J Psycholinguist Res (2006) 35:531–554
DOI 10.1007/s10936-006-9028-5

ORIGINAL PAPER

Development of Lexical and Sentence Level Context Effects for Dominant and Subordinate Word Meanings of Homonyms

James R. Booth · Yasuaki Harasaki · Douglas D. Burman

Published online: 12 October 2006

Abstract Nine-ten-and twelve-year-old children ($N = 75$) read aloud dominant, subordinate or ambiguous bias sentences ($N = 120$) that ended in a homonym (BALL). After the sentence (1,000 ms), children read aloud targets that were related to the dominant (BAT) or subordinate (DANCE) meaning of the homonym or control targets. Participants were also divided into three reading skill groups based on an independent measure of single word oral reading accuracy. There were three main developmental and reading skill findings. First, 9-year-olds and low skill readers showed lexical level facilitation in accuracy. Second, 9- and 10-year-olds or low and moderate skill readers showed lexical level facilitation in reaction time. Third, 12-year-olds or high skill readers showed sentence level facilitation in reaction time with high skill readers additionally showing sentence level inhibition in reaction time. These results show that lexical level context effects decreased and that sentence level context effects increased with development and skill. These results are discussed in terms of connectionist models of visual word recognition that incorporate distributed attractor principles.

Keywords Homonyms · Development · Semantic · Context

Introduction

Developmental and Reading Skill Differences in Sentence Context Effects

One of the most reliable findings in the literature on individual differences in lexical processing is that younger or less skilled readers show greater priming than older or

J. R. Booth (✉) · Y. Harasaki · D. D. Burman
Department of Communication Sciences and Disorders,
Northwestern University,
2240 Campus Drive,
Evanston, IL, 60208, USA
e-mail: j-booth@northwestern.edu

more skilled readers for target words following biasing sentences (Perfetti, Goldman, & Hogaboam, 1979, Schwantes, 1981a, 1982). However, most of these studies have confounded lexical level and sentence level context effects, because their sentences contained individual words that were associated with the target words. Table 1 presents example sentences from 10 different studies and shows that the mean forward association value (between one word in the sentence and the target) across studies was .25 and the mean backward association value was .18 (Nelson et al., 1998). All studies, except one, had either a forward or backward free association value above .02. However, it is difficult to fully evaluate these studies because only Raduege and Schwantes (1987) included all stimuli to allow for a complete analysis of the free association values. An analysis of the Raduege and Schwantes (1987) study, that seems to be representative of other studies in the literature, revealed average forward ($M = .14 : SD = 1.00$; range = 0–1.00) and backward ($M = .13 : SD = .21$, range = 0–.80) association values that were quite high. Although developmental research has not separately examined sentence and lexical level priming, one study with adults showed that a sizeable portion of the sentence level context effect can be accounted for by lexical level priming (West & Stanovich, 1988).

Developmental Differences in Homonym Processing

Homonyms are words that have the same written and spoken form, but have ambiguous meanings as in EAR that can refer to OF A BODY or OF CORN (Crystal, 1992). Earlier models of lexical ambiguity focused on the question of whether access to word meaning was modular or interactive. Modular models argued that all meanings of a word are immediately accessed (Kintsch & Mross, 1985, Swinney, 1979; Tanenhaus, Lieman, & Seidenberg, 1979), whereas interactive models argued that only the meaning consistent with context are accessed (Glucksberg, Kreuz, & Rho, 1986, Simpson, 1981, Van Petten & Kutas, 1987). More recent research has supported interactive models by showing that context can bias the reader's access to the dominant and

Table 1 Sentence contexts with sentence final targets and the forward (F) and backward (B) free association value between a word (underlined) in the sentence context and the target

Sentence	F	B	Citation
The *dog* ran after the—cat	.67	.51	(West & Stanovich, 1978)
Every *fox* had a white tip on its—tail	.02	.00	(Schwantes, Boesl, & Ritz, 1980)
I was very *tired* so I went to—sleep	.48	.09	(Schwantes, 1981b)
The *pilot* flew the—plane	.73	.00	(Stanovich, West, & Freeman, 1981)
Drop off a load at the *garbage*—dump	.00	.33	(Perfetti & Roth, 1981)
Rowboats are tossed up onto the—rocks	.00	.00	(West, Stanovich, Freeman & Cunningham, 1983)
The *dog* ate the—bone	.00	.26	(Briggs, Austin, & Underwood, 1984)
The *farmer* planted the—corn	.03	.00	(Stanovich, Nathan, West & Vala-Rossi, 1985)
Out in the *rain* he got cold and—wet	.24	.08	(Schwantes, 1985)
He jumped in his *car* and away he—drove	.12	.48	
The door was *locked* so I used my—key	0.41	0.26	(Raduege and Schwantes, 1987)

subordinate meanings of homonyms (Simpson & Krueger, 1991, Vu, Kellas, Metcalf, & Herman, 2000, Vu et al., 1998). However, the nature of the interaction depends on the relative frequency of homonym meanings and the strength of the biasing context (Dixon & Twilley, 1999, Duffy, Morris, & Rayner, 1988, Hogaboam & Perfetti, 1975, Martin, Vu, Kellas, & Metcalf, 1999, Neill, Hilliard, & Cooper, 1988, Twilley & Dixon, 2000).

