and the child was allowed to adjust the angle of the screen. Sentences were played over two external speakers, and pairs of pictures were presented on the laptop's 15" color monitor with the left and right pictures in each pair filling half of the screen. Auditory and visual stimuli were presented simultaneously. The experimental program E-prime was used to present stimuli and to record responses. A research assistant used a button box to control the presentation of trials and to record children's responses. A second research assistant videotaped the child during the experiment.

Each trial began with a visual prompt in the center of the computer screen (a flashing picture of the *Toy Story* cowboy Woody) and the pre-recorded auditory prompt "Look at Woody." The fixation prompt was followed 250 milliseconds (msec) later by a sentence and its corresponding pair of pictures. The same (prerecorded) carrier question *Which picture shows ….* preceded each sentence (e.g., *Which* *picture shows … The girl was pushing the boy*). Once the child pointed to one of the pictures, the pair of pictures disappeared, and a cartoon character appeared on the same side of the screen as the chosen picture. This cartoon 'reward' appeared regardless of whether the child chose the target (correct) or distractor (incorrect) picture. After each trial, the experimenter asked the child if he or she was ready for the next trial. There was an inter-stimulus interval of one second between when the child assented to continue and the next fixation prompt.

The research assistant read the following script: "We're going to play a game where you see two pictures next to each other on the computer screen, and you will hear someone describe one of the pictures. I want you to point to the picture that the person describes. I want you to play the game as fast as you can without making mistakes. Let's practice the game together." If a child seemed confused about the directions, the experimenter paraphrased the instructions. If the child still didn't understand, the research assistant demonstrated the procedure with the first practice trial. Children received 8 practice trials that contained the nouns used in the experiment (e.g., *which picture shows a girl, which picture shows a boy and a girl?*, etc.) and 6 practice trials that contained the verbs used in the experiment (e.g., *which picture shows pushing?*). Children only received feedback during practice trials.

2.4. Treatment of the accuracy and RT data

During the experiment, a research assistant recorded the pictures the child chose. Afterwards, a second research assistant, who did not know the content of the sentences, watched a silent videotape of the experiment and coded off-line which pictures were chosen. If a child initially pointed to one picture and then pointed to the other picture, the child's final choice was coded. The concordance rate for on-line and off-line coding of accuracy data was over 99%. In the handful of cases in which there was disagreement, we used the responses that were coded off-line. Children's response times (RTs) were also collected on-line. A second experimenter (who did not know whether sentences were active or passive or whether children's responses were correct or incorrect) checked on-line RTs by analyzing the videotapes. In 98% of the trials, on-line and off-line RTs were within 150 msec of each other. In these cases, we used on-line RTs. When on-line and off-line RTs differed by more than 150 msec, we eliminated the trials from RT analyses.

Because we anticipated that there would be individual differences in children's performance, whenever possible, we analyzed our accuracy and RT data using subject as a random variable. Sometimes, however, it was not possible to do so because some child(ren) lacked data in some condition(s). To help the reader keep track of the type of categorical analyses performed, we report *F*-statistics when subject was treated as a random variable, and *t*-statistics when subject was not treated as a random variable.

2.5. Results

2.5.1. Accuracy results

Children's accuracy data were analyzed using a 4 (Age) x 2 (Sentence Type) x 6 (Verb) ANOVA. There was a significant main effect of Age ($F(3, 29) = 7.96$, $p = .0005$). We tested the *a priori* prediction that accuracy increased linearly with age using a linear contrast ANOVA with the weights of –1.5, -0.5, +0.5, and +1.5. This ANOVA revealed there was a significant linear effect of age ($F(1, 29) = 47.41$, $p < .0000005$). As a group, children were more accurate on actives than passives (84% vs. 68%, $F(1, 29) = 14.41$, $p = .0007$). As shown in Figure 2, planned comparisons revealed that, although 3- and 4- year olds were no more accurate on actives than passives, 5-year olds were significantly more accurate on actives than passives (93% and 71% respectively, $F(1, 7) = 5.52$, $p = .05$), and 6-year olds were marginally more accurate on actives than passives (96% and 84% respectively, $F(1,7) = 4.44$, $p = .07$). Overall, however, there was no interaction between age of participant and sentence structure ($F < 1$), suggesting that children's accuracy at processing active and passive sentences follows the same general developmental trajectory. Consistent with the lack of an Age x Sentence interaction, *post hoc* linear contrast ANOVAs revealed that accuracy increased linearly with age for both actives ($F(1, 29) = 35.28$, $p = .000002$) and passives ($F(1, 29) = 45.01$, $p < .0000005$). The correlation coefficients for age and accuracy were identical for active and passive sentences (both *r* 's = .24, $p < .00005$). In addition, the slopes were essentially identical for the two sentence types (8.0% for actives and 9.9% for passives), but the *Y*-intercepts differed substantially (45.4% for actives and 20.6% for passives). Taken together, these results indicate that, although children were more accurate on actives than passives, their (correct) comprehension of active and passive sentences followed virtually identical developmental trajectories. Lastly, there was a significant effect of Verb ($F(5, 145) = 3.23$, $p = .009$), which was largely due to children doing particularly well on *shove* sentences (85% correct for *shove* vs. an average of 74% correct for the other 5 verbs). When data from *shove* sentences were removed, the effect of Verb was not significant ($F(4, 116) = 1.87$, $p > .10$).

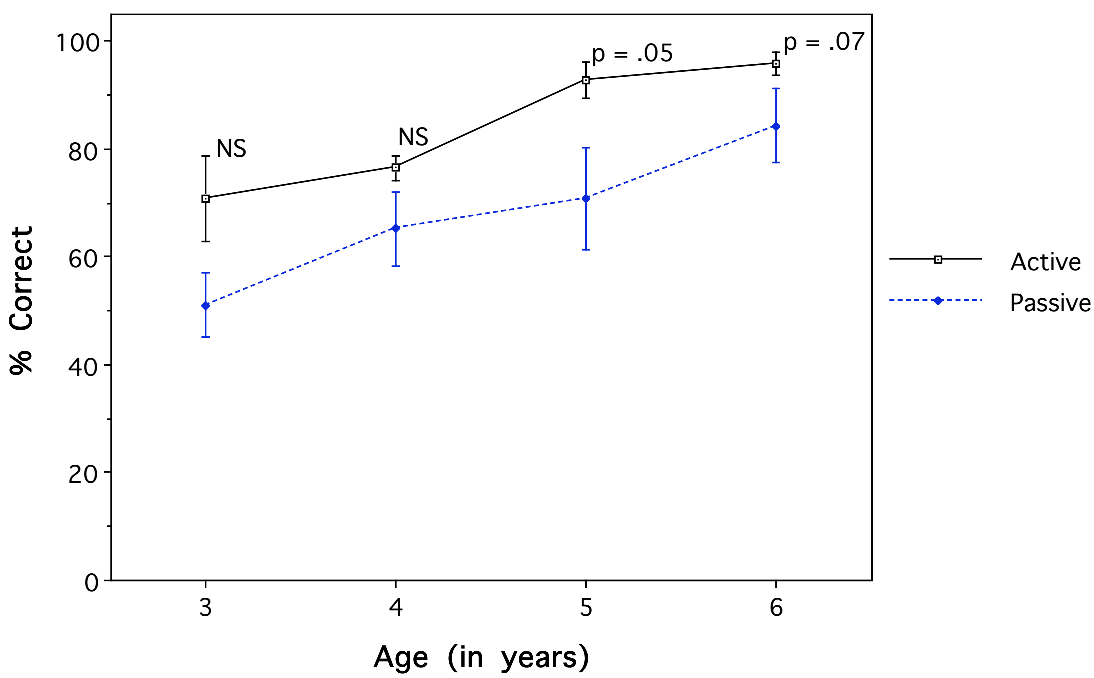

Figure 2: Children's Accuracy (Error Bars are Standard Errors)

Because averaging across children can obscure differences among individual children's performance, we also analyzed the data for each child separately. These analyses revealed that 4 of the preschool children were significantly more accurate on active than passive sentences. For the other 13 preschoolers, there was no significant difference in accuracy for active and passive sentences. Subject analyses of the elementary school children revealed that three of these children were significantly more accurate on actives than passives. For the other 13 elementary school children, there was no significant difference in accuracy for actives and passives.

If we set the chance level for each trial at 50% and assume that performance on each trial is independent, we can use the cumulative binomial probability distribution to determine whether each child performed significantly better or worse than chance on active and passive sentences. Doing this revealed that 5 preschool children performed significantly above chance on both actives and passives, 6 preschool children performed significantly above chance on actives and at chance on passives, 1 preschool child performed significantly above chance on actives and significantly below chance on passives, and 5 preschool children performed at chance on both active and passive sentences. Of the elementary school children, 12 performed significantly above chance on both actives and passives and 4 performed significantly above chance on actives and at chance on passives.

2.5.2 RT results

For two children, a computer error occurred and on-line RTs were not recorded. The remaining children's RT data were analyzed using a 4 (Age) x 2 (Sentence Type) x 6 (Verb) ANOVA with subject as a random variable. When RT data for correct and incorrect data were included, there was no significant effect of Verb. There was, however, a marginally significant main effect of Age ($F(3, 27) = 2.64$, $p = .07$). An *a priori* linear contrast ANOVA revealed that speed increased linearly with age ($F(1, 27) = 7.22$, $p = .01$). There was no significant main effect of Sentence Type ($F < 1$). However, *a priori* analyses revealed that although 4- and 6-year olds were equally fast on actives and passives, 3-year olds tended to be slightly slower on actives than passive ($F(1, 7) = 4.35$, $p = .08$) and 5-year olds tended to be faster on actives than passives ($F(1, 7) = 4.68$, $p = .07$). Consistent with this, there was a marginally significant interaction between Sentence Type and Age ($F(3, 27) = 2.78$, $p = .06$, see Figure 3a). *Post hoc* analyses revealed that this was due to 5-year olds being faster on actives than passives: when 5-year olds'

RTs were eliminated, the Age x Sentence Type interaction was no longer significant ($F(2, 20) = 1.56$, $p >$ .10).

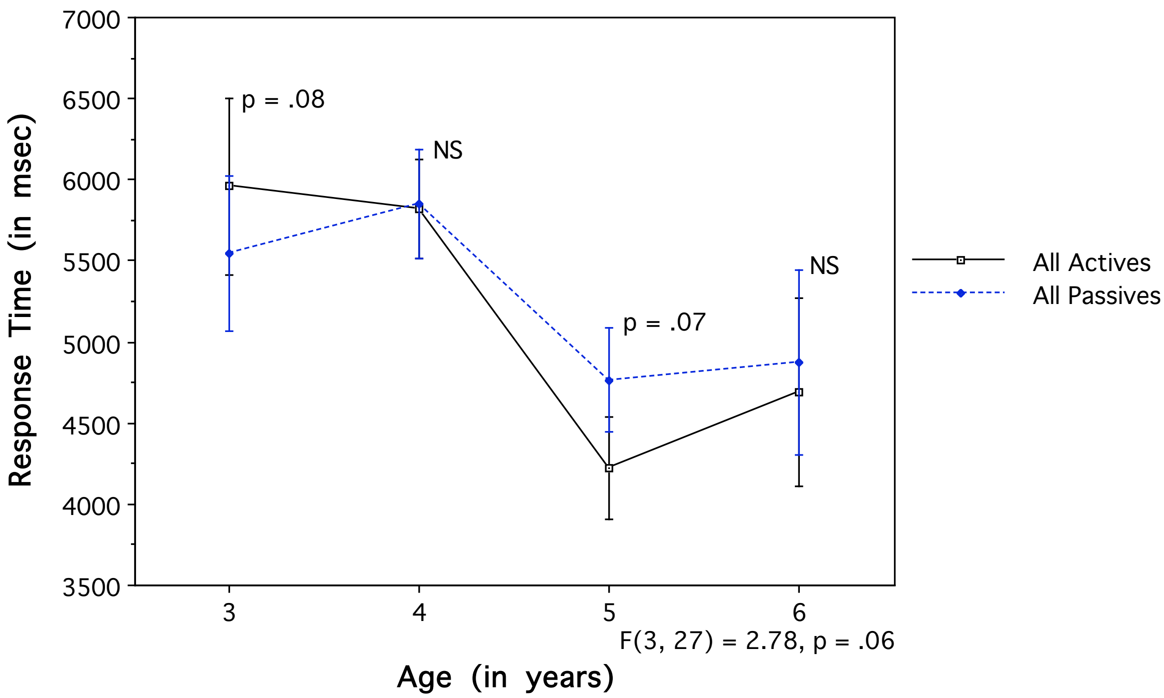

Figure 3a: Children's Reaction Times for Active and Passive Sentences (All Trials)

An (Age) x 2 (Sentence Type) ANOVA was used to analyze the RTs for the sentences children interpreted correctly.[2] In contrast to the RT results when incorrect trials were included, there was no main effect of Age ($F(3, 27) = 1.56$, $p > .10$). In addition, children were significantly faster on actives than passives ($F(1, 27) = 23.21$, $p < .00005$). *A priori* analyses revealed that although 3- and 6- year olds were equally on actives and passives, 4- and 5-year olds were significantly faster on actives than passives (4-year olds: $F(1, 7) = 16.29$, $p = .005$: 5-year olds: $F(1, 7) = 22.13$, $p = .002$). Consistent with this, there was a significant interaction between Sentence Type and Age ($F(3, 27) = 7.87$, $p = .0006$, see Figure 3b).

[2] It was not possible to include Verb in these analyses because some children had missing data for some verbs.

Three *post hoc* analyses revealed that the interaction between Age and Sentence Type remained significant when any one of the 4 age groups was eliminated. However, when data from both 3-year olds and 6-year olds were eliminated, the interaction was no longer significant ($F(1, 14) = 1.76$, p .10). Finally, linear contrast ANOVAs revealed that children's speed on actives increased linearly with age ($F(1, 27) = 8.32$, $p = .008$), whereas the linear increase in children's speed on passives was only marginally significant ($F(1, 27) = 3.46$, $p = .07$). Taken together these results suggest that the speed of processing for correctly interpreted actives and passives followed different developmental trajectories.

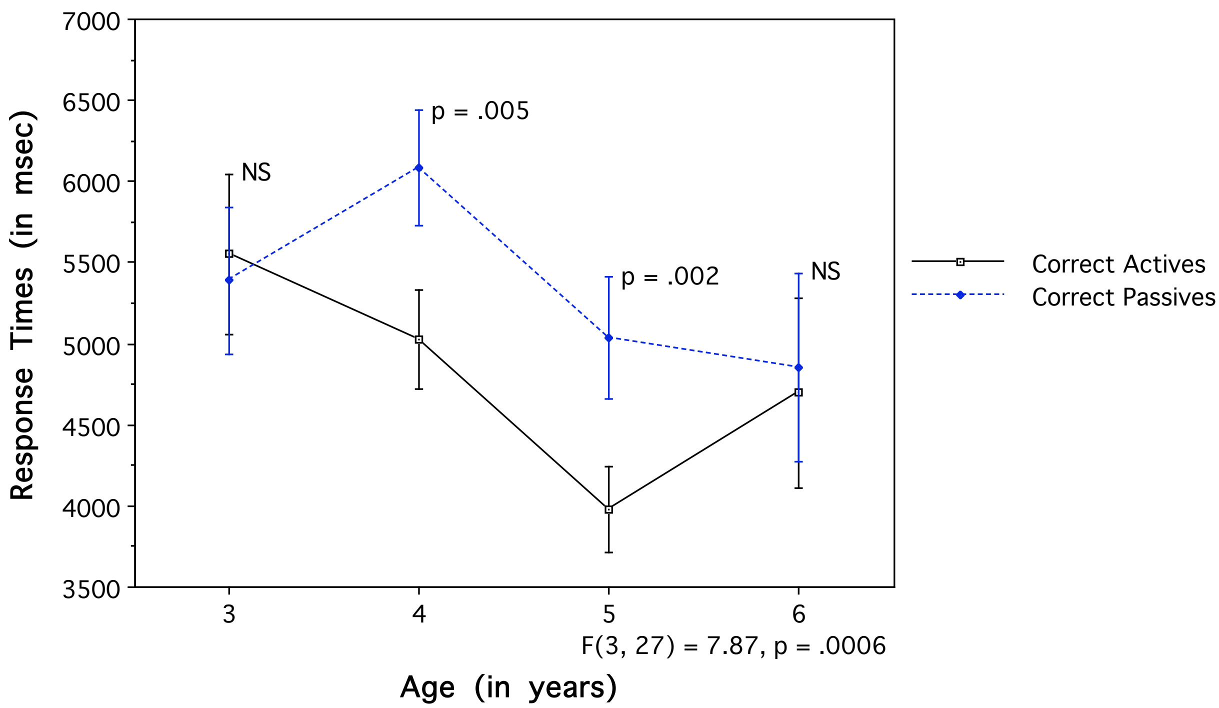

Figure 3b: Children's Reaction Times for Active and Passive Sentences (Correct Trials)

We next analyzed the active-passive RT difference for the trials that children got wrong (see Figure 3c). We were unable to perform analyses with subject as a random variable because some children had no data for one or more conditions. As a group, children were about 2.5 seconds slower on incorrect actives than incorrect passives ($t(179) = 5.53$, $p < .00005$), but, again, the RT active-passive differences were not the same for all age groups: 3-, 4- and 5-year olds were significantly slower on incorrect actives than incorrect passives (3 year olds: $t(73) = 2.17$, $p = .03$; 4-year olds: $t(52) = 4.67$, $p < .00005$; 5-year olds: $t(33) = 2.77$, $p = .009$), whereas 6-year olds were equally fast on incorrect actives and incorrect passives.