Children as young as 3 years old have the metalinguistic skills necessary to identify homonym pairs and realize that homonyms represent two different categories (Backscheider & Gelman, 1995). However, the development of knowledge about polysemous words with many meanings continues throughout childhood (Booth & Hall, 1995, Booth, Hall, Robinson, & Kim, 1997). The development of lexical access of homonyms is important to study because knowledge of polysemous words in older children has been shown to be related to better conservation skills (Cramer, 1983), mathematical problem solving (Durkin & Shire, 1991) and reading comprehension (Booth & Hall, 1994). Although knowledge of polysemous words has been demonstrated to be important in cognitive development, the number of studies that have examined developmental differences in the effect of context on processing of dominant and subordinate homonyms is limited. Only three studies have examined naming latency and accuracy to written targets following homonyms (Marmurek and Rossi, 1993, Simpson and Forster, 1986; Simpson, Krueger, Kang, & Elofson, 1994).

Simpson and Forster (1986) presented 8-, 10- and 12-year-olds with written homonym primes (BARK) that were followed by written targets that were related to either the dominant (DOG) or subordinate (TREE) meaning of the homonym. They compared naming latencies to targets following homonym primes to naming latencies to targets following neutral primes (------) and unrelated primes (BOWL) in order to measure facilitation versus inhibition. They also examined the time course of activation by manipulating the duration between prime and target (150, 300 and 700 ms stimulus-onset-asynchrony: SOA). At short SOA, there was little evidence for facilitation or inhibition for any age group. At medium SOA, 10- and 12-year-olds showed facilitation for dominant and subordinate meanings; however, 8-year-olds showed facilitation for only dominant meanings. At long SOA, 8- and 10-year-olds showed facilitation for both dominant and subordinate meanings; however, 12-year-olds showed facilitation for dominant meanings and inhibition for subordinate meanings. The results at the medium and long SOA show that 8-year-olds activate dominant meanings early and subordinate meanings later, that 10-year-olds activate both meanings early, and that 12-year-olds activate both meanings early and then inhibit the subordinate meaning later. These results suggest that development is associated with more selective activation of homonym meanings. Because Simpson and Forster (1986) used single homonyms as primes, there was no context to bias the subordinate or dominant meaning.

Marmurek and Rossi (1993) presented 10- and 12-year-olds with spoken neutral sentences (IT WAS A DECK), or with spoken riddles (WHY COULDN'Y ANYBODY PLAY POKER ON THE ARK? BECAUSE NOAH SAT ON THE DECK) that biased both the dominant and subordinate meanings of sentence final homonyms. They measured facilitation by comparing the naming latency of written target words that were neutral (PRESS) to the naming latency of target words related to either the dominant (PORCH) or subordinate (CARDS) meaning of the homonyms. All target words were presented 500 ms after the onset of the homonym. They found that 12-year-olds showed facilitation for both dominant and subordinate targets following riddle sentences, but only for dominant targets following neutral sentences. In contrast, 10-year-olds showed facilitation for both dominant and subordinate targets following both riddle and neutral sentences. This study suggests that both 10- and 12-year-olds activate the multiple meanings of homonyms in riddle sentences that bias both dominant and subordinate meanings, but 12-year-olds only activate the dominant meaning of homonyms in neutral sentences. As with Simpson and Forster (1986), the results of this study suggest a more selective activation of homonym meanings in a non-biasing context.

Simpson et al. (1994) also examined context effects by asking 9- and 12-year-olds to read aloud written sentences that biased either the dominant meaning (I WAS SCARED BY HIS VERY LOUD) or the subordinate meaning (I SCRATCHED MY HAND ON THE ROUGH) of sentence final homonyms (BARK). They measured naming latency to dominant (DOG) or subordinate targets (TREE) that followed these sentences at different SOA (0, 300, 700 ms). Regardless of SOA, they found that 9-year-olds showed facilitation for dominant targets following dominant bias sentences and for subordinate targets following subordinate bias sentences. In contrast, 12-year-olds showed facilitation for dominant targets following dominant bias sentences, but not for subordinate targets following subordinate bias sentences. Neither age group showed reliable facilitation for the contextually inappropriate target conditions (subordinate targets following dominant bias sentences or dominant targets following subordinate bias sentences). Because the Simpson et al. (1994) study did not use ambiguous sentences as a baseline, relative statements about facilitation and inhibition cannot be made.

In summary, the developmental work on homonym processing suggests that dominant contexts or meanings consistently produce facilitation, whereas the effects for subordinate contexts or meanings depend on age. Older children are more sensitive than younger children to relative frequency of homonym meanings (Marmurek & Rossi, 1993, Simpson & Forster, 1986, Simpson et al. 1994). Furthermore, the single word priming study suggest that inhibition does not appear until later in development at about 12 years of age (Simpson and Forster, 1986).

Reading Skill Differences in Homonym Processing

Research on the relation of individual differences in comprehension skill to homonym processing is broadly consistent with the developmental differences summarized above (Gernsbacher & Faust, 1991, Gernsbacher, Varner, & Faust, 1990). Gernsbacher et al. (1990) presented adults with biasing sentences on a computer screen (HE DUG WITH THE) that contained a sentence final homonym (SPADE) or an unambiguous word (SHOVEL). These sentences were followed by a visual target word that was related to the homonym (ACE) but not to the unambiguous word. At short SOA (100 ms), all participants were slower to decide that a target was unrelated to the meaning of a sentence with a homonym than to the meaning of a sentence with an unambiguous word. This suggests that the all meanings of the homonym were activated at short SOA regardless of comprehension skill. However, at long SOA (850 ms), only lower skill comprehenders were slower at deciding that a target was unrelated to the meaning of a sentence with a homonym. This suggests that lower skill comprehenders were not capable of inhibiting the homonym meaning inconsistent with the sentence context.

In a subsequent experiment, Gernsbacher and Faust (1991) presented adults with visual sentences that had a biasing context (HE DUG WITH THE SPADE) or a neutral context (HE PICKED UP THE SPADE). These sentences were followed by target words related to the sentence final homonyms (GARDEN). At both short (100 ms) and long (1,000 ms) SOAs, lower skill comprehenders showed greater facilitation for biasing context than higher skill comprehenders. These studies suggest that lower skill participants activate all meanings of a homonym and are less able to inhibit (or not activate) meanings that are inconsistent with sentence context. However, as with the developmental studies described above, sentence level and context level effects were not separated in these reading skill studies, so the locus of the context effect is unclear.

Specific Aims of Current Study

The specific aim of this study was to determine whether there are developmental and reading skill differences in the role of lexical and sentence level context in the processing of homonyms. Previous research has provided most support for an interactive model suggesting that previous context can influence homonym processing, but that it depends on a variety of factoring including the frequency of the homonym meanings and the strength of the biasing context. In the current study, we presented children (9- to12-year-olds) with dominant, subordinate and ambiguous biasing written sentences that ended in polarized homonyms (see Table 2)with a more frequent dominant meaning and a less frequent subordinate meaning (Twilley et al., 1994). We measured accuracy and naming latency to related targets that were presented after the homonyms and that were associated with the dominant or subordinate meaning of the homonyms. We compared reaction time of the related targets to control targets that were matched for stimulus characteristics. A long SOA (1,000 ms) between the homonym and target was chosen to allow ample time for both facilitation and inhibition to operate as demonstrated by previous studies examining the effect of reading skill (Gernsbacher & Faust, 1991; Gernsbacher et al., 1990) and developmental level (Simpson & Forster, 1986) on homonym processing.

As reviewed earlier, previous developmental and reading skill studies have confounded lexical and sentence level context effects. In order to avoid this, we did not include any words within the sentences that had a free association value greater than .02 with the target words. Therefore, we could examine the effect of the sentence context (THE GOAT'S FAVORITE FOOD WAS) on processing of the target (WHEAT or SAND) separately from the association between the sentence final homonym (GRAIN) and target. Furthermore, previous studies that have examined developmental differences in context effects on homonym processing have not used ambiguous bias sentences (Simpson et al., 1994), so lexical versus sentence level context effects have not been examined. In our study, lexical level facilitation was defined as no

Table 2 Example of the dominant, subordinate and ambiguous sentences with their related target and control targets

		Target type	
		Related	Control
Dominant	The refrigerator needed a new bulb	Light	Month
Subordinate	The father planted the bulb	Flower	Driver
Ambiguous	The mother needed a bulb		

significant difference in facilitation (related versus control target) between ambiguous bias sentences and dominant or subordinate bias sentences. Sentence level facilitation was defined as significantly greater difference between related target (and consistent with sentence context) and control target for biasing sentences (dominant or subordinate) as compared to ambiguous sentences. Sentence level inhibition was defined as significantly smaller difference between related target (and inconsistent with sentence context) and control target for biasing sentences (dominant or subordinate) as compared to ambiguous sentences.

We had two primary predictions based on previous research. First, younger or lower skill readers should show greater lexical level facilitation than older and higher skill readers (see Table 1). Second, older or higher skill readers should show greater sentence level inhibition than younger or lower skill readers (Gernsbacher & Faust, 1991; Gernsbacher et al., 1990; Simpson & Forster, 1986).

Methods

Participants

Participants were divided into the following age groups: 9-year-olds, 10-year-olds and 12-year-olds (see Table 3). The children came from private and parochial elementary schools in the Pittsburgh metropolitan area. All children were native English speakers with normal hearing and normal or corrected to normal vision. Informed consent was obtained from all participants.

Materials

Pilot Experiment

We designed a questionnaire of 207 sentences that included 69 dominant, 69 subordinate and 69 ambiguous bias sentences for 69 homonyms. Each homonym was used in all three sentence types. For the questionnaire, the sentences were put into three groups, with an equal number of dominant, subordinate and ambiguous bias sentences in each group. Within any of the three groups of sentences, the homonym was not repeated and the sentences were randomly presented. After each sentence, there was a scale from −4 to 0 to +4 with dominant and subordinate sense target words at the ends of the scale. Fifty percent of items had the dominant target at the −4 end and the subordinate target at the +4 end of the scale. Fifty percent of the items had the subordinate target at the −4 end and the dominant target at the +4 end of the

Table 3 Means and standard deviations for age and reading skill (percentage correct) for the three age groups

	9-year-olds ($N = 25$)	10-year-olds ($N = 25$)	12-year-olds ($N = 25$)
Age	8.8 (.5)	10.1 (.3)	12.0 (.7)
Word identification	58.5 (11.0)	63.7 (7.9)	76.0 (7.5)
Exception words	44.6 (17.3)	59.1 (12.4)	79.7 (12.0)

Note: see text for details on single word oral reading measures scale. The participants were instructed that each of the target words was related to the homonym at the end of the sentence. They were asked to mark a number indicating which meaning of the word seemed most compatible with the homonym in the context of the sentence: −4 for more compatible with the word on the left, 0 for ambiguous and +4 for more compatible with the word on the right.