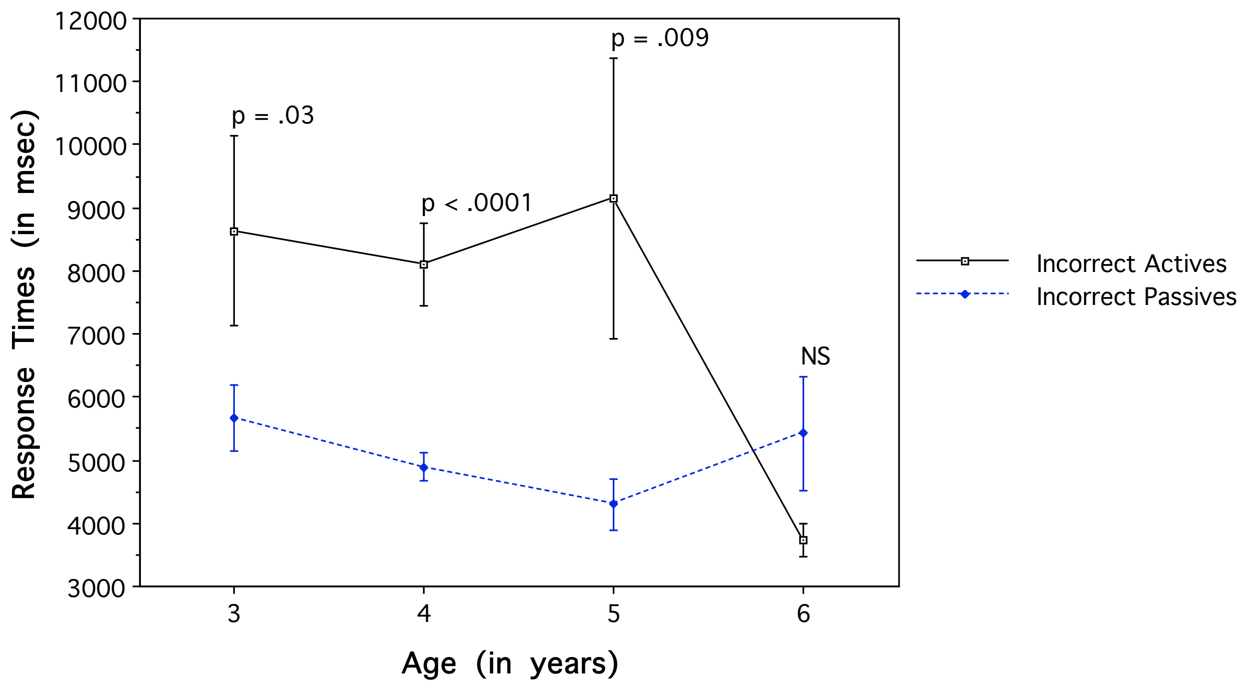

Figure 3c: Children's Reaction Times for Active and Passive Sentences (Incorrect Trials)

As a group, children were almost 3 seconds faster on the actives they got right versus the actives they got wrong ($t(369) = 8.57$, $p < .0005$). However, as shown in Figure 4a, the pattern was not the same for all age groups. Specifically, the 3-, 4- and 5-year olds were faster on correct actives than incorrect actives (3 year olds: $t(94) = 2.69$, $p = .009$; 4-year olds: $t(93) = 6.14$, $p < .0001$; 5-year olds: $t(93) = 6.48$, $p <$ 00005), whereas the 6-year olds were equally fast on correct and incorrect actives. As a group, children were equally fast on the passives they got right and wrong ($t(370) = 1.34$, $p > .10$), but as shown in Figure 4b, again, the RT patterns differed by age group: 4-year olds were about 1.5 seconds slower on

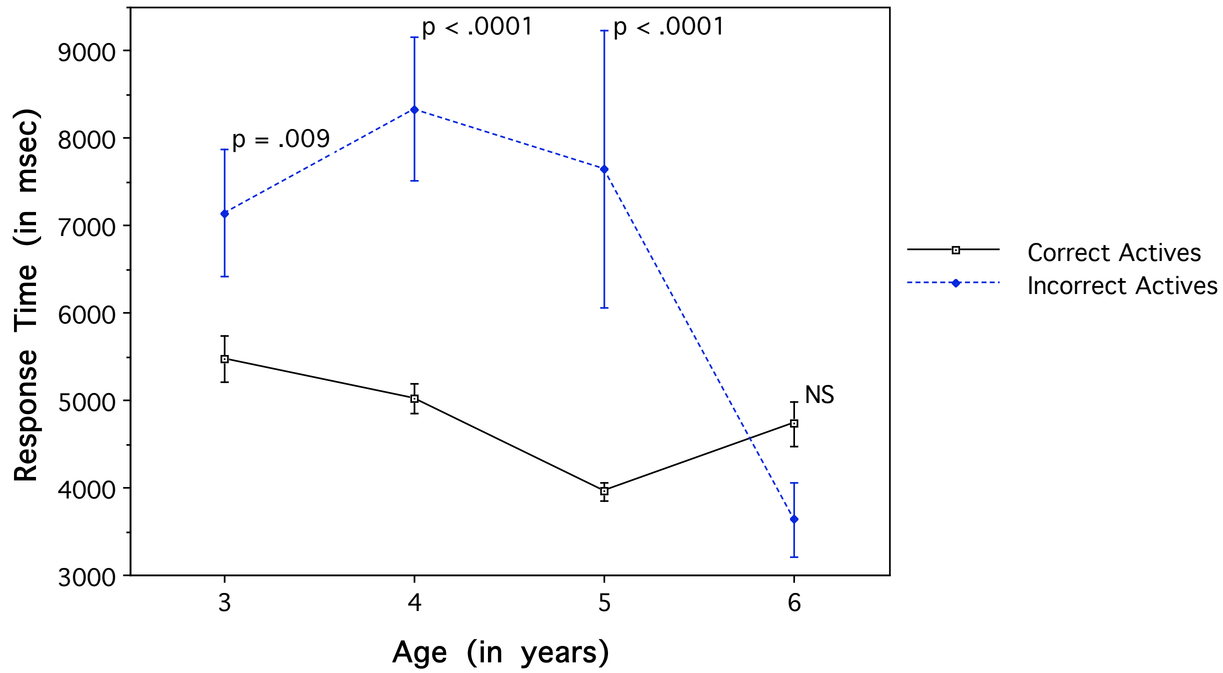

Figure 4a: Children's Reaction Times for Correct and Incorrect Active Trials

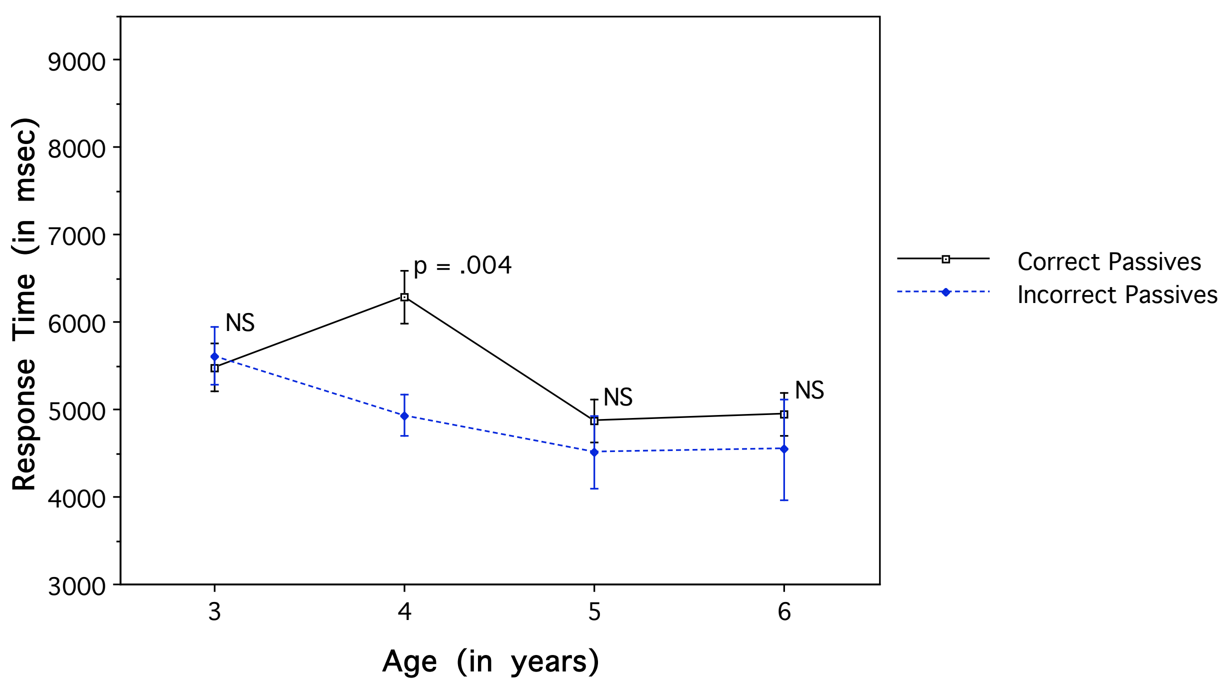

Figure 4b: Children's Reaction Times for Correct and Incorrect Passives Trials]

correct than incorrect passives ($t(94) = 2.92$, $p = .004$), whereas there was no RT difference for the 3-, 5- and 6-year olds.

2.6 Summary and Discussion of Accuracy and RT Data

Accuracy and the acquisition of actives and passives. We did everything we could to make our passive sentences hard for children to understand: we used full *by* passives (rather than truncated passives) that had–*ed* passive participles (rather than –*en* passive participles) and the auxiliary *was* (rather than *got*). In addition, the auxiliary *was* appeared in both active and passive sentences, and all sentences were semantically reversible. Despite stacking the deck against the children, consistent with most previous studies, only one of the 33 children interpreted passives at lower than chance level. Also consistent with the results of most studies, although the 3-year olds performed at chance level on passives (51% correct), none of the age groups interpreted passives at lower than chance level. We also found that, although as a group children correctly interpreted more active sentences than passive sentences, the active-passive comprehension rate difference was only significant for the 5-year olds. Lastly, we found that, as children got older, their accuracy in interpreting actives and passives increased linearly and at the same rate for both types of sentences.

How do the accuracy rates in this study square with the predictions made by the developmental theories discussed in section 1.4? Tomasello and colleagues (Savage et al., 2003; Tomasello, 2000a, 2000b; Tomasello et al., 1998) have argued that children's language development is driven by the linguistic input they receive from adults. Tomasello's verb island hypothesis predicts that children's comprehension of any type of sentences will be more accurate for verbs that they hear more frequently. Contrary to this prediction, the children in our study were most accurate for sentences that contained the verb that adults in the CHILDES corpora said the least (*shove*). According to Tomasello et al., their should also be a construction-specific frequency effect for verb. Contrary to this prediction, in our study, there was not even a hint of a significant interaction between Verb and Sentence Type. Pinker and colleagues (Pinker, 1989; Pinker et al., 1987) have also argued that, in the early stages of acquisition, children only form passives with a restricted set of verbs (mainly transitive, actional verbs with affector themes). Because all of the verbs in our experiment were of this semantic type, the fact that we did not find an interaction between Verb and Sentence Type does not pose a problem for Pinker and colleagues.

Fox and Grodzinsky (1998) have argued that passive *by* transmits an affector theta role to object NPs. Because *by* transmits the correct theta role for our (actional) passives, their theory incorrectly predicts that the children in our study would do equally well on actives and passives. Borer and Wexler (1987) have argued that children can't form A-chains. If our 3-year olds had treated all of the passives as active, they should have gotten them all wrong, and if they had treated all of the passives as adjectival (i.e., if they had treated *the woman was pushed* as having the same structure as *the horse was tired*), they should have gotten them all right. The only way Borer and Wexler could account for the fact that the 3-year olds' correctly interpreted half of the passives is to argue that (for some unexplained reason), 3-year olds treated half of the passives as actives and half as adjectival. If Bever's 1st NP = Agent account is correct and 4-year old children use the canonical word order of English to process passives, 4-year olds should misinterpret all passives, whereas we found that, as a group, the 4-year olds only misinterpreted 35% of passives. Even more problematic for Bever's account is the fact that only 1 of the 33 children in this study were worse than chance at interpreting passives. In summary, the accuracy data obtained in this study do not provide support for any of the developmental theories discussed in section 1.4.

According to all of the theories discussed in section 1, children at all ages should correctly understand active sentences. Thus, children's error rates on active sentences provides a measure of the extent to which children's accuracy on passive sentences is affected by nonlinguistic performance factors (e.g., factors having to do with attention, working memory, and scanning, comparing and picking a picture) and linguistic performance factors that will affect children's processing of both active and passive sentences (e.g., interpreting the meaning of the lexical items that appear in the sentences). By adding children's active error rate to their accuracy rate on passives, we can measure the extent to which passive-specific factors affect children's comprehension of passives. For example, the 3-year old children in this study correctly interpreted 71% of active sentences and 51% of passive sentences. Thus, we can say that, if it weren't for extraneous performance factors, the 3-year olds would have gotten 80% of passives correct. In other words, the 3-year olds got 20% of passives wrong for reasons that were passive-specific. Four-year olds got 23% of actives wrong, so their adjusted accuracy rate on passives is 88% (23% + 65%). Five-year olds got only 8% of actives wrong, giving them an adjusted accuracy rate on passives of 78%, and 6-year olds got 4% of actives wrong giving them an adjusted accuracy rate of 88%. In other words, from age 3 to age 6, the rate of passive-specific errors did not decrease monotonically, but rather fluctuated between 12% and 22%.[3] Thus, our accuracy data indicate that, once we adjust for passive errors that are due to factors that are not specific to passives, children's error rates on passives are fairly low and constant from age 3 to 6. This coupled with the lack of an Age x Sentence Type interaction suggest that, contrary to the theories discussed in section 1, children do not suddenly acquire a piece of English grammar necessary to form passives.

The accuracy rates obtained in this study suggest that children misunderstand passives because they have difficult processing them, not because they have yet to acquire them. Performance factors could account for the developmental trajectory in accuracy being the same for actives and passives: children have the syntactic knowledge required to understand both actives and passives (i.e., they have adult-like competence), but they misunderstand some actives and passives for non-linguistic reasons. According to this Limited Resources/Performance Account (LRPA), younger children make more errors than older children because their attention spans, working memories etc. are smaller and, so, the experiment's task demands are more likely to overtax them. The LRPA also predicts that children of all

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[3] The adjusted accuracy rates for passives are also not consistent with any of the theories discussed in section 1. Fox and Grodzinsky (1998) would erroneously predict that performance on actives and actional passives would be the same (because the same extraneous factors affect both types of sentences), and Borer and Wexler (1987) and Bever (1970) would erroneously predict that the 4-year olds would only get about a quarter of passives right, whereas in our study, they got two-thirds of passives right.

ages will make more errors on passives than actives because passive sentences are longer and syntactically more complex (they require some type of syntactic machinery to indicate that the semantic roles of the subject and object NP have switched) and therefore passives require more processing resources than actives.