In the first pilot experiment, we had 5 adult participants complete the questionnaire. We then revised the dominant and subordinate bias sentences that did not have a mean score greater than the absolute value of 3 in order to make them more biasing. We also revised the ambiguous bias sentences that did not have a mean score less than the absolute value of 2 in order to make them more neutral. In the second pilot experiment, we had 10 adult participants complete the questionnaire. Our criteria for inclusion in the final stimulus list was a mean score greater than the absolute value of 3 for the dominant and subordinate bias sentences and a mean score less than the absolute value of 2 for the ambiguous bias sentences.

Experimental Stimulus List

The pilot experiment resulted in 60 homonyms for the final stimulus list. Word frequencies per million were calculated from The Educator's Word Frequency guide that contains over 16 million words in the 3rd–6th grades (The Educator's Word Frequency Guide, 1996). Word frequency ranged from 0 to 127 for homonyms ($M = 16.7; SD = 26.9$). The likert ratings from the pilot study clearly showed that the 60 dominant sentences ($M = 3.88; SD = .19$; range = 3.11–4.00) and 60 subordinate sentences ($M = 3.83; SD = .24$; range = 3.11–4.00) were biasing and that the 60 ambiguous sentences ($M = -.13; SD = .88$; range = −2.00–1.67) were neutral. Negative values for ambiguous sentences indicate that these sentences were slightly more dominant biasing.

There was a dominant and subordinate related target for each sentence final homonym. There were higher free association values between the sentence final homonym and the related targets (Twilley et al., 1994) for dominant bias sentences ($M = 0.73; SD = 0.11$; range = .50–.93) than for subordinate bias sentences ($M = .16; SD = .10$; range = .02–.40). Notice that the distribution of the free association values for dominant and subordinate related targets did not overlap. In addition, individual words in sentences did not have a free association value greater than .02 with the related or control targets, so sentence context effects cannot be attributed to lexical level overlap (Nelson et al., 1998).

Each related target had a control target that was matched to it on several variables. The word frequency for the 60 dominant related targets ($M = 47.6; SD = 105.2$) was not significantly different than for the 60 control targets ($M = 28.3; SD = 41.6; t(59) = 1.60, P = .114$). In addition, the word frequency for the 60 subordinate related targets ($M = 34.2; SD = 73.6$) was not significantly different that for the 60 control targets ($M = 21.5; SD = 28.8; t(59) = 1.65, P = .105$). We used different control targets for the dominant and subordinate related targets, so that the control targets were more closely matched to the related targets in word frequency. We realize that there is a trend for a difference in the frequency for the related and control targets. However, the ratio of the frequency for the related and control targets is similar for the subordinate targets (63%) and for the dominant targets (59%). The letter length for dominant related targets was not significantly different than for control targets. Because each pair was matched exactly in length, a t-test could not be computed. In addition, the letter length for subordinate related targets ($M = 4.76; SD = 1.21$) was not significantly different that for control targets ($M = 4.80; SD = 1.25; t(59) = 1.42., P = .15$). The number of syllables for dominant related targets ($M = 1.26; SD = .51$) was not significantly different than for control targets ($M = 1.33; SD = .54; t(59) = 1.27, P = .29$). In addition, the number of syllables for subordinate related targets ($M = 1.35; SD = .54$) was not significantly different that for control targets ($M = 1.38; SD = .64; t(59) = .53, P = .59$). The baseline naming latency for the single syllable dominant related targets ($M = 455; SD = 17.2$) was not significantly different than for control targets ($M = 459; SD = 15.5; t(30) = .84, P = .40$). In addition, the baseline naming latency for the single syllable subordinate related targets ($M = 460; SD = 16.4$) was not significantly different that for control targets ($M = 465; SD = 15.3; t(29) = 1.26, P = .21$) (Spieler & Balota, 2001).

In order to determine if the distribution of sentence structures was similar across conditions, we calculated the frequency of phrase types that contained the homonym (prepositional phrase, noun phrase, adjectival phrase and noun phrase), the semantic role of the homonym (goal, theme, instrument, agent, manner, temporal recipient, source), the number of clauses in the sentence (1, 2, 3), the number of subjects in the sentence (1, 2) and the number of verb arguments (1, 2, 3). The distributions of these structures were similar across conditions. Most of the homonyms were in prepositional or noun phrases (95%), most of the sentences were one or two clauses (98%), most of the sentences contained one subject (97%), most of the homonyms played a thematic role (76%), and most of the sentences contained verbs with one or two arguments (96%). Even if there were differences across conditions, this should not influence the results because each target type (dominant related, dominant control, subordinate related, subordinate control) followed each sentence in the three conditions.

Counterbalancing

Each sentence type (dominant, subordinate, ambiguous) had four potential targets (dominant related, dominant control, subordinate related, subordinate control) so there were 12 counterbalancing lists. In each counterbalancing list, there was only one sentence type for a particular homonym. Furthermore, there were an equal number (5) of homonyms per sentence and target type. Because 5 items per condition would not allow for a reliable subject analysis, each participant was administered two counterbalancing lists. These lists were administered at least one month apart in order to limit any potential practice effects. Participants were administered the same homonyms in the second session; however, these homonyms did not have the same sentence biasing context or the same target as in the first session. An analysis of variance including session as an independent variable revealed no main effect of session or interactions involving session, so all data was collapsed across session.

Reading Skill Measures

Two reading skill measures were administered to all participants: Word Identification Test and Exception Word Task. The Word Identification Test contained 96 items and was from the Woodcock Reading Mastery Test—Revised (Woodcock, 1987). Test administration was stopped when the participant pronounced six consecutive words incorrectly. Each participant was also administered an Exception Word Task (Adams

& Huggins, 1985) which required them to read aloud 45 exception words. Participants were administered all of the words for this task. These tasks were chosen as the measure of reading skill for our study because the experimental task required reading aloud.