If one merely looked at children's passive-specific error rates, one could conclude that the additional burden of processing passives remains constant from age 3 to age 6 and that, to a first approximation, children process passives and actives in similar fashions. However, error rate data don't provide enough information to determine whether children of all ages process sentences similarly and whether children process active and passive sentences similarly. Simply put, error rate data are not rich enough to investigate how children process sentences. Historically, researchers have investigated how adults process different types of sentences by measuring the speed with which they process these sentences, with these differences in processing speed sometimes taken to reflect properties of the adult grammar. To a lesser extent, RT data have also been used to investigate children's language (see McKee, 1996). Although children's RTs for different types of sentences are usually taken as primarily reflecting properties of children's grammars and only secondarily reflecting their language processors, given that the adjusted accuracy rates indicate that the children have the syntactic machinery that underlie passives and actives, we would argue that our RT results reflect the nature of children's language processors at well as the maturity of their grammars.

Speed and the processing of active and passive sentences. We cannot compare our RT results with those of previous studies because ours is the first study to investigate the speed with which young children process active and passive sentences. To recap our RT results, with the exception of the 3-year olds, children in our study were both faster and more accurate on actives than passives, indicating that their more accurate performance on actives was not simply the result of a speed-accuracy tradeoff. When children's RTs for both correct and incorrect trials were included, as a group, children's RTs decreased linearly with age, but children were no faster on active sentences than passive sentences. When RTs for incorrect trials were excluded, as a group, children were significantly faster on active sentences than passive sentences, but this difference was only significant for the 4- and 5- year olds. Furthermore, although there was no main effect of age, children's processing speed for actives increased linearly with age, whereas the linear effect of age was only marginally significant for passives. For the trials they got wrong, 3-, 4-, and 5-year olds were much slower on actives than passives. Analyses also revealed that 3-, 4- and 5-year olds were about 3 seconds faster on the active trials they correctly interpreted compared to the ones they misunderstood, and that 4-year olds were slower on the passives they correctly understood than the passives they misunderstood.

Of the theories reviewed in section 1, only Bever (1970) and Townsend and Bever (2001) discuss how children process sentences.[4] Because Bever's (1970) account has difficulty explaining children's accuracy data, we will restrict our discussion to the empirical adequacy of Townsend and Bever's (2001) LAST. According to the LAST, active sentences will be understood correctly if they are syntactically parsed or pseudo-parsed, whereas passive sentences will only be understood correctly if they are syntactically parsed. According to the LAST, parsing is slower than pseudo-parsing. Thus, to account for our accuracy data, the LAST would have to argue that even the 3-year olds syntactically parsed most passives, with syntactic parsing being as fast as pseudo-parsing 50% of the time. With respect to children's speed at processing actives and passives, the LAST predicts that children will be slower on correctly interpreted passives than on correctly interpreted actives, because correctly interpreting passives

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[4] It is not straightforward to extrapolate predictions about the rate at which children should process sentences from the order in which they acquire these sentences. One could argue that children will process more slowly those sentences that they have yet to acquire (because they are confused, wait until the end of the sentence, etc), in which case children should be slower on the sentences that a theory predicts they acquire later (i.e., those that are misunderstood). If, on the other hand, children respond more quickly when they hear a sentence that their grammar cannot generate (because they quickly give up and guess randomly on such sentences, etc.), then they should be <u>faster</u> on sentences that are predicted to be acquired late.

require syntactic parsing whereas correctly interpreting actives does not. By the same logic, the LAST predicts that children will be slower on correctly interpreted passives than on incorrectly interpreted passives. Contrary to either RT prediction, in our study, 3-year olds were equally fast on correct active and correct passive trials, and they were equally fast on correct and incorrect passive trials. Our 4-year olds' data were consistent with both of the LAST RT predictions. Consistent with the LAST, the 5-year olds were faster on correct actives than correct passives, but contrary to the LAST's prediction, they were equally fast on correct and incorrect passive trials. Finally neither LAST RT prediction was borne out for the 6-year olds.

If we assume – as essentially all adult psycholinguistic studies do – that children process more slowly those sentences that they find more difficult, the LRPA predicts that children will be faster on active sentences than passive sentences. Similarly, if we assume that children's processing resources increase with age, the LRPA predicts that older children will be faster than younger children. When RTs from correct and incorrect trials were combined, consistent with the LRPA, children's speed increased linearly with age. However, contrary to the LRPA, children were no faster on actives than passives. When RTs for incorrect trials were eliminated, consistent with the LRPA, children were significantly faster on actives than passives. However, the developmental trajectory may not be the same for actives and passives as the children's speed increased linearly for actives ($p < .008$), whereas the linear increase with age was only marginally significant for passives ($p < .07$).

Although as formulated, the LRPA cannot account for the children's accuracy and RT data, the accuracy and RT findings could still be the result of performance factors. For example, a performance factor account could argue that 3-year olds' resources are so limited that they always use a "give up and guess" strategy on passives: although they have the syntactic machinery necessary to recognize the difference between actives and passives, they quickly realize they don't have the resources necessary to parse passives (hence their fast RTs for passives) and so they pick a picture at random (hence their 50% accuracy rate for passives). Such an account could argue that the 4 -year olds' accuracy rates on passives were above chance because their resources were great enough that they attempted to parse some passives, and, when they succeeded, they correctly interpreted the passive. However, because parsing passives is more taxing than parsing actives, 4-year olds had greater RTs for correct passives than correct actives. A performance account could argue that when 4-year olds got passive trials wrong they did so because they guessed, and this explains why they were faster on incorrect than correct passive trials. A performance account could argue that the 5-year olds' processing resources were great enough that they attempted to parse almost all passives (i.e., they rarely guessed), and they succeeded about three-quarters of the time. However, they were still slower on passives than actives because parsing passives takes more resources. Because 5-year olds parsed the passives in both their correct and incorrect passive trials, they were equally fast on both. The performance account could argue that the task demands of the experiment did not overtax the 6-year old' abilities. The 6-year olds' processing resources were great enough that they parsed all sentences and did so correctly most of the time. They were equally fast on actives and passives because neither type of sentence overtaxed their resources. Finally, the performance account just outlined could argue that the younger children had extremely long RTs for the active trials they got wrong because they weren't paying attention during these trials. It should be noted that this performance factor model only fits the accuracy and RT data because it was handcrafted to do so. Thus, before it can be considered a viable model of children's sentence processing, it must make additional correct predictions.

Despite the empirical inadequacy of the LAST and LRPA at accounting for the RT data and the ad hoc quality of the performance factor model just laid out, the fact that the children's RTs varied systematically depending on the structure of the sentence, the correctness of the trial and the age of the child suggest that these factors affect sentence processing. Unfortunately, children's accuracy and RT data don't provide enough information to reveal how or why these factors affect sentence processing. For example, they don't reveal whether children process actives and passives in the same way (but at different speeds and with different precision) or in different ways. They don't reveal whether children process the sentences that they get right and wrong in the same way (but at different speeds) or in different ways. Finally, they don't reveal whether children of all ages process sentences in the same way (but at different speeds) or in different ways.

3. Children's Eye Gaze Patterns for Active and Passive Sentences

3.1 Rationale

In the last few years, researchers have begun to investigate how children process sentences by analyzing their eye gaze as they listen to sentences (e.g., Sekerina, Stromswold, & Hestvik, 2004; Snedeker & Trueswell, 2004; Trueswell, Sekerina, Hill, & Logrip, 1999). The idea that underlies the use of eye gaze to investigate sentence processing is that when people listen to a sentence, what they look at during a given point of the sentence reflects their interpretation of the sentence at that particular moment. In our study, the 5-year olds got over 93% of active trials right and the 6-year olds got over 95% of active trials right, indicating that they could handle the experiment's non-syntactic task demands. Because the 5- and 6-year olds could do the task, we can use their eye gaze data to investigate whether and how children use word order and morphological cues to process sentences. By comparing their eye gaze when they process sentences that have canonical grammatical role-thematic role mapping (i.e., active sentences) with their eye gaze when they process sentences that do not have this canonical mapping (i.e., passive sentences), we can investigate whether (and when) children use word order to assign thematic roles to NPs. By comparing children's eye gaze as different grammatical morphemes are said, we can investigate whether (and how) morphological cues affect sentence processing. We can also use the children's eye gaze data to investigate the time course of sentence processing: do children process sentences as they hear each word (i.e., on-line heuristic processing), do they delay processing sentences until they are syntactically unambiguous (i. e., on-line syntactic parsing), or do they only process sentences once they are over (i.e., off-line processing)?

More specifically, we can use the children's eye gaze to investigate how children process active and passive sentences. For example, we can use these data to determine whether children use a 1st NP = Agent strategy to assign thematic roles to the NPs in active and passive sentences. We can use children's eye gaze data to investigate whether and how each of the 3 morphological cues that distinguish active from passive sentences affects children's sentence processing. Because 5- and 6-year olds still misinterpret some passive sentences, we can investigate why children misunderstand passives by comparing their eye gaze for correct and incorrect passive trials. Using these same data, we can investigate what children do when they assign the wrong thematic role to an NP. Do they attempt to reanalyze the sentence and fail (i.e., do they backtrack) or do they simply misinterpret the sentence? Finally, because the 5- and 6-year olds' accuracy and RT data indicate that the 5- and 6-year olds may have processed sentences differently, by comparing the 5- and 6-year olds' eye gaze data we can investigate whether and how sentence processing changes from age 5 to age 6.

3.2 Participants

Eye gaze data were analyzed for the 16 school-aged children described in section 2.1.[5]

3.3 Eyetracking procedures

We used an ISCAN eye-tracker to collect eye gaze data. This eye-tracker determines eye gaze by tracking the center of the pupil and the corneal reflection. We used ISCAN's head-mounted eye-tracking visor because doing so meant that children could move their heads and bodies freely during the experiment. This visor consists of a monocle and two miniature cameras. One camera records the scene from the participant's perspective and the other records an image of the left eye. The two cameras and monocle are attached to a visor that is worn like a baseball cap. The stimulus image and the superimposed eye position, along with all auditory stimuli were recorded on a frame-accurate digital video recorder that recorded at a rate of 30 frames per second. The eye-tracker was calibrated by having the child wear the visor and look at 5 locations on the computer screen. One research assistant interacted with the child, a second controlled the presentation of trials and recorded the child's responses and RTs, and a third was responsible for calibrating the eye-tracker and collecting eye gaze data. Throughout the

[5] We did not collect eye gaze data from the preschool participants because pilot testing revealed we were unable to get usable eye gaze data from preschool children (usually because they refused to wear the visor, couldn't be calibrated or had very poor tracking).

experiment, the third assistant monitored the picture image and superimposed eye position, and adjusted the angle of the eye-tracking monocle as needed.

3.4 Treatment of the eye gaze data

Eye-gaze data were hand-coded by trained coders who went through the digital videotapes frame-by-frame and determined for each frame if the participant was looking at the left picture, the right picture or the cross, or if there was track loss. Because the audio was turned off during coding, coders did not know whether sentences were active or passive or whether the child chose the correct picture. Two people coded each child's eye gaze data. The results of the two coders were compared, and a third coder resolved any discrepancies. Data were entered into computer spreadsheets that were then checked by a second person.

For each frame, we averaged across eye gaze data for all active trials (i.e., correct and incorrect active trials) to determine the percentage of the time a child looked at the target picture. We did this separately for each child, and then used these data to compute group averages. We repeated this procedure, first including only those active trials that children got correct, and then including only those active trials children got wrong. The eye gaze graphs for all passive trials, correct passive trials and incorrect passive trials were generated in the same manner. We truncated the eye-gaze data at 150 frames because the data were too sparse after this point. In all graphs and all analyses, the word onsets are offset by 6 frames to allow for the time needed to execute eye movements (see Snedeker & Trueswell, 2004).

3.5 Analyses of the eye gaze data

For the purposes of eye gaze analyses, we divided trials into temporal intervals of interest (IOIs). The first IOI corresponds to the entire sentence. Sentences were also divided into major syntactic phrases, with the second IOI being the subject NP (i.e., the first NP), the third IOI being the VP (e.g., *was pushing/was pushed*), and the fourth IOI being the patient NP for actives and the agentive *by* phrase for passives. Because the active and passive sentences were morphosyntactically ambiguous until the verbal inflection (e.g., *The girl was push-<u>ing</u> the boy/push-<u>ed</u> by the boy*), we defined a fifth IOI that corresponds to the portion of the sentence prior to morphological disambiguation (e.g., *The girl was push*) and a sixth IOI that corresponds to the portion of the sentence after morphological disambiguation (e.g., *-ing the boy*/*-ed by the boy*). We defined a seventh post-sentence IOI that begins at the end of the sentence and continues until frame 150. After looking at the data, we defined 3 additional *post hoc* IOIs. The first corresponds to the auxiliary and the verb stem (e.g., *was push*), the second corresponds to the interval from the end of the sentence to frame 100, and the third is the interval from frame 101 to frame 150.

Eye gaze data were analyzed in two ways. First, following the procedures typically used to analyze eye gaze data (see Snedeker & Trueswell, 2004), for each IOI, we collapsed the data into a single category and used categorical statistical techniques (ANOVAs and *t*-tests) to compare looks to the target picture in that IOI with looks to the target picture in temporally contiguous IOIs. Within IOIs, we also compared the rate of target looks for different conditions (e.g., active and passive sentences). For each IOI, we also analyzed the data by performing simple linear regressions of frame number and looks to the target picture. Although linear regression has the drawback that can only test if there is a significant linear component to eye gaze patterns, in some ways it is preferable to categorical techniques traditionally used to analyze eye gaze data. One reason is that a key assumption underlying categorical analyses is that there are no relationships among the data points within a category and, therefore, all data points within a category may be treated as equivalent to one another. This assumption is clearly violated in eye gaze datasets where there is a clear temporal relationship among eye gaze data points. A second advantage of regression analyses is that they can be used to determine whether (and how) eye gaze changes within an IOI. To compensate for the large number of analyses performed on the eye gaze data, we set the p level for significance at $p \leq .01$.

3.6 Interpretation of eye gaze data

By analyzing which of the two pictures children look at as the active and passive sentences unfold, we get a snap shot of their moment-by-moment interpretation of the sentences. Specifically, children's eye gaze provides information about their incremental interpretations of sentences and the strategies and biases they use in interpreting them. If children look at the target and distractor picture equally often (i.e., 50% target looks) during part of the sentence, this suggests that children do not have an interpretation of the sentence during that IOI. So, for example, if children's target looks stay at the 50% mark throughout the sentence, this suggests that they are processing the sentence off line, rather than syntactically parsing or using heuristics to understand the sentence as it unfolds. If they look at the target picture more than 50% of the time, this could reflect that they are syntactically parsing the sentence or it could reflect that they are using a heuristic that yields the correct meaning for that sentence. If children look at the target picture less than 50% of the time, this means that they are not syntactically parsing the sentence, but rather are using non-syntactic heuristics that yield the wrong meaning for that sentence. For example, if children use heuristics that result in them interpreting passive sentences as if they were active throughout the sentence, only realizing their mistake at the end of the passive sentence, their target looks would only increase once the passive was over.

If children rely on morphosyntactic information to interpret sentences, they should look at the target and distractor pictures equally often while actives and passives are ambiguous (i.e., until the *–ing* and *–ed*). However, if they use a 1^{st} NP = Agent heuristic to interpret sentences, once they process the first noun, their target looks should increase for active sentences and decrease for passive sentences. Furthermore, the perturbation from chance looking (50% target looks) should have mirror symmetry for active and passive sentences (e.g., 60% target looks for actives, 40% target looks for passives), with the absolute value of the perturbation being a measure of the strength of the 1^{st} NP = Agent bias during the interval. Lack of mirror symmetry for active and passive eye gaze lines could mean that children process actives and passives heuristically, but at different rates. If this is the case, temporally shifting the eye gaze lines will result in the two lines having mirror symmetry. If the eye gaze lines for actives and passives have mirror symmetry, but the absolute value of the deviation from chance looking is greater for one of the two sentence types, this suggests children use the same heuristics to process both types of sentences, but they rely on them to different degrees. Finally, the shape of active and passive eye gaze lines will be different and will not have mirror symmetry if children use a cue that is only found in one of the two sentence types (e.g., *by*).