Procedure

All materials administered to the participants were presented on identical 15 Multi-Scan Macintosh monitors (800 × 600 resolution) controlled by a PowerPC Macintosh desktop computer. All tasks were presented with PsyScope (Cohen, MacWhinney, Flatt, & Provost, 1993) which allowed for the collection of accuracy and reaction time data. A voice key on a button box detected the naming response and naming latency was calculated relative to the onset of the target stimulus. For each trial, the experimenter entered via a keyboard whether the participant's pronunciation was correct, incorrect or did not trigger the button box appropriately.

Before the practice (6 sentences) and test trials, the participant was read directions that were also presented on the computer screen. The experimenter emphasized that the participant should read each sentence for understanding and that they should clearly read each sentence out loud. Participants were also asked to read the target word as quickly as possible without making any mistakes. The participant could control when each sentence was presented by pressing a yellow button on a button box. Pressing the button caused a "Get Ready" sign in the center of the screen to disappear and a plus (+) to appear on the left side of the screen. The participant was asked to look at the plus. After 1,000 ms, the entire sentence was presented on one line (16-point courier) with the first letter of the sentence replacing the cross on the screen. Participants were asked to immediately begin reading the sentence aloud. When the participant finished reading the final word of the sentence (the homonym), the sentence disappeared and the target word to appeared after 1,000 ms. The target word appeared one space after the last word of the sentence. The voice key on the button box detected the voice of the participant and erased the target from the screen. This caused a "Get Ready" sign to appear on the screen for the next trial.

The experimenters triggered the target word by pressing a button when they judged that the word was fully pronounced. Because we were concerned that the experimenters may have been variable in their response we compared reaction time of the experimenters to our coding of the oral reading of the sentences by the participants. All participants reading was digitally recorded time locked to stimulus onset. We separately had two people code the duration of the sentence reading based on the amplitude waveforms and then compared their average to the experimenters' reaction time. On average, the experimenters were 13 ms slower than the participants reading time, but importantly this did not significantly differ between the dominant, subordinate and ambiguous experimental conditions.

Results

Design

The dependent measures were accuracy and reaction time for correct responses on the sentence task. The three within-item variables were sentence bias (dominant, subordinate, ambiguous), target type (dominant, subordinate) and target relatedness (related, control). The two between-subject variables included age group (9-year-olds, 10-year-olds, 12-year-olds) and reading skill group (low, moderate, high).

The following analyses of variance (ANOVAs) were used for accuracy and reaction time. (1) Sentence bias (dominant, ambiguous) by dominant target type (related, control) to examine *facilitation* by dominant sentences relative to ambiguous sentences. (2) Sentence bias (dominant, ambiguous) by subordinate target type (related, control) to examine *inhibition* by dominant sentences relative to ambiguous sentences. (3) Sentence bias (subordinate, ambiguous) by subordinate target type (related, control) to examine *facilitation* by subordinate sentences relative to ambiguous sentences. (4) Sentence bias (subordinate, ambiguous) by dominant target type (related, control) to examine *inhibition* by subordinate sentences relative to ambiguous sentences. This analysis approach was used in order to examine both lexical and sentence level context effects. In each of these ANOVAs, lexical level facilitation should produce a main effect of target type, whereas sentence level facilitation or inhibition should produce an interaction between sentence bias and target type. For example, sentence level facilitation should produce a larger difference between dominant and control targets for dominant bias sentences compared to ambiguous bias sentences, whereas inhibition should produce a smaller difference between subordinate and control targets for dominant bias sentences compared to ambiguous bias sentences. These analyses were done separately for each age group or reading skill group. We calculated separate analyses for each group because of the well established developmental and skill differences in processing speed (Kail, 1993, Kail & Hall, 1994). Both item (F_1) and subject (F_2) statistics are presented.

Data Trimming

For all participants, responses were considered missing data if reaction times were less than 200 ms or greater than 4,000 ms (<1% items). Reaction times outside of this range were discarded because they were likely to result from inappropriate voice detection (low reaction time) or distraction (high reaction time), and not from lexical processing. Reaction times were also considered missing data if the participant did not read the homonym correctly on the first try (<1% items) because target word processing would not accurately indicate the time course of meaning activation for the homonyms. After this procedure, reaction time to items that were greater or less than 2.5*SD* from the mean for the dominant, subordinate or ambiguous bias sentences were truncated to 2.5*SD* above or below the mean for that condition for that participant (<2% items). The truncating was done separately for dominant and subordinate targets and their control conditions.

Reaction Time within Age Groups

Table 4 presents reaction time data for dominant, subordinate and ambiguous bias sentences for the age groups. Main effects analysis of *dominant* bias sentences revealed lexical level facilitation among 9-year-olds for both dominant targets [$F_1(1,239) = 8.66, P < .01; F_2(1,99) = 4.77, P < .05$] and subordinate targets [$F_1(1,239) = 5.54, P < .05; F_2(1,99) = 4.27, P < .05$]. Lexical level facilitation was also observed among 10-year-olds for both dominant targets [$F_1(1,239) = 26.86, P < .001; F_2(1,99) = 7.68, P < .01$] and subordinate targets [$F_1(1,239) = 5.97, P < .05; F_2(1,99) = 4.23,$

Table 4 Item means and standard errors (±1) for reaction time (ms) for the 9-, 10- and 12-year-olds