Children's eye gaze can also provide insight into what cues children use to interpret sentences. For example, if *was* acts as a cue that a sentence is active, at the *was*, children's target looks should go up for actives and down for passives. If children know the syntactic import of the progressive and passive inflections, their target looks should increase at the inflection for both active and passive sentences. If, on the other hand, children know the syntactic import of the progressive inflection but not the passive inflection, their target looks should increase at the verbal inflection for active sentences but not passive sentences. Finally, if children treat *by* as a cue that a sentence is passive, at the *by*, their target should increase for passives, but not for actives. Another way to investigate how cues that appear in different IOIs affect children's interpretation of the sentence is to compare the percent of target looks in contiguous IOIs within a sentence type. For example, if children do not 'decide' that active sentences are active until they process the *-ing*, the number of target looks should be significantly greater in post-*ing* IOIs than in pre-*ing* IOIs. A third way to investigate how particular cues affect children's interpretations of sentences is to perform regression analyses of eye gaze during the relevant IOIs. If, for example, children use a 1st NP = Agent strategy to interpret sentences prior to the point at which they become syntactically unambiguous, we would expect target looks for actives to increase during the " *the girl was push"* IOI. If this is the case, the correlation between frame number and target looks should be positive for active sentences and negative for passive sentences.

One can also use children's gaze to investigate why they misinterpret sentences. This can be done in several ways. First, one can compare children's eye gaze for the trials that they get right and wrong. If the eye gaze pattern for correct and incorrect trials is the same for all IOIs up to the point that they choose a picture, this suggests that their errors may be performance errors and not sentence interpretation errors. If, on the other hand, there are systematic differences in eye gaze for correct and incorrect trials, this may provide clues as to what children do when they misinterpret sentences. For example, if children correctly interpret the passives they syntactically parse and misinterpret the passives they heuristically parse (e.g., with a 1st NP = Agent strategy), target looks during the passive should be below chance for incorrect passive trials, whereas for correct passive trials, target looks should be at chance (if children parse passives off-line) or above chance (if children parse passives on line).

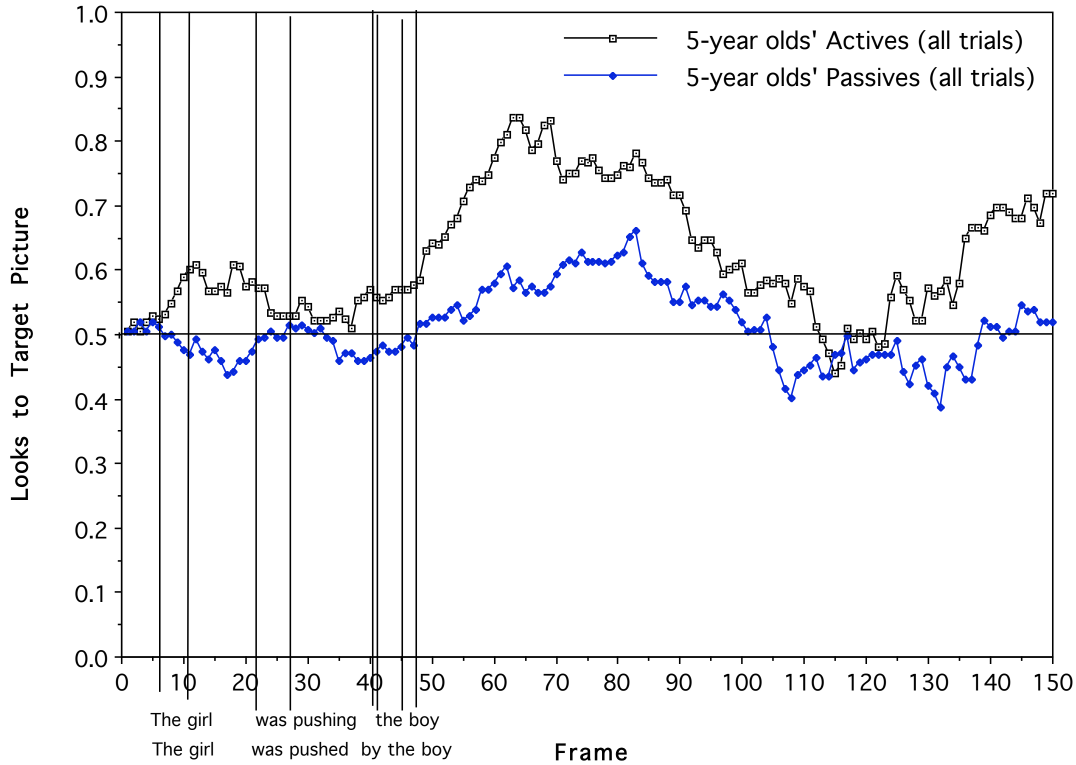

Figure 5a: 5-year Olds' Target Picture Looks for Actives & Passives (All Trials)

3.7 Comparison of eye gaze for active and passive sentences

5- year olds' eye gaze for actives and passives. Because the 5- and 6-year olds' accuracy and RT data were significantly different in several respects, we analyzed the eye gaze data for the two age groups separately.[6] Inspection of Figure 5a suggests that when 5-year olds' correct and incorrect trials were combined, 5-year olds' eye gaze for active and passive trials began to exhibit mirror symmetry at the very beginning of the first NP and this symmetry continued throughout the VP and possibly longer. The perturbation from 50% target looks was greatest during the first NP, reaching a maximum of about 15 percentage points. During the VP, target looks for both actives and passives returned to the 50% mark. For active sentences there was a sharp increase in target looks that started at the beginning of the progressive inflection and rose steadily at a rate of about 50 percentage points per second. For passives, the 5-year olds' target looks fluctuated between 45% and 50% until the end of the second NP at which time target looks began to increase slowly at a rate of about 15 percentage points per second, peaking at about 60% target looks about a half second after the end of the passive.

As depicted in Figure 5b, when incorrect trials were eliminated, the perturbation from chance looking began slightly later (at the beginning of the first noun, rather than at the beginning of the *the*), and the maximum perturbation was slightly greater. An even more striking difference was that, for correct passives, target looks increased sharply from 40% two-thirds of the way through the first noun to 60% at the end of the *was*, whereas for actives, target looks decreased from 60% to 50% during the same interval. For correct active trials there was a sharp and linear increase in target looks starting at the beginning of the progressive inflection (50% target looks) and peaking at 85% target looks 200 msec after the end of the sentence. For correct passive trials, during the interval from the beginning of the lexical verb through

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[6] We also conducted active-passive analyses in which we combined the 5- and 6-year olds' eye gaze data (Stromswold, Eisenband, Norland, & Ratzan, 2002). The advantage of doing this is that we had enough children that we were able to perform analyses in which subject was a random variable, whereas when we analyzed the 5- and 6-year old children's eye gaze separately, the small number of subjects in each age group precluded the use of analyses with subject as a random variable. The disadvantage of combining the 5- and 6-year olds' data is that important developmental trends were obscured (e.g., that the 5-year olds, but not the 6-year olds, use a 1st NP = Agent strategy to interpret sentences).

the beginning of the second noun, target looks fluctuated between 50% and 60%. At the beginning of the second noun, target looks slowly began rising, peaking at about 65% target looks 300 msec after the end of the sentence.

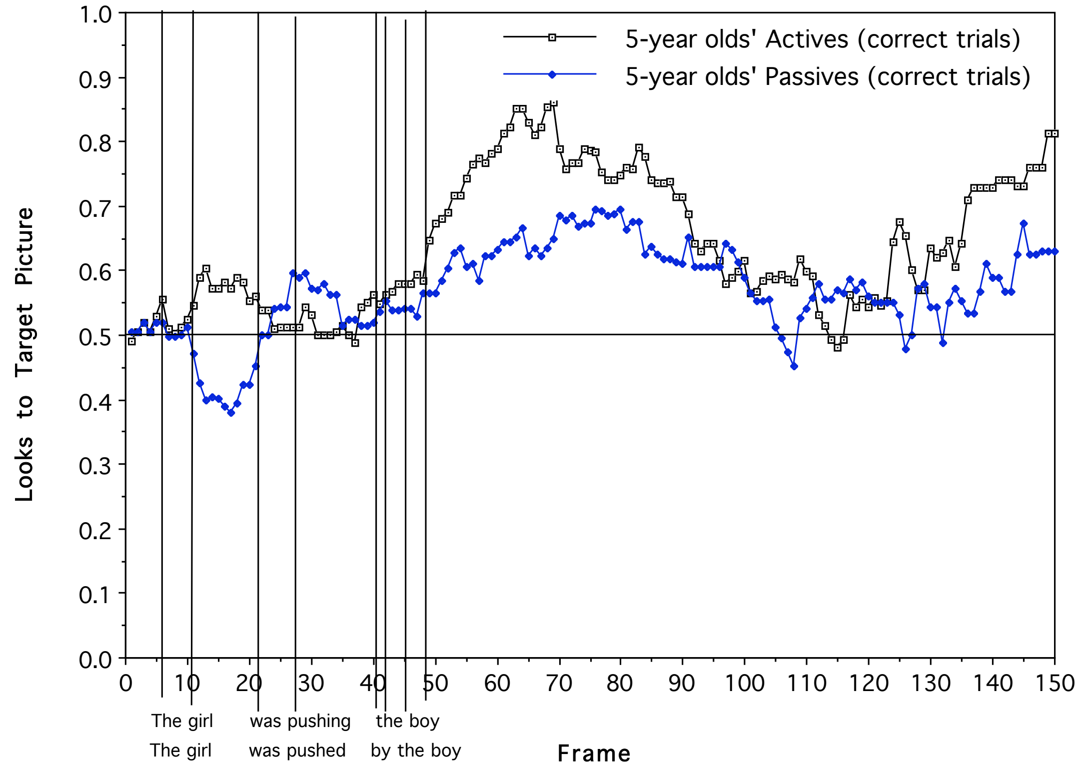

Figure 5b: 5-year Olds' Target Picture Looks for Actives & Passives (Correct Trials)

When eye gaze data from incorrect and correct trials were combined, the differences in active target looks and passive target looks were significant by *t*-tests for all IOIs (all *p*'s < .001), with a greater number of target looks for active sentences than passive sentences. When incorrect trials were excluded, the active-passive differences were significant for all IOIs ($p < .005$) except the VP, the *was*+verb stem, and the second half of the post-sentence interval (i.e., frames 101-150).

<u>6- year olds' eye gaze for actives and passives.</u> The 6-year olds' eye gaze patterns were quite different from the 5-year olds' in several respects. As depicted in Figure 6a, when correct and incorrect trials were combined, 6-year olds' active and passive sentence eye gaze lines began to exhibit mirror symmetry toward the end of the first NP. The symmetric perturbation from chance looking continued

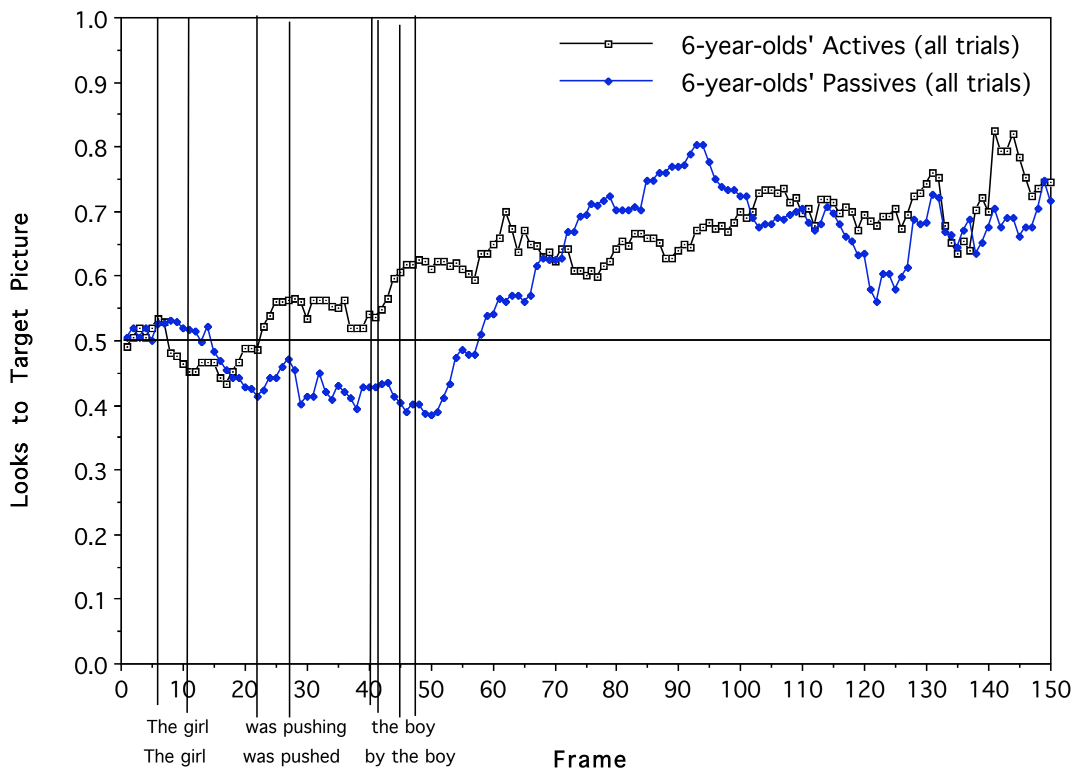

Figure 6a: 6-year Olds' Target Picture Looks for Actives & Passives (All Trials)

until the sentences were finished at which point it reached a maximum of about 25 percentage points. For active sentences, target looks increased moderately (20 percentage points per second) beginning at the progressive inflection, reaching 70% target looks about a third of a second after the actives were finished. For passives, target looks began to increase briskly (40 percentage points per second) from 40% target looks midway through the second noun to about 80% targets looks 1.3 seconds after the passives were finished.

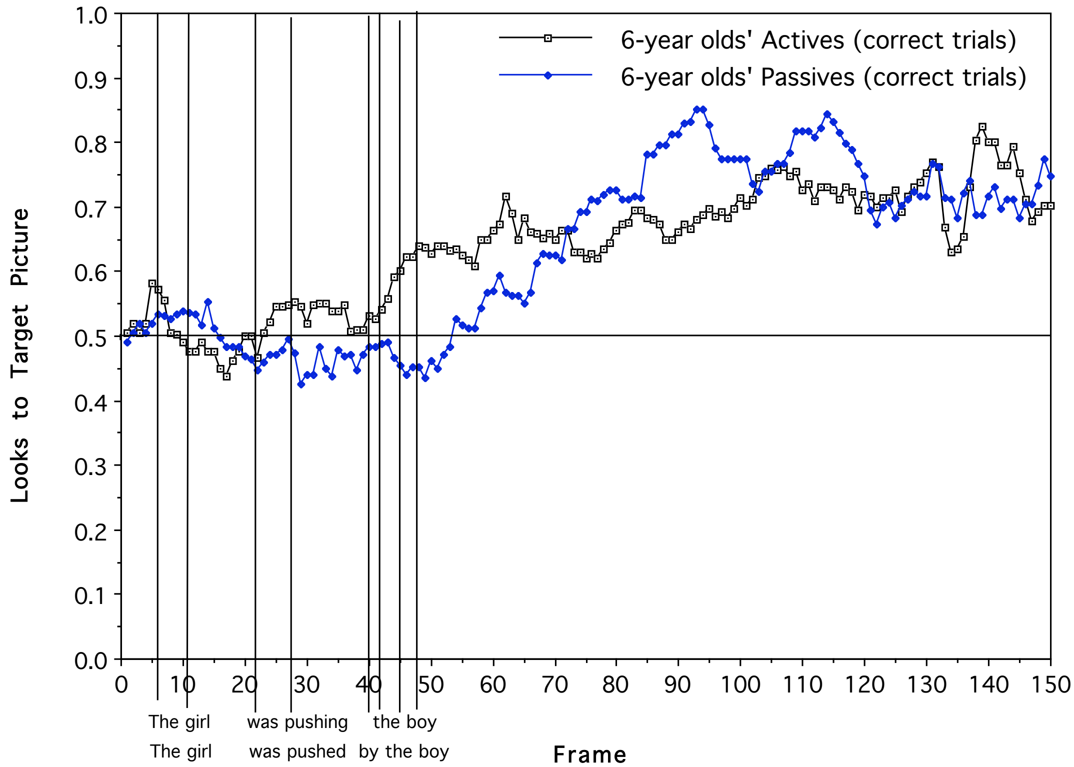

Figure 6b: 6-year Olds' Target Picture Looks for Actives & Passives (Correct Trials)

Comparison of Figures 6a and 6b suggests that, for active sentences, 6-year olds' eye gaze was much the same regardless of whether incorrect trials were included or excluded. In contrast, 6-year olds' eye gaze was somewhat different for all passive trials versus correct passive trials only. As depicted in Figure 6b, 6-year olds' eye gaze for correct passives hovered closely around 50% target looks until the end of the passive sentences at which point target looks increased from 50% to 85% a second later.