Bias	Dominant		Subordinate		Ambiguous	
9-year-olds						
Subordinate	872	(64)	785	(36)	787	(34)
Control	903	(49)	917	(53)	900	(52)
Dominant	791	(42)	782	(36)	761	(33)
Control	865	(60)	923	(61)	864	(43)
10-year-olds						
Subordinate	686	(22)	676	(31)	673	(20)
Control	719	(29)	748	(28)	727	(33)
Dominant	647	(18)	665	(20)	672	(23)
Control	736	(26)	727	(32)	734	(21)
12-year-olds						
Subordinate	654	(18)	599	(15)	654	(12)
Control	658	(18)	690	(19)	682	(20)
Dominant	606	(16)	662	(24)	619	(13)
Control	690	(16)	669	(20)	649	(17)

$P < .05$]. Neither 9– or 10-year-olds showed significant interactions between sentence bias and target type, thus failing to demonstrate sentence level effects. For 12-year-olds, main effects analysis revealed that lexical level facilitation was limited to dominant targets [$F_1(1,239) = 27.69, P < .001; F_2(1,99) = 14.99, P < .001$]. Furthermore, there was a significant interaction between sentence bias and target type [$F_1(1,239) = 7.06, P < .01; F_2(1,99) = 4.56, P < .05$] for dominant targets representing sentence level facilitation for the 12-year-olds. However, there was not a significant interaction for subordinate targets, representing the absence of a sentence level inhibitory effect for the 12-year-olds [$F_1(1,239) = .73, P = .39; F_2(1,99) = .24, P = .62$].

The results for subordinate bias sentences followed a similar pattern as for dominant bias sentences. Main effects analysis of *subordinate* bias sentences revealed lexical level facilitation among 9-year-olds for both subordinate targets [$F_1(1,239) = 17.39, P < .001; F_2(1,99) = 5.21, P < .05$] and dominant targets [$F_1(1,239) = 16.99, P < .001; F_2(1,99) = 5.92, P < .05$]. Lexical level facilitation was also observed among 10-year-olds for both subordinate targets [$F_1(1,239) = 11.18, P < .01; F_2(1,99) = 5.47, P < .05$] and dominant targets [$F_1(1,239) = 15.11, P < .001; F_2(1,99) = 6.33, P < .05$]. Neither 9- nor 10-year-olds showed significant interactions between sentence bias and target type, thus failing to demonstrate sentence level effects. For 12-year-olds, main effects analysis revealed that lexical level facilitation was limited to subordinate targets [$F_1(1,239) = 34.92, P < .001; F_2(1,99) = 15.69, P < .001$]. Furthermore, there was a significant interaction between sentence bias and target type [$F_1(1,239) = 5.49, P < .05; F_2(1,99) = 4.22, P < .05$] for subordinate targets representing sentence level facilitation for the 12-year-olds. However, there was not a significant interaction for dominant targets, representing the absence of a sentence level inhibitory effect for the 12-year-olds [$F_1(1,239) = 1.56, P = .21; F_2(1,99) = .72, P = .39$].

Accuracy within Age Groups

Table 5 presents percentage error data for dominant, subordinate and ambiguous bias sentences for the age groups. Main effects analysis of *dominant* bias sentences revealed

Table 5 Item means and standard errors (±1) for % errors for the 9-, 10- and 12-year-olds

Bias	Dominant		Subordinate		Ambiguous	
9-year-olds						
Subordinate	1.7	(1.3)	2.4	(1.9)	.6	(.7)
Control	8.2	(4.4)	6.5	(3.9)	9.0	(3.6)
Dominant	3.1	(2.1)	5.6	(3.5)	4.1	(3.0)
Control	10.2	(4.4)	12.5	(4.2)	7.7	(2.0)
10-year-olds						
Subordinate	2.7	(1.7)	.4	(.5)	5.3	(2.2)
Control	4.6	(3.0)	1.7	(1.2)	6.9	(3.7)
Dominant	3.3	(2.8)	.2	(.3)	3.2	(2.1)
Control	2.5	(1.7)	3.5	(1.8)	3.8	(1.8)
12-year-olds						
Subordinate	1.2	(1.0)	1.1	(1.1)	1.6	(1.2)
Control	.7	(.8)	1.0	(1.1)	1.8	(1.2)
Dominant	1.7	(1.3)	.9	(1.0)	2.0	(1.3)
Control	1.7	(1.4)	1.5	(1.3)	1.1	(1.0)

lexical level facilitation among 9-year-olds for both dominant targets [$F_1(1, 239) = 7.44, P < .01; F_2(1, 99) = 9.26, P < .01$] and subordinate targets [$F_1(1, 239) = 15.39, P < .001; F_2(1, 99) = 13.58, P < .001$]. Significant lexical level facilitation for dominant bias sentences was not seen for the two older age groups. In addition, there were no significant interactions between sentence bias and target type within any age group, thus failing to demonstrate sentence level effects.

Main effects analysis of *subordinate* bias sentences revealed lexical level facilitation among 9-year-olds for both dominant targets [$F_1(1, 239) = 6.20, P < .05; F_2(1, 99) = 14.68, P < .001$] and subordinate targets [$F_1(1, 239) = 11.36, P < .01; F_2(1, 99) = 13.72, P < .001$]. Significant lexical level facilitation for subordinate bias sentences was not seen for the two older age groups. In addition, there were no significant interactions between sentence bias and target type within any age group, thus failing to demonstrate sentence level effects.

Reaction Time within Reading Skill Groups

In the reading skill analyses, we used the combined mean of the Word Identification Test and Exception Word Task as the reading skill measure because they were significantly correlated [$r(74) = .88, P < .001$]. We formed three groups (low, moderate, high) based on this combined reading skill measure so that there were 25 participants in each group. A combined measure was used because these measures were highly correlated and a greater number of items should provide a more reliable measure of reading skill. Reading skill analyses are likely to result in similar results as age group analyses because age was significantly correlated with the Word Identification Test [$r(74) = .70, P < .001$] and with the Exception Word Task [$r(74) = .78, P < .001$]. Furthermore, there were mostly 9-year-olds in the low reading skill group (19 9-year-olds and 6 10-year-olds), mostly 10-year-olds in the moderate reading skill group and (4 9-year-olds, 16 10-year-olds and 5 12-year-olds), and mostly 12-year-olds in the high reading skill group (2 9-year-olds, 3 10-year-olds and 20 12-year-olds). However, reading skill may be more related to inhibition because, as discussed in the introduction, past research has suggested a relation between comprehension skill and inhibitory processes in reading (Gernsbacher and Faust, 1991; Gernsbacher et al., 1990).

Table 6 presents reaction time data for dominant, subordinate and ambiguous bias sentences for the reading skill groups. Main effects analysis of *dominant* bias sentences revealed lexical level facilitation among low skill readers for both dominant targets [$F_1(1,239) = 17.51, P < .001; F_2(1,99) = 5.25, P < .05$] and subordinate targets [$F_1(1,239) = 11.03, P < .01; F_2(1,99) = 4.43, P < .05$]. Lexical level facilitation was also observed among moderate skill readers for both dominant targets [$F_1(1,239) = 23.04, P < .001; F_2(1,99) = 10.33, P < .001$] and subordinate targets [$F_1(1,239) = 11.60, P < .01; F_2(1,99) = 4.01, P < .05$]. Neither low or moderate skill readers showed significant interactions between sentence bias and target type, thus failing to demonstrate sentence level effects. For high skill readers, main effects analysis from dominant bias sentences revealed that facilitation was limited to dominant targets [$F_1(1,239) = 43.60, P < .001; F_2(1,99) = 15.97, P < .001$]. Furthermore, interactions for dominant bias sentences revealed that high skill readers showed sentence level facilitation for dominant targets [$F_1(1,239) = 6.38, P < .05; F_2(1,99) = 4.28, P < .05$] and sentence level inhibition for the subordinate targets [$F_1(1,239) = 8.22, P < .05; F_2(1,99) = 4.86, P < .05$]. Figure 1 shows the sentence level facilitation and inhibition in reaction time for the low, moderate and high skill readers.

The results for subordinate bias sentences followed a similar pattern as for dominant bias sentences. Main effects analysis of *subordinate* bias sentences revealed lexical level facilitation among low skill readers for both subordinate targets [$F_1(1,239) = 19.10, P < .001; F_2(1,99) = 5.85, P < .05$] and dominant targets [$F_1(1,239) = 18.05, P < .001; F_2(1,99) = 7.06, P < .01$]. Lexical level facilitation was also observed among moderate skill readers for both subordinate targets [$F_1(1,239) = 20.97, P < .001; F_2(1,99) = 7.65, P < .01$] and dominant targets [$F_1(1,239) = 15.18, P < .001; F_2(1,99) = 7.44, P < .01$]. Neither low or moderate skill readers showed significant interactions between sentence bias and target type, thus failing to demonstrate sentence level effects. For high skill readers, main effects analysis from

Table 6 Item means and standard errors (±1) for reaction time (ms) for low, moderate and high skill readers

Bias	Dominant		Subordinate		Ambiguous	
Low skill						
Subordinate	860	(41)	806	(33)	816	(35)
Control	948	(51)	955	(56)	925	(51)
Dominant	779	(31)	798	(32)	790	(46)
Control	907	(59)	928	(56)	908	(41)
Moderate skill						
Subordinate	683	(22)	660	(28)	666	(20)
Control	723	(25)	750	(28)	724	(20)
Dominant	649	(17)	663	(17)	668	(22)
Control	721	(20)	714	(22)	721	(18)
High skill						
Subordinate	629	(18)	572	(12)	610	(12)
Control	634	(17)	667	(16)	662	(21)
Dominant	576	(13)	632	(17)	590	(12)
Control	657	(16)	636	(16)	632	(15)

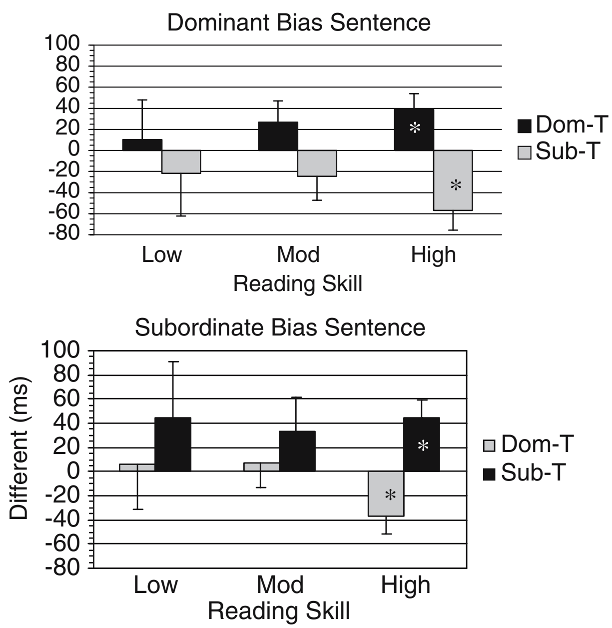

Fig. 1 Sentence level facilitation and inhibition (in reaction time) for the low, moderate and high skill readers. Sentence level facilitation (positive difference score in ms) was defined as faster reaction time for related targets, as compared to control targets, following dominant bias or subordinate bias sentences as compared to ambiguous bias sentences. Sentence level inhibition (negative difference score in ms) was defined as *slower* reaction time for related targets, as compared to control targets, following dominant bias or subordinate bias sentences as compared to ambiguous bias sentences. Only the high skill readers showed significant sentence level facilitation and inhibition in reaction time ($*, P < .05$)