When incorrect trials were included (Figure 6a), the active-passive differences in target looks were significant for all IOIs except the first NP and the entire post-sentence interval (i.e., frames 59-150). When incorrect trials were excluded (Figure 6b), the active-passive differences were significant for all IOIs except the sentence fragment prior to disambiguation (i.e., *The girl was push*) and the second half of the post-sentence interval (frames 101-150).

<u>Comparison of 5- and 6-year olds' eye gaze for actives and passives.</u> By comparing 5-year olds' active-passive difference in target looks with 6-year olds' active-passive difference in target looks, we can investigate whether 5- and 6-year olds process sentences in the same way. In order to satisfy the normality assumptions of the *t*-test, we linearized the 5- and 6-year olds' active-passive differences by computing the log of the percent target looks for active sentences divided by the percent target looks for passive sentences. In Figures 7a and 7b, if the *Y* value for a frame is zero, this means that at that frame children looked at the target picture equally often for active and passive sentences. If the *Y* value is positive, this means that at that frame children looked at the target picture more for actives than for passives. For example, if children used a 1st NP = Agent heuristic, the *Y* value would be positive for the part of the sentence that children used the heuristic. Even if children syntactically parsed both actives and passives, the *Y* value would be positive if children parsed actives faster (or began to parse them earlier) than passives. If the *Y* value is negative, this means that children looked at the target picture more for passives than for actives at that frame. For example, if upon hearing *was push* children treated a sentence as passive, the value would be negative in the *was push* region.

If in Figures 7a and 7b, 5- and 6-year olds' lines are superimposed on one another during the sentence, this suggests that 5- and 6- year olds used the same processes (heuristics, biases or syntactical) to process that portion of the sentence, and they did so equally fast and to the same extent. If the contours of the 5- and 6-year olds' lines are the same for a region, but the curves differ in amplitude, this suggests that the two age groups used the same procedures to process that portion of the sentence, but they did so to different degrees. If the contours of the curves are similar, but shifted temporally, this suggests that 5- and 6-year olds used the same procedures, but the speed at which they did so differed. Lastly, if the contours of the 5- and 6-year olds' eye gaze lines differ radically in a region (e.g., there is a

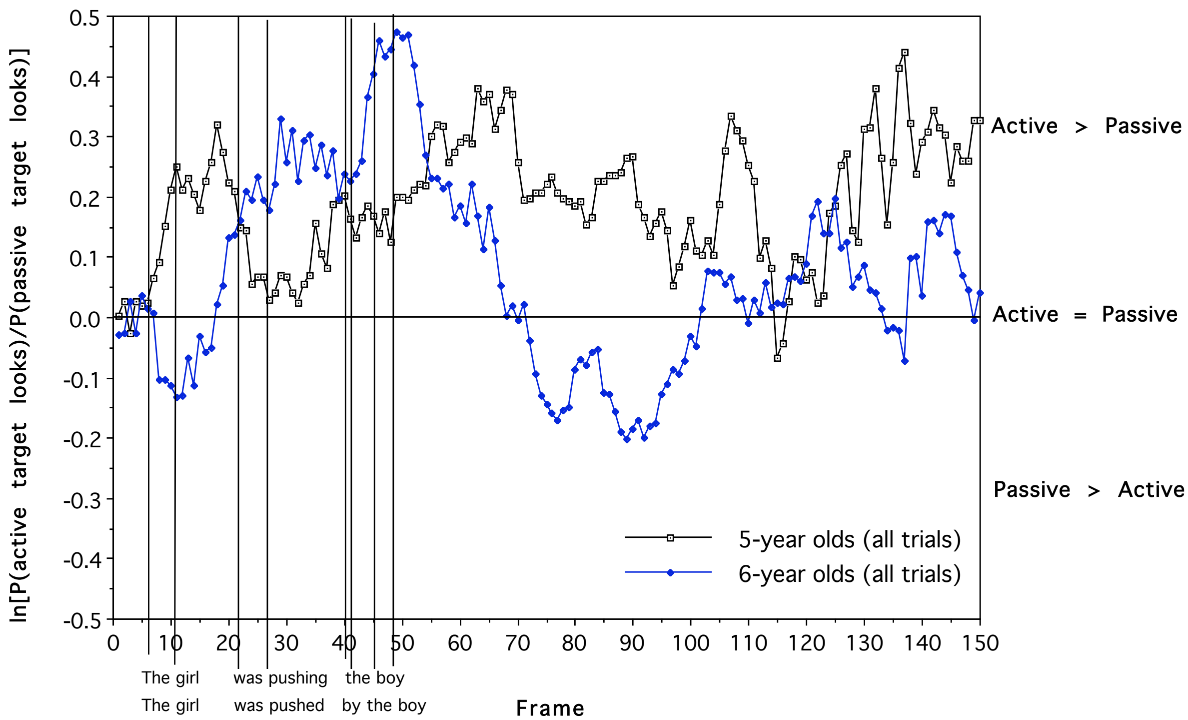

Figure 7a: Comparison of 5- and 6-year Olds' Active/Passive Eye Gaze (All Trials)

positive deflection for only one age group), this suggests that 5- and 6-year olds processed that region of the sentences in different ways.

Inspection of Figures 7a and 7b reveals that the shapes of the 5- and 6-year olds' curves differed substantially, suggesting 5- and 6-year olds processed the sentences in very different ways. For each IOI, we performed a *t*-test to determine whether the 5- and 6-year olds' looking patterns were significantly different. During the 1st NP, the 5-year olds' had more target looks for actives than passives, whereas the 6-year olds' had more target looks for passives than actives (all trials log mean difference = .24, $t(14) = 8.30$, $p < .0001$ for all trials; correct trials log mean difference = .30, $t(14) = 6.44$, $p < .0001$). For all

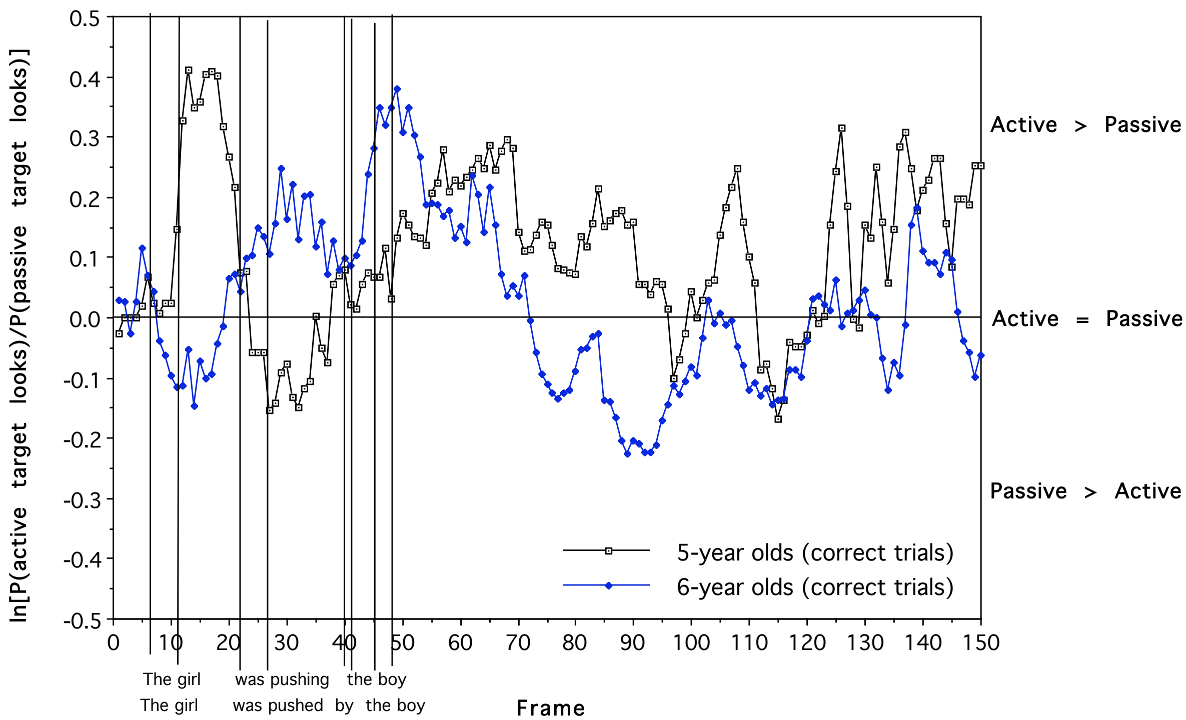

Figure 7b: Comparison of 5- and 6-year Olds' Active/Passive Eye Gaze (Correct Trials)

within-sentence IOIs after the first NP, the pattern was reversed with the 5-year olds having significantly smaller proportions of target looks for actives than the 6-year olds for both all trials and correct trials (all p's $< .005$). During all post-sentence intervals, the pattern switched back with the 5-year olds having a higher proportion of target looks for actives than the 6-year olds (all p's $< .0001$ for all trials and correct trials).

3.8 Comparison of eye gaze for different active IOIs

5-year olds' active sentence IOIs. To investigate how active cues that appear in different IOIs affected the 5-year old children's interpretation of active sentences, we compared the percentage of target looks in contiguous active IOI (see the black lines in Figures 5a and 5b). Five-year olds tended to look at the target picture more during the first NP than during the VP ($t(2698) = 1.70$, $p = .08$ for all trials; $t(2494) = 2.93$, $p = .05$), but for all other contiguous IOIs, 5-year olds looked at the target picture less during earlier IOIs than later IOIs (all p's $< .01$ for all trials; all p's $< .0001$ for correct trials). Regression analyses revealed that the 5-year olds' target looks increased significantly over the course of the entire sentence, the second NP, the unambiguous portion of the sentence (*-ing the boy*), and the second half of the post-sentence interval (all p's $< .0001$ for both all trials and correct trials). Although the 5-year olds' target looks did not change during the first NP, the VP, or the *was verb* IOIs, over the course of the ambiguous region of the sentence (i.e., *The girl was push* IOI), children's looks to the target picture decreased ($r = -.75$ for all trials, $r = -.56$ for correct trials, both p's $< .0001$). Children's target looks also decreased during the first half of the post-sentence interval and during the entire post-sentence interval (all p's $< .0001$ for both all trials and correct trials).

6-year olds' active sentence IOIs. The 6-year olds' target looks were virtually identical regardless of whether their incorrect active trials were included (the black line in Figure 6a) or excluded (the black line in Figure 6b). *T*-tests revealed that for all contiguous IOIs, the 6-year olds looked at the target picture less during the earlier IOI than the later IOI (all p's $< .005$ for both all trials and correct trials). Regression results were quite similar. The 6-year olds' target looks increased over the course of the entire active sentence and over the course of all IOIs after the active sentences were unambiguously active (all p's < .01 for both all trials and correct trials). In addition, although 6-year olds' target looks did not change during the first NP, the VP, or the *was verb* IOIs, the 6-year olds' target looks <u>increased</u> substantially over the course of the ambiguous region of the sentence (i.e., *The girl was push* IOI, $r = .87$, $p < .0001$ for all trials; $r = .75$, $p < .0001$ for correct trials). This is in striking contrast to the eye gaze pattern for the 5-year olds whose target looks <u>decreased</u> significantly during the same interval.

<u>Comparison of 5- and 6-year olds' eye gaze for active sentence IOIs.</u> For each active IOI we compared the percentage of the time the 5- and the 6-year olds looked at the target picture. During the active *was verb*, the VP, and object NP, 5- and 6-year olds looked at the target picture equally often ($p >$ .10 for both all trials and correct trials). For all other within active IOIs, the 5-year olds had more target looks than the 6-year olds, whereas in all post-active IOIs, the 6-year olds had more target looks than the 5-year olds (all p's $\leq .01$ for both all trials and correct trials). These results are consistent with the 5-year olds, but not the 6-year olds, initially using a first NP = Agent heuristic to process active sentences.

3.9 Comparison of eye gaze for correct and incorrect active trials

We next compared the children's eye gaze patterns for the active trials they got right and wrong. The paucity of incorrect active trials made it necessary to combine the 5- and 6-year olds' eye gaze data. Inspection of Figure 8 suggests that in all portions of the active sentences, children's looking patterns were different for active sentences that they got right versus wrong. For active sentences they correctly interpreted, at the outset of the sentence, children looked at the target picture slightly more than 50% of the time, and their looks to the target picture remained fairly stable until after the end of the VP, at which time their looks to the target picture began to increase at a constant rate of about a percentage point per frame. For the active trials that they got wrong, even before they had processed the first noun, children looked at the target picture only about 30% of the time. As they processed the first noun, their looks to the target picture jumped from 25% to 85% (overshooting their looks to the target picture for correct trials by about 50%) and then steadily decline to about 30-40% after the sentence was over.

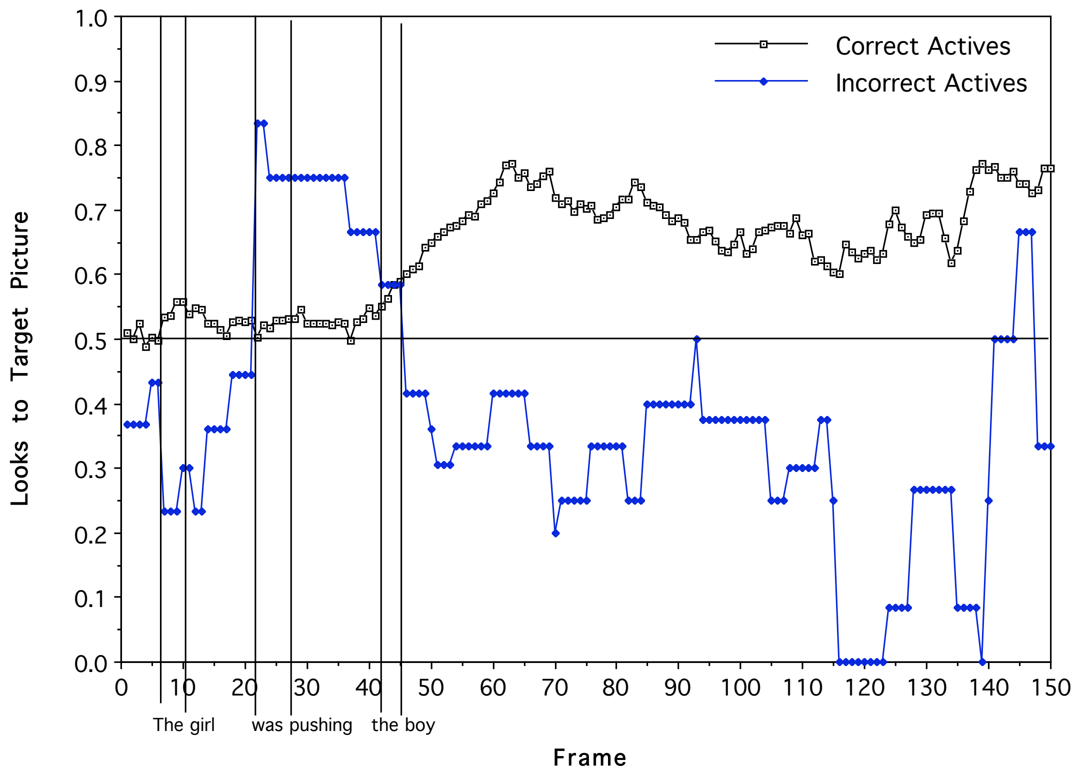

Figure 8: All Children's Target Picture Looks for Correct versus Incorrect Active Trials

T-tests revealed that during the first NP, the second NP, the *–ing the boy*, and all post-active IOIs, the children looked at the target picture more for correct than incorrect active trials (all *p*'s ≤ .01). However, during the *the girl was push*, the *was push*, and the VP IOIs, the children looked at the target picture less during their correct active trials than their incorrect active trials (all *p*'s < .001). Regression analyses provide a similar – but more detailed – picture of how the children processed the active sentences they got right versus wrong. For their correct active trials, the children's target looks increased over the course of the entire sentence (r = +. 75, Z = 6.72, p < .0001), the sentence from the point of morphological disambiguation on (*-ing the boy* $r = +.99$, $Z = 11.80$, $p < .0001$) and the second NP ($r = +.98$, $Z = 8.73$, $p < .0001$), and the children's target looks decreased during the first NP ($r = -.82$, $Z = -4.01$, $p < .0001$) and the first half of the sentence (*The girl was push* $r = -.49$, $Z = -2.76$, $p = .006$). Children's eye gaze for incorrect active trials was essentially the opposite of their eye gaze for correct active trials. For incorrect active trials, the children's target looks increased during the beginning of the sentence (first NP $r = +.81$, $Z = 3.87$, $p = .0001$; *The girl was push* $r = +.89$, $Z = 7.28$, $p < .0001$), and decreased during the latter part of the sentence (*-ing the boy* $r = -.93$, $Z = -7.36$, $p < .0001$; second NP $r = -.84$, $Z = -4.37$, $p < .001$; VP $r = -.83$, $Z = -4.84$, $p < .0001$).

3.10 Comparison of eye gaze for different passive IOIs

5-year olds' passive sentence IOIs. To investigate how passive cues that appear in different IOIs affected the 5-year old children's interpretation of passive sentences, we compared the percentage of target looks in contiguous passive IOIs (see the blue lines in Figures 5a and 5b). The 5-year olds looked at the target picture less during the ambiguous passive IOI than during the unambiguous passive IOI ($t(4328) = 2.58$, $p = .01$ for all trials; $t(2978) = 2.84$, $p = .0004$ for correct trial). When incorrect trials were included, the 5-year olds tended to look at the target picture less during the VP than the *by* phrase ($t(3174) = 2.43$, $p = .02$) and when incorrect trials were excluded, they looked at the target picture significantly less during the first NP than during the VP ($t(1798) = 2.80$, $p = .005$). In addition for all contiguous within-passive/post-passive IOIs, the 5-year olds looked at the target picture significantly more during the post-passive IOI (all p's $< .0001$ for both all trials and correct trials). Regression analyses revealed that when the 5-year olds' eye gaze data for correct and incorrect passive trials were combined, the 5-year olds' target looks increased over the entire passive ($r = .62$, $p < .0001$), the ambiguous half of the passive ($r = .37$, $p = .05$), the unambiguous half of the sentence ($r = .95$, $p < .0001$), and the *by* phrase ($r = .93$, $p < .0001$). The only within-passive IOI during which target looks decreased significantly was the VP IOI ($r = -.78$, $p < .0001$). The 5-year olds' eye-gaze pattern in post-passive intervals was biphasic, with target looks decreasing during the first post-passive IOI (frames 59-100: $r =$

-.39*,* *Z* = -2.56, *p* = .10 for all trials,; *r* = -.42, *Z* = -2.79, *p* = .005 for correct trials) and increasing during the second post-passive IOI (frames 101-150: *r* = + .36*,* *Z* = 2.54, *p* = .01 for all trials; *r* = + .58, *Z* = 4.58, *p* < .0001 for correct trials).

6-year olds'passives IOI. As depicted by the blue line in Figure 6a, when 6-year olds' eye gaze data for correct and incorrect passive sentences were combined, the 6-year olds looked at the target picture more during the NP than during the *was* push interval (*t*(2744) = 2.66, *p* = .008) and the VP (*t*(2744) = 2.66, *p* = .008) . When incorrect trials were excluded, these IOI differences were not significant. For all contiguous within-passive/post-passive IOIs, the 6-year olds looked at the target picture significantly more during the post-passive IOI (all *p*'s < .0001 for both all trials and correct trials). When 6-year olds' eye gaze data for correct and incorrect passive trials were combined, their target looks decreased over the entire passive (*r* = -.37, *Z* = -2.70, *p* = .007), the first NP (*r* = -.97, *Z* = -7.14, *p* < .0001), and the *the girl was push* IOIs (*r* = -.82, *Z* = -5.89, *p* < .0001), and increased during later IOIs (*by* phrase *r* = .73, *Z* = 3.58*,* *p* = .0003; *-ed by the boy* *r* = .63, Z = 3.33, *p* = .0009, first half of post-passive interval *r* = .91, *Z* = 9.54, *p* < .0001). When incorrect trials were excluded, 6-year olds' target looks decreased during the first NP (*r* = -.90, *Z* = -5.05, *p* < .0001), the *the girl was push* IOI (*r* = -.80, *Z* = -5.5.58, *p* < .0001) and the second post-passive IOI (*r* = -.55, *Z* = -4.23, *p* < .0001), and increased during the *by* phrase (*r* = .71*,* *Z* = 3.42, *p* = .0006), the *–ed by the boy* IOI, the first post-passive IOI (*r* = .94*,* *Z* = 10.65, *p* < .0001) and the entire post-passive IOI (*r* = .36, *Z* = 3.57, *p*= .0004).

Comparison of 5- and 6-year olds' eye gaze for passive sentence IOIs. For each passive IOI we compared the percentage of the time 5- and 6-year olds looked at the target picture. When children's correct and incorrect passive trials were combined, the 5- and 6-year olds' target looks did not differ during the first NP and *the girl was push* IOIs (both *p*'s > .10). During all other within-passive IOIs, the 5-year olds looked at the target picture significantly more than the 6-year olds (all *p*'s ≤ .01), whereas during all post-passive IOIs,the 6-year olds looked at the target picture more than the 5-year olds (all *p*'s < .0001). When incorrect trials were excluded, the pattern was the same for all IOIs except one. The exception was that during the first NP, the 6-year olds tended to look at the target picture more than the 5-year olds ($t(1659) = 1.97$, $p = .05$).

3.11 Comparison of eye gaze for correct and incorrect passive trials

5- year olds' eye gaze for correct and incorrect passives. We next compared the children's eye gaze patterns for the passive trials they got right and wrong. Because both the 5-year olds and the 6-year olds got enough passive trials wrong, it was possible to analyze the 5- and 6-year olds' eye gaze data

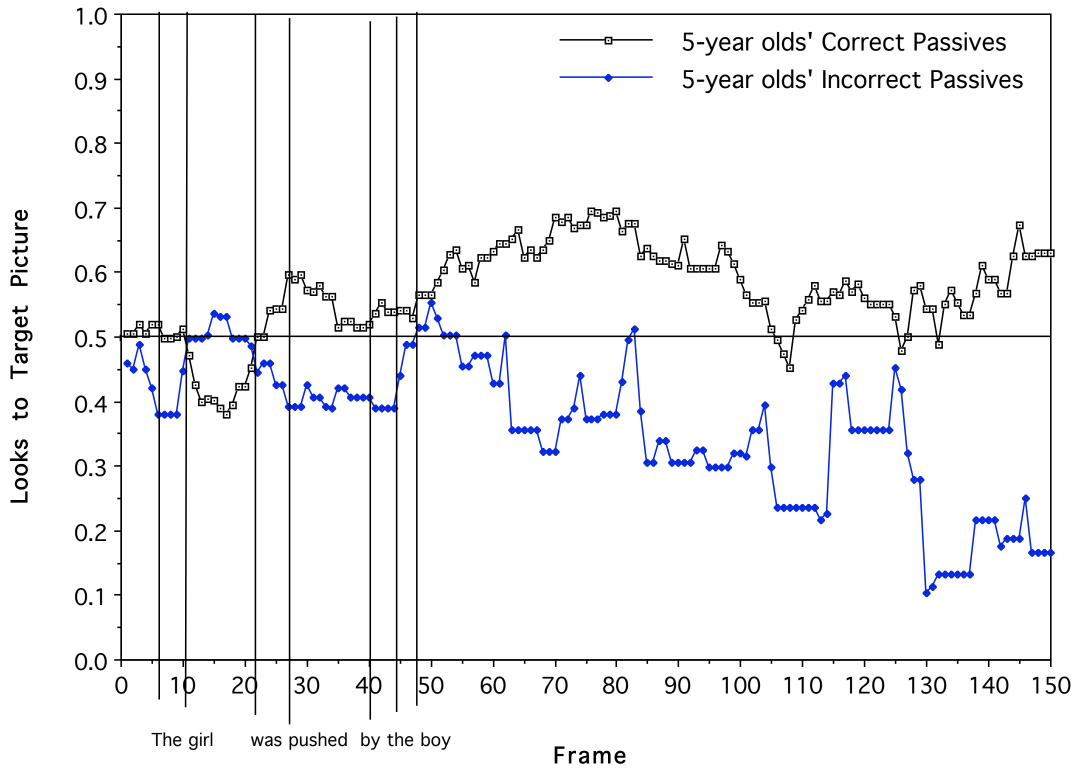

Figure 9a: 5-year Olds' Target Picture Looks for Correct versus Incorrect Passive Trials

separately. Inspection of Figure 9a reveals that the 5-year old children's eye gaze for correct and incorrect passives were symmetric for all IOI prior to the *by* phrase. *T*-tests revealed that 5-year olds had significantly more target looks for correct than incorrect passive trials for all passive IOIs (all p's < .001) except the first NP (p > .10). Consistent with the 5-year olds' eye gaze for correct and incorrect passives having mirror symmetry, regression analyses revealed that, for most IOIs, the correlation coefficients for correct and incorrect passives were substantially different. Indeed, the only passive IOI during which the

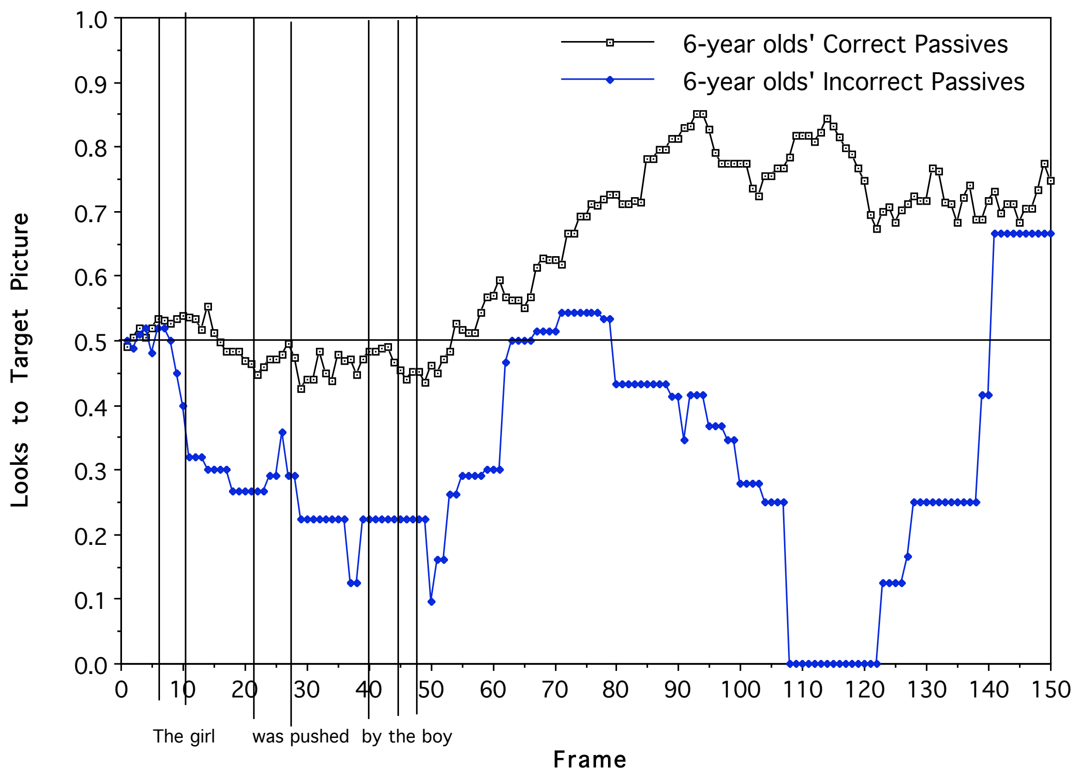

Figure 9b: 6-year Olds' Target Picture Looks for Correct versus Incorrect Passive Trials

5-year olds' eye gaze patterns were the same for correct and incorrect passive trails were the unambiguous portion of passives (*-ed by the boy* $r = .91$, $p < .0001$ for correct trials, $r = .63$, $p = .0009$ for incorrect passives), the first half of the post-passive interval ($r = -.42$, $p = .005$ for correct passives, $r = -.54$, $p = .0002$ for incorrect passives), and the entire post-passive interval ($r = -.55$, $p < .0001$ for correct passives, -.69, $p < .0001$ for incorrect passives).

6- year olds' eye gaze for correct and incorrect passives. Inspection of Figure 9b suggests that the 6-year olds' looking patterns were very different for the passive trials they got right versus wrong. As depicted by the black line in Figure 9b, the 6-year olds' target looks for correct passive trials fluctuated around 50% until the end of the passive at which point their target looks increased linearly. In striking contrast, for incorrect passive trials, the 6-year olds' target looks steadily declined throughout the passive until about a third of the way through the second noun at which point their target looks increased but never exceeded chance levels (see the blue line in Figure 9b). Consistent with this, *t*-tests revealed that the 6-year olds had significantly more target looks for correct than incorrect passive trials during all IOIs (all *p*'s < .0001). Regression analyses confirmed that, for the passives they correctly interpreted, the 6-year olds' eye gaze did not change as the passive unfolded ($p > .10$ for all within-passive IOIs). Regression analyses also confirmed that, for incorrect passive trials, the 6-year olds' target looks decreased over the course of the entire passive ($r = -.55$, $p < .0001$), during all early within-passive IOIs (1st NP $r = -.85$, $p < .0001$, VP $r = -.70$, $p = .0005$, *was push* $r = -.73$, $p = .002$, *the girl was push* $r = -.78$, $p < .0001$), and the first half of the post-passive IOI ($r = -.42$, $p = .005$). Indeed, for the passive trials they got wrong, the 6-year olds' target look only increased during the *–ed by the boy* IOI ($r = .58$, $p = .003$) and the second post-passive IOI ($r = .74$, $p < .0001$).

3.12 Summary of the eye gaze results

Processing of active and passive sentences. The eye gaze data indicate that children process active and passive sentences differently and, furthermore, that the way children process active and passive sentences depends on the age of the child. When the eye gaze data from incorrect trials were excluded, the 5-year old children's perturbation from chance looking had mirror symmetry during the first noun, with more target looks for active sentences than passive sentences, suggesting that 5-year olds begin sentence processing with a 1st NP = Agent bias. However, by the beginning of the VP, the 5-year olds had more target looks for passives than actives. This suggests that when 5-year olds correctly interpret actives and passives, they abandon the 1st NP = Agent heuristic at the *was*. The 5-year old children's active target looks increased rapidly and linearly after the progressive participle, indicating that 5-year olds syntactically parse actives on-line. In contrast, for passives, the 5-year olds' target looks only began increasing at the end of second noun, suggesting that 5-year olds syntactically parse passives off-line.[7]

Taken as a whole, the 5-year olds' eye gaze data strongly suggest that 5-year olds treat *was* as a cue that a sentence is passive. Comparison of the 5-year olds' eye gaze for correctly interpreted active and passive sentences reveals that, at the *was*, the 5-year olds' target looks increased for passives (from about 40% during the first noun to 60% at the end of the *was*) and decreased for actives (from 60% to 50% during the same interval). One can also see evidence that 5-year olds treat *was* as a cue that a sentence is passive by comparing the 5-year olds' eye gaze for the passive trials they got right versus wrong. For incorrect passive trials, the 5-year olds' target looks decreased from 50% during the first noun to 40% at the end of *was*, whereas for correct passive trials, the 5-year olds' target looks increased from 40% to 60% during this same period.

The 6-year olds' eye gaze data suggest that, in some ways 6-year olds process sentences like 5-year olds, and in some ways they process sentences differently. Like the 5-year olds eye gaze, the 6-year olds' eye gaze during active sentences suggests that 6-year olds begin to syntactically and incrementally parse actives once active sentences are syntactically unambiguous (i.e., both 5- and 6-year olds syntactically parse actives on-line). Similarly, as was the case with the 5-year olds eye gaze, the 6-year

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[7] One could argue that these data merely indicate that children syntactically parse passives very slowly. However, the fact that target looks begin to increase immediately after passives are finished argues against this interpretation.

olds' eye gaze during passives suggests that 6 year olds do not syntactically parse passives until the passives are over (i.e., both 5- and 6-year olds syntactically parse passives off-line). However, the eye gaze data suggest that, unlike 5-year olds, 6-year olds do not approach sentence processing with a 1st NP = Agent strategy. A second striking contrast is that, whereas the 5-year olds' eye gaze data indicate that 5-year olds treat *was* as a cue that a sentence is passive, the 6-year olds' active target looks increased during the *was*, suggesting that 6-year olds treat *was* as a cue that a sentence is active.

<u>Understanding and misunderstanding sentences.</u> We can gain further insight into how children process sentences by comparing their eye gaze patterns during experimental trials they get right and wrong. Because the children rarely got actives trials wrong, we could only compare children's eye gaze for correct and incorrect active trials when we combined the 5- and 6-year olds' data. When we did this, we found that, for all but the first NP, children's eye gaze patterns were different for correct and incorrect active trials. Although we cannot be certain why children got active trials wrong, like the RT data, the children's eye gaze during correct and incorrect active trials suggest that children may have gotten active trials wrong because they weren't paying attention during the trial. Recall that, at the beginning of each trial, children were instructed to look at the cross that appeared between the two pictures. Children did exactly this for the active trials they got right. However, for the active trials they got wrong, rather than looking at the cross, they fixated on the distractor picture. A quarter of the way through the sentence, they abruptly shifted their eye gaze and stared at the other (target) picture, but they were unable to recover and ended up getting the active trial wrong.

Comparison of the 5- and 6-year olds' eye gaze for correct and incorrect passive trials also provides insight into how 5- and 6-year olds process passive sentences. During the sentence-initial *the*, the 5-year olds looked equally often at the target and distracter pictures for the passive trials they got right, whereas they looked at the distracter picture more than the target picture for the passive trials they got wrong. This pattern was reversed during the first noun, with equal number of target and distracter picture looks for incorrect passives and more distracter than target picture looks for correct passives. Because the sentence initial *the* provides no information about the meaning of the first noun, the children should have looked at the pictures randomly (i.e., 50% target looks) during the *the*. The fact that, when the 5-year olds got passive trials wrong, they looked at the distracter picture more during the *the* suggests that, as was the case with actives, the 5-year olds got at least some passive trials wrong because they weren't paying attention at the beginning of the trial. Consistent with this, when the 5-year olds got passive trials right, they began the trial by looking at the two pictures randomly. The 5-year olds' eye gaze during the first NP suggests that they only used a 1st NP = Agent heuristic when they correctly interpreted passives. Furthermore, the 5-year olds' eye gaze during the *was* suggests that when the 5-year olds correctly interpreted passives, they treated the presence of *was* as evidence that the sentence was passive, whereas when they misinterpreted passives, they treated the presence of *was* as evidence that the sentence was active. One last observation is that the 5-year olds' target looks for incorrect passive trials abruptly increased from 40% at the *by* to 55% at the beginning of the second noun (the highest level of target looks observed for incorrect passive trials). This suggests that the presence of *by* may have made the 5-year olds briefly reconsider whether sentences really were active.

The 6-year olds' eye gaze patterns for correct and incorrect passives were quite different from the 5-year olds'. For the passive trials they got right, the 6-year olds did not use the order of the NPs when assigning thematic roles to the NPs, but rather waited until the end of the passives to do so. In contrast, when 6-year olds got passive trials wrong, they did use the order of the NPs when assigning thematic roles to the NPs. Another way the 5- and 6-year olds' eye gaze patterns differed is that, unlike with the 5-year olds, the 6-year olds' target looks for incorrect passive trials did not change at the *by* suggesting that the presence of *by* has no effect on 6-year olds' interpretation of passives. A final way that the 6-year olds' eye gaze for incorrect passive trials differed from that of the 5-year olds is that the 6-year olds' target looks increased from 10% at the beginning of the second noun to 55% about a half second after the passives were over, suggesting that, by the end of the passive trials they got wrong, the 6-year olds may have realized that they had misinterpreted the sentences and attempted (unsuccessfully) to reanalyze them.

4. Discussion and Conclusion

4.1 The acquisition of passives

Our accuracy and RT data indicate that even 3-year olds can distinguish between active and passive sentences: if they could not, the 3-year olds in this study would have been equally accurate on active and passive sentences. Many studies have shown that 3-year olds have little difficulty understanding semantically reversible active sentences. Thus, the fact that, in this study, the 3-year olds got one-third of active trials wrong indicates that the non-syntactic task demands of the experiment were great enough that our study underestimates 3-year olds' syntactic knowledge of active and passive sentences. Once we factor out the non-syntactic demands of the experiment, children's error rates on passives remain fairly low and constant (between about 10% to 20%) from age 3 to age 6. This, coupled with the lack of an Age x Sentence Type interaction suggests that, contrary to the theories discussed in section 1, by age 3, children have already acquired the linguistic machinery that underlies passives. The conclusion that, by age 3, children have the linguistic competence necessary to comprehend passives – but that performance factors adversely affect their comprehension of passives – is consistent with studies that show that English-speaking children are already producing passives by the time they are 3 years old (Snyder & Stromswold, 1997; Stromswold & Snyder, 1995). Our accuracy findings are also consistent with studies that show that passives can be elicited from 2- and 3- year olds (Brooks & Tomasello, 1999; Horgan, 1978; Tomasello et al., 1998).

4.2 Word order and passive processing

Our analyses of the adult speech in the CHILDES corpora reveal that adults say 1,000 times more active sentences than passive sentences when they speak to children. Our 5-year olds' eye gaze when they listened to active and passive sentences indicates that 5-year olds (and by downward extension, 4-year olds) initially process sentences by assigning an agentive role to the first NP of the sentence. In other words, Bever (1970) was partially right when he proposed that young children learn that Agent-Action-Patient is the canonical pattern for English sentences and that they use this generalization to process all NVN sentences. However, where Bever seems to be wrong is that young children don't use the Agent-Action-Patient pattern to process entire sentences (a "semantics first" approach). Instead, the 5-year olds' eye gaze data indicate that they only use the strategy during the first noun of sentences, abandoning it at the beginning of the VP when additional information about sentences becomes available.

It makes sense that 5-year olds approach sentence processing by assuming that the first noun they hear is the agent of the sentence: this regularity is easy to discover, statistically robust, computationally inexpensive to use, and usually results in the subject NP receiving the correct thematic role. Furthermore, by assuming that the first noun is an agent (i.e., that a sentence is active), 5-year olds reduce the number of possible parses of a sentence that they must consider simultaneously. This greatly decreases the amount of computational resources and working memory required to process sentences. Although 5-year olds initially assume that the first noun is an agent, 6-year olds do not. Given the benefits of approaching the task of sentence processing by assuming the first noun is an agent, the real question is why do children stop doing this by the time they are 6? There are several possible explanations. The first is that, between age 5 and 6, children learn that not all subjects are agents. This explanation is implausible because even 2- and 3-year olds produce sentences that have non-agent subjects (Bloom, 1970; Brown, 1973). A second possible explanation is that, between age 5 and age 6, children's non-syntactic abilities (e.g., lexical access abilities, working memories, attention, ability to scan pictures, etc.) have grown enough that they can afford to wait for additional information before assigning a thematic role to the first NP of a sentence. Because the communicative 'costs' of assigning the wrong thematic role to the first NP (believing X did something, whereas X actually had something done to it) is very high, 6-year olds may have 'decided' that the computational costs associated with delaying processing are less than the computational costs associated with having to reanalyze a sentence.

4.3 Morphological cues and passive processing

As reviewed in the Introduction, previous studies have yielded different results with respect to how preschool children's comprehension of passives is affected by the three morphological cues that distinguish active sentences from passive sentences. The problem with previous studies is that, in order to study the effects of the three passive cues, researchers asked children to act out sentences that had one, two, or all three passive morphemes. However, sentences that have one or two passive morphemes are not grammatical (e.g., **the girl was pushed the boy*, **the girl pushed by the boy*, **the girl was push by the boy*), and it is unclear what children do when they are asked to interpret ungrammatical sentences. Eye tracking studies allow us to sidestep this problem and investigate how the three passive cues affect children's interpretation of grammatical sentences.

-ing vs. *-ed.* Both the 5- and 6-year olds' target looks for actives increased sharply at the *–ing* inflection, whereas their target looks for passives did not change at the *–ed* inflection. There are several possible explanations for this pattern. It could be that children know the syntactic import of *–ing* (that it indicates that a sentence is progressive and almost certainly active), whereas they don't yet know the syntactic import of the*–ed* inflection. A second possible explanation is that this pattern reflects the relative phonological salience of the progressive and passive inflections: the *–ing* inflection is syllabic whereas, for the verbs used in this experiment, the *–ed* inflection is not. If phonological salience is the explanation, children's target looks should increase at the *–ed* if the passive inflection is syllabic (e.g., *was patted*). A third possible explanation is that *–ing* is an extremely strong and reliable statistical cue that a sentence is active, whereas *–ed* is not a good cue that a sentence is passive. Indeed, given that the adults in the CHILDES corpora used *–ed* 500 times more frequently in active sentences than in passive sentences, if children's sentence processing is largely guided by the relative frequency of particular inflections in particular constructions, at the *–ed*, children's passive target looks should have decreased and their active target looks should have increased.

By. The 6-year olds' eye gaze did not change at the *by* for either correct or incorrect passive trials, suggesting that 6-year olds ignore *by* when they process sentences. It's easy to explain why 6-year olds ignore *by*: a sentence can be passive without having a *by* (e.g., *the girl was pushed*) and sentences can contain a *by* without being passive (e.g., *the cup was by the window*). Consistent with this, our analyses of the CHILDES corpora indicate that when adults speak to children they are 15 times more likely to use a truncated passive than a full passives, and if they use the word *by* it is 20 times more likely to occur in an active sentence than in a passive sentence. In contrast to the 6-year olds, the 5-year olds' target looks on incorrect passive trials increased sharply at the *by*, suggesting that *by* is a passive cue for 5-year old children. Given that *by* is neither a sensitive nor specific indicator that a sentence is passive, why do 5-year olds treat *by* as a passive cue? One possibility is the finding is spurious. This possibility is consistent with the observation that 5 year olds' target looks for correct passive trials did not change at the *by*. However, in light of the fact that some comprehension studies show children treat *by* as being particularly diagnostic of passiveness (Maratsos & Abramovitch, 1975; Stromswold et al., 1985), the *by* finding should be taken seriously.

Although, we found that only 5% of adult usages of *by* are passive, Stromswold, Pinker and Kaplan's (1985) analyses of the CHILDES corpora indicate that most adult usages of *by* are agentive or instrumental (e.g., *I did it by myself*), and not spatial (e.g., *the coffee is by the sink*). Thus, it is possible that 5-year olds, but not 6-year olds, notice the agentive quality of *by* and, therefore, treat *by* as a cue that a sentence is passive. Another possibility is that 5-year old children's processors don't care that *by* usually occurs in active sentences because all the processor notices is that a preposition is present and not what the preposition is. This explanation is consistent with Clark and Carpenter's (1989) finding that children sometimes say passives with the prepositions *from* or *with* rather than the proposition *by*. It is also consistent with Felser, Marinis and Clahsen's (2003) finding that that in sentences like *The doctor recognized the nurse of(with) the pupil who was feeling very tired*, young children attached the relative clause to the first NP irrespective of whether the preposition was *of* or *with*. In other words, maybe 5-year olds treat *by* as a cue that a sentence is passive because their sentence processing is guided by structurally-based principles rather than lexical biases.

<u>Auxiliary *was*.</u> In the CHILDES corpora, the word *was* occurs 32 times more frequently in adults' progressive sentences than in their passives sentences (even when adjectival passives such as *it was broken* are treated as passives) and, when non-progressive usages of *was* are included in the count, *was* occurs 175 times more often in adults' active sentences than passive sentences. In other words, the

presence of a *was* is a strong statistically reliable cue that a sentence is active not passive. Therefore, if the construction-specific frequency of words in the input drives the way children process sentences, when children hear the auxiliary *was,* their target looks for passives should decrease and their target looks for actives should increase. This frequency-in-the-input pattern was observed for the 6-year olds. However, the 5-year olds' eye gaze pattern was exactly the opposite of what the frequency-in-the-input account predicts: at the *was*, the 5-year olds' target looks increased for passives and decreased for actives. These results suggest that 6 year olds' sentence processing is guided by the frequency of elements in the input, but 5-year olds' sentence processing is not.

Given that, statistically speaking, the presence of *was* is a very good indicator that a sentence is active, why don't 5-year olds treat it as such? One possibility is that 5-year olds have not yet developed a robust database of the frequency of various morphemes in different constructions (i.e., given the string *The girl was,* what is the likelihood that sentence is active). A second possibility is that 5-year old children have such a database, but they cannot use its information in real-time. However, neither of these accounts can be correct because both accounts predict that *was* will have <u>no</u> impact on 5-year olds' interpretation of sentences, whereas our eye gaze data indicate that 5-year olds treat *was* as a cue that a sentence is passive.

In the past tense progressive sentence *the girl was pushing the boy*, the event of pushing is ongoing, whereas in the simple past tense sentence *the girl pushed the boy* the event of pushing has a clear end point (i.e., is telic). In the passive sentence *the girl was pushed by the boy*, the event of pushing also has a clear endpoint. Perhaps 5-year olds are more sensitive to the aspectual difference between *was pushing/was pushed* and, given the static nature of the pictures, they treat the word *was* as a cue that a sentence is passive. Notice that aspect is a grammatical property of the passive auxiliary. Therefore, if 5-year olds treat *was* as a passive auxiliary because it is +telic, ignoring the fact that *was* appears more commonly in active sentences than passive sentences, this is evidence that 5-year olds' sentence processing is guided more by formal/structural properties than by frequency information.

4.4 Time course of active and passive sentence processing

Despite the differences in how 5- and 6-year olds process active and passive sentences, our eye gaze data indicate that the time course with which 5- and 6-year olds process active sentences is different from the time course with which they process passive sentences. Both 5- and 6-year olds begin to syntactically parse actives once they are unambiguously active (i.e., at the *–ing*). From this point on, both 5- and 6-year olds incrementally parse actives, with the rate of parsing being the same for both groups. In contrast to their processing of active sentences, neither 5-year olds nor 6-year olds begin to syntactically parse passives until the passive sentences are over. In other words, both 5- and 6-year olds syntactically parse actives on-line and they syntactically parse passives off-line.

4.5 Understanding and misunderstanding passives

According to Bever, young children misinterpret passives because they process all NVN sentences as if they were Agent-Action-Patient sentences. Thus, in passive sentences, young children erroneously assign the agent thematic role to the first NP and the patient thematic role to the second NP. If this is the explanation for children's passive errors, for passive trials children get wrong, children's target looks should be below chance during the first NP and then decrease monotonically throughout the passive. The 6-year olds' eye gaze patterns are consistent with this, but the 5-year olds' are not. For incorrect passive trials, the 5-year olds' target looks were at chance level during the first noun, decreased during the first half of the VP and then increased during the first half of the second NP. Let us now consider Townsend and Bever's (2001) LAST account of passive errors. The LAST is essentially a horse race model of sentence processing: people simultaneously syntactically parse and pseudo-parse sentences and they misunderstand sentences when pseudo-parsing wins the race and yields the wrong interpretation for a sentence. So, according to the LAST, when we pull out the sentences that the children misunderstand, we pull out exactly those sentences where pseudo-parsing was faster than syntactic parsing. According to the LAST, the primary heuristic used to pseudo-parse passives is that the first NP is the agent of the sentence. Thus, the LAST correctly predicts that the 6-year olds' eye gaze patterns on incorrect passive trials. However, like Bever's (1970) account, the LAST cannot explain the 5-year olds' eye gaze patterns on incorrect passive trials. According to Bever (1970), older children are less reliant on the Agent-Action-Patient heuristic than younger children, and according to the LAST, older children syntactically parse more rapidly than younger children. Thus, the fact that 6-year olds – but not 5-year olds – misunderstand passives because they use the 1^{st} NP = Agent strategy is problematic for both Bever's account and the LAST account of passive errors.

4.6 A developmental model of sentence processing.

In this study, we collected accuracy, RT and eye gaze data as English-speaking children listened to simple, unambiguous active and passive sentences and performed a picture-matching comprehension test. The primary goal of this study was to answer long-standing questions regarding when English-speaking children acquire passives, how they process passives, and why they sometimes misunderstand passives. Our accuracy and RT findings suggest that, by the time they are three years old, English-speaking children already have the syntactic machinery need to produce and understand passives. However, because passive sentences are longer and syntactically more complex than active sentences, the linguistic and nonlinguistic demands associated with processing passive sentences (e.g., the memory load associated with processing sentences with filler-gap dependencies) are greater than the demands associated with processing active sentences. This means that children's processing resources are more likely to be overtaxed when they process passive sentences than when they process active sentences. The result is that children are more likely to misunderstand passive sentences than active sentences, and younger children are more likely to make these errors than older children being their processing resources are more limited.

Our accuracy and RT data suggest that children have already acquired passives by the time they are three years old and that children's errors on passives are due to processing limitations. Furthermore, age-dependent differences in accuracy, RT and eye gaze patterns suggest that the way children process passive (and active) sentences changes from age 3 to age 6. For example, our eye gaze data indicate that

5- and 6-year olds process sentences differently in a number of ways. First, when 5-year olds listen to a sentence, they assume that the first noun they hear is the agent, whereas 6-year olds do not. Second, 5-year olds treat *was* as a cue that a sentence is passive, whereas 6-year olds treat *was* as a cue that a sentence is active. Third, 5-year olds treat *by* as a cue that a sentence is passive, whereas 6-year olds' interpretation of passives is unaffected by the presence of *by*. Fourth, 5- and 6-year olds misunderstand passives for different reasons: 5-year olds misunderstand passives when they interpret *was* as a cue that a sentence is active, and 6-year olds misunderstand passives when they use an Agent-Action-Patient strategy to process passives. Finally, 5-year olds do not attempt to re-analyze passive sentences when they get them wrong, whereas the 6-year olds seem to.

Although 6-year olds process sentences differently than 5-year olds, comparison of the 6-year olds' eye gaze data with eye gaze data collect from adults when they did the same experimental task (Stromswold et al., 2002) indicates that the 6-year olds' sentence processing is still not adult-like. First, the adults' eye gaze patterns indicate that adults begin to syntactically and incrementally parse passives as soon as passives are unambiguously passive (i.e., immediately after the –*ed*), whereas 6-year olds don't begin to syntactically parse passives until passives are over. Second, even when adults misinterpreted passives, their eye gaze showed no evidence of them having used an Agent-Action-Patient heuristic to process passives. Third, the adults' eye gaze patterns indicate that adults use subtle acoustical cues to disambiguate actives from passives prior to the point at which the two types of sentences are morphologically unambiguous.[8] In contrast, the 6-year olds' eye gaze patterns show no evidence that 6-year olds use acoustic cues to guide sentence processing.

Some of our eye gaze findings are easy to explain and interpret. For example, a limited processing account such as that laid out in section 2.6 or the one recently developed by Clahsen and

[8] Although the prosodic contours of the active and passive sentences used in this study do not differ (see Appendix), passive verb stems (e.g., the *push* in *pushed*) are significantly longer than active verb stems (e.g., the push in pushing, Stromswold et al., 2002).

colleagues (Clahsen & Felser, 2006; Felser et al., 2003) can easily explain why children process active sentences online and passive off-line. Children process active sentences on-line because actives do not place excess demands on children's language processors, and children process passive sentences off-line because children do not have the resources to process passives on-line. Adults process both active and passive sentences on-line because neither type of sentence overburdens adults' processing capabilities.

There are several possible reasons why the children in our study did not use the acoustical differences between the active and passive sentences when they processed the sentences. Many studies report that 6-year olds are not adult-like in their ability to use prosodic information to understand syntactically ambiguous sentences (e. g., Choi & Mazuka, 2003; Cruttenden, 1974; Holdgrafer & Campbell, 1986; Snedeker & Yuan, 2003; Wells, Peppe, & Goulandris, 2004). Thus, it is possible that 6-year old children have not yet learned the language-specific acoustic-syntactic correspondences that disambiguate temporarily ambiguous sentences. A second possibility is that 6-year olds can use acoustic cues to disambiguate actives from passives, but they are unable to do so in real-time. Consistent with this, the published studies that have found evidence of children using prosodic cues in syntactic parsing have typically used off-line measures (e.g., Beach, Katz, & Skowronski, 1996). A third possibility is that, children can use prosodic cues that are strong and always present in particular syntactic environments, but they cannot use the type of subtle, probabilistic acoustic cues present in our stimuli. This account is consistent with Wheldall's (1978) finding that 3- and 4-year old children comprehend passive sentences (but not active sentences) better when they are presented in a "highly intonated, lively form" than in a "flat, monotonic" form.

The finding that is much more difficult to explain is why, when they process sentences, 5-year old children use the statistical regularity that most subjects are agents, but they do not use the statistical regularity that almost all sentences with *was* and *by* are active. One tempting possibility is that 5-year old children used the 1^{st} NP = Agent regularity but not the *was* and *by* regularity because the 1^{st} NP = Agent regularity is statistically much more robust. However, this cannot be the explanation because, when they process sentences, 5-year old children don't simple ignore *was* and *by* – as such an explanation would predict – but rather they treat *was* and *by* as cues that a sentence is passive. Another problem with a simple statistical account is that, when 6-year olds process sentences, they do not exploit the 1st NP = Agent regularity whereas they do use the statistically less reliable regularity that *was* typically appears in active sentences.

One way of reconciling the fact that 5-year olds use the 1st NP = Agent bias and they treat *was* and *by* as passive cues is to argue that 5-year olds' sentence processing is guided by semantics. According to a semantic account, 5-year olds use the 1st NP = Agent bias because it is semantic. Similarly, they treat *by* as a cue that a sentence is passive because most adult usages of *by* are agentive not locative. Lastly, they treat *was* as a passive cue because ongoing actions are hard to represent in static drawings. Thus, the pictures used in this experiment match the "action-completed" semantics of passive *was* better than they match the "action-ongoing" semantics of progressive *was*. There are three problems with this semantic account. First, when children produce passives, they sometimes use a preposition other than *by* and these other prepositions are not agentive (Clark & Carpenter, 1989). Second, Felser et al. (2003) have shown that young children's relative clause attachment preferences are not affected by the semantics of the preposition used in a sentence. Third, on-line studies have generally shown that when young children process sentences, they are insensitive to referential context (Snedeker & Trueswell, 2004; Snedeker & Yuan, 2003; Trueswell et al., 1999). Given that when children process sentences, they ignore blatant differences in the visual scene (e. g, whether one or two frogs are present), it is unlikely that 5-year olds' sentence processing is guided by such subtle semantic distinctions such as the action ongoing/action completed semantics of progressive and passive *was*.

Another way of reconciling the fact that 5-year olds use the 1st NP = Agent bias and they treat *was* and *by* as passive cues is to argue that 5-year olds' sentence processing is guided almost exclusively by the structural/syntactic properties of sentences. According to a structure/syntax account, 5-year old children interpret *was* as a passive auxiliary because *was* has a +telic grammatical feature. They treat *by* as a passive cue simply because it is non-locative preposition that occurs with passive *was.* For this structure/syntactic account to work, the 1st NP = Agent regularity must be a structural property of sentences and not (just) a semantic property. This is consistent with many recent linguistic theories that argue that argument structure is part of syntax (see for example, the Uniformity of Theta Assignment Hypothesis put forth in Baker, 1985). Given the proposed limitations of children's language processors, there are several advantages to having a language processor that is structurally/syntactically encapsulated when it processes sentences. First, simply limiting the amount of information available to the processor will allow it to process sentences more efficiently. Second, a language processor that only uses structural/syntactic information does not have to integrate multiple sources of information that could potentially conflict and lead to different interpretations of a sentence. Third, many sentences – including passives – must be syntactically parsed to be understood correctly. Using structural/syntactic properties to process and interpret sentences may be advantageous for children with limited processing resources because the moment-by-moment output created by a structural processor is in the right type of format for syntactic parsing to proceed smoothly. In addition to having these practical advantages, a structure/syntax account is consistent with recent work that shows that young children have difficulty using non-structural information when they process sentences (Snedeker & Trueswell, 2004; Snedeker & Yuan, 2003; Trueswell et al., 1999).

The question that remains is why 6-year old children don't rely on structural properties when they process sentences. With respect to the 6-year olds' failure to use the 1st NP = Agent structural regularity, the answer may be that 6-year olds' processing capabilities and working memories are great enough that they can delay assigning a thematic role to the first NP until additional information becomes available. That the 6-year olds treat *was* as a cue that a sentence is active (rather than passive) may reflect their nascent abilities to use the construction-specific frequency information to guide on-line sentence processing. It is possible that the breakthrough that occurs between age 5 and age 6 is that children's sentence processors have grown to the point that they can handle multiple streams of incoming information. Because the goal of this study was to investigate how children use grammatical morphological cues and word order to assign thematic roles to NPs, we worked very hard to make sure that our sentences did not differ lexically, referentially or prosodically. Unfortunately, this means that we are unable to determine whether children begin to use construction-specific frequency cues in sentence processing sooner, later or at the same time as they begin to use these other types of nonstructural cues. We are also unable to determine the relative strength of these cues in guiding children's sentence processing.

In summary, in this study, we made several discoveries about how children process passive sentences that were hitherto unknown and could not have been discovered using standard accuracy or response time measures. First, we discovered that children syntactically process active sentences on line, whereas they syntactically process passives off line. Second, we discovered that upon hearing the first NP of an active or passive sentence, 5-year olds assume the NP is the agent of the sentence, whereas 6-year olds do not. Third, we discovered that 5-year olds treat *was* and *by* as cues that a sentence is passive, whereas 6-year olds do not. Fourth, we discovered that 5- and 6-year olds misunderstand passive sentences for different reasons: 5-year olds misunderstand passives when they interpret *was* as a cue that a sentence is active, and 6-year olds misunderstand passives when use an Agent-Action-Patient heuristic to process the entire sentence. Finally, our eye gaze data suggest that even 6-year olds do not process passives in an adult-like fashion.

In addition to providing answers to long-standing questions about children's acquisition, understanding and misunderstanding of passives, the results of our study have broader implications. The results of our study suggest that young children's apparent linguistic limitations are sometimes the result of immature language processors and not immature grammars. Our results also suggest that, at age 5, children rely on structural/syntactic information when they process sentences, but that by age 6, children's processing abilities have grown enough that they can use the frequency of particular morphemes in particular constructions to guide sentence processing. However, our results indicate that children's language processing capabilities are not yet adult-like at age 6. In summary, the model we propose is similar to and different from Clahsen and Felser's (2006) model. It is similar in that both models argue that the way children process sentences depends on the resources they can bring to the task. Where the two models appear to differ is that, unlike Clahsen and Felser, we argue that young children process sentences in a qualitatively different way than adults.

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LIST 1 EXPERIMENTAL SENTENCES	**The N**	**was V-ing/ed (by)**	**the N**
1-Act The woman was tickling the man	L+H* L- H%	H+L*	H* L- L%
2-Act The girl was touching the boy	H+L* L- H%	H+L*	L+H* L- L%
3-Psv The man was pushed by the woman.	L+H* L- H%	H+L*	L+H* L- L%
4-Act The boy was sniffing the girl.	H* L-	H* L-	H* L- L%
5-Psv The woman was shoved by the man.	H+L* L- H%	H+L*	H* L- L%
6-Act The girl was pushing the boy.	H* L- L%	H* L-	H* L- L%
7-Psv The man was kissed by the woman.	H* L-	H+L* L-	L+H* L- L%
8-Psv The boy was shoved by the girl.	H+L* L- H%	H+L*	H* L- L%
9-Psv The boy was tickled by the girl.	L+H* H-	H+L* L-	L+H* L- L%
10-Act The girl was kissing the boy.	L+H* L-	H+L* L- H%	L+H* L- L%
11-Psv The man was touched by the woman.	H+L* L- H%	H+L* L- L%	L+H* L- L%
12-Psv The girl was touched by the boy.	L+H* L- H%	H+L* L-	L+H* L- L%
13-Act The man was kissing the woman.	L+H* L- L%	L+H* L-	L+H* L- L%
14-Act The boy was shoving the girl.	H+L* L- H%	L*	H* L- L%
15-Psv The boy was sniffed by the girl.	L+H* L- L%	L+H* L-	L+H* L- L%
16-Act The woman was shoving the man.	H+L* L- H%	H+L*	L+H* L- L%
17-Psv The woman was tickled by the man.	L+H* L-	H+L* L-	H* L- L%
18-Psv The woman was sniffed by the man.	L+H* !H-	H+L*	L+H* L- L%
19-Psv The girl was kissed by the boy.	H+L* H-	H+L* L-	L+H* L- L%
20-Act The man was pushing the woman.	L+H* L- L%	L+H* L-	L+H* L- L%
21-Act The boy was tickling the girl.	H+L* L- H%	H+L*	L+H* L- L%
22-Psv The girl was pushed by the boy.	H+L* L- H%	H+L* L-	L+H* L- L%
23-Act The woman was sniffing the man.	L+H* !H-	H+L* L-	H* L- L%
24-Act The man was touching the woman.	L+H* L- H%	H+L*	L+H* L- L%
LIST 2 EXPERIMENTAL SENTENCES	**The N**	**was V-ing/ed (by)**	**the N**
1-Act The man was tickling the woman	L+H* H-	H+L*	L+H* L- L%
2-Act The boy was touching the girl	L+H* L- H%	H* L- H%	L+H* L- L%
3-Psv The woman was pushed by the man	L+H* L- H%	H+L* L-	L+H* L- L%
4-Act The girl was sniffing the boy	L+H* L- H%	L+H* L- H%	L+H* L- L%
5-Psv The man was shoved by the woman	H+L* L- H%	H+L* H-	L+H* L- L%
6-Act The boy was pushing the girl	H* L- H%	L+H* L- H%	L+H* L- L%
7-Psv The woman was kissed by the man	H+L* L- H%	H+L* L-	H* L- L%
8-Psv The girl was shoved by the boy	H+L* L- H%	H+L*	L+H* L- L%
9-Psv The girl was tickled by the boy	L+H* !H-	H+L* L-	L+H* L- L%
10-Act The boy was kissing the girl	H+L* L- H%	H+L*	L+H* L- L%
11-Psv The woman was touched by the man	H+L* L- H%	H+L* L-	L+H* L- L%
12-Psv The boy was touched by the girl	H+L* L- H%	H+L* L-	L+H* L- L%
13-Act The woman was kissing the man	H+L* L- H%	H+L* H-	L+H* L- L%
14-Act The girl was shoving the boy	H+L* L- H%	H+L*	L+H* L- L%
15-Psv The girl was sniffed by the boy	H* L-	L+H* L-	L+H* L- L%
16-Act The man was shoving the woman	L+H* !H-	L+H* L-	L+H* L- L%
17-Psv The man was tickled by the woman	L+H* !H-	L*	L+H* L- L%
18-Psv The man was sniffed by the woman	L+H* !H-	H+L* L-	L+H* L- L%
19-Psv The boy was kissed by the girl	L+H* L-	L+H* L-	L+H* L- L%
20-Act The woman was pushing the man	L+H* L- L%	L+H* L-	L+H* L- L%
21-Act The girl was tickling the boy	H+L* H-	H+L*	L+H* L- L%
22-Psv The boy was pushed by the girl	L+H* !H-	H+L*	H* L- L%
23-Act The man was sniffing the woman	H+L* L- H%	H+L*	L+H* L- L%
24-Act The woman was touching the man	H+L* L- H%	H+L*	H* L- L%

Appendix: Lists of Experimental Sentences and Their Prosodic Contours