subordinate bias sentences revealed that facilitation was limited to subordinate targets [$F_1(1, 239) = 48.98, P < .001; F_2(1, 99) = 19.54, P < .001$]. Furthermore, interactions for subordinate bias revealed that high skill readers showed sentence level facilitation for subordinate targets [$F_1(1, 239) = 6.04, P < .05; F_2(1, 99) = 4.57, P < .05$] and sentence level inhibition for dominant targets [$F_1(1, 239) = 5.33, P < .05; F_2(1, 99) = 4.64, P < .05$].

Accuracy within Reading Skill Groups

Table 7 presents percentage error data for dominant, subordinate and ambiguous bias sentences for the reading skill groups. Main effects analysis of dominant bias sentences revealed lexical level facilitation among low skill readers for both dominant targets [$F_1(1, 239) = 14.25, P < .001; F_2(1, 99) = 13.31, P < .001$] and subordinate targets [$F_1(1, 239) = 7.36, P < .01; F_2(1, 99) = 10.31, P < .01$]. Significant lexical level facilitation of accuracy for dominant bias sentences was not seen for the moderate or high skill readers. In addition, there were no significant interactions between sentence bias and target type within any reading skill group, thus failing to demonstrate sentence level effects. Figure 2 shows the sentence level facilitation and inhibition in accuracy for the low, moderate and high skill readers.

Table 7 Item means and standard errors (±1) for reaction time (ms) for low, moderate and high skill readers

Bias	Dominant		Subordinate		Ambiguous	
Low skill						
Subordinate	4.2	(2.1)	1.9	(1.7)	3.8	(2.1)
Control	8.9	(4.6)	7.1	(4.1)	11.6	(4.6)
Dominant	1.6	(1.2)	4.7	(3.2)	3.5	(2.3)
Control	7.4	(3.3)	10.8	(3.6)	9.8	(2.6)
Moderate skill						
Subordinate	.9	(.8)	.7	(.7)	3.3	(1.7)
Control	3.7	(2.8)	1.8	(1.3)	4.9	(3.1)
Dominant	4.8	(3.2)	1.5	(1.5)	3.7	(2.6)
Control	2.8	(1.5)	3.1	(1.7)	2.8	(1.7)
High skill						
Subordinate	1.1	(1.0)	1.0	(1.1)	.4	(.6)
Control	.3	(.4)	.9	(.8)	1.1	(1.0)
Dominant	1.1	(1.0)	.2	(.3)	1.9	(1.4)
Control	1.3	(1.2)	1.5	(1.4)	1.9	(1.6)

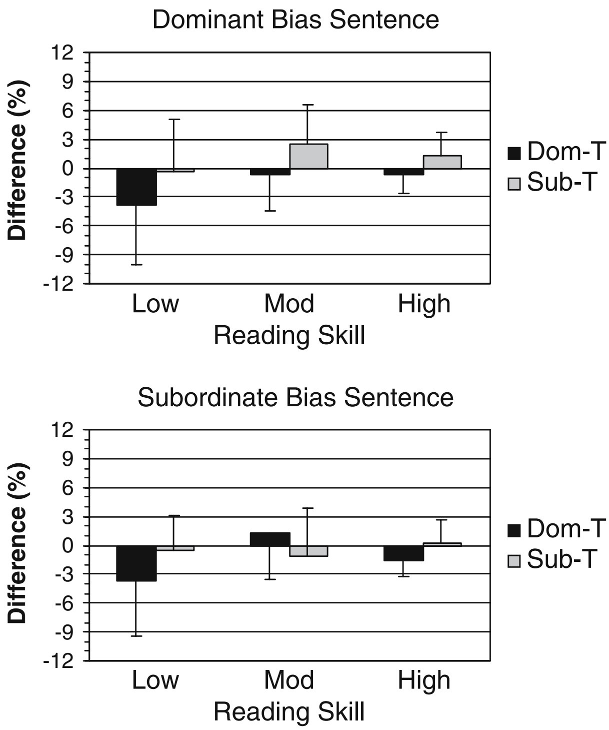

Fig. 2 Sentence level facilitation and inhibition (in errors) for the low, moderate and high skill readers. Sentence level facilitation (positive difference score in %) was defined as *higher* accuracy for related targets, as compared to control targets, following dominant bias or subordinate bias sentences as compared to ambiguous bias sentences. Sentence level inhibition (negative difference score in %) was defined as *lower* accuracy for related targets, as compared to control targets, following dominant bias or subordinate bias sentences as compared to ambiguous bias sentences. No reading skill group showed significant sentence level facilitation or inhibition in accuracy

Main effects analysis of *subordinate* bias sentences also revealed lexical level facilitation of accuracy among low skill readers for both dominant targets [$F_1(1,239) = 10.43$, $P < .01$; $F_2(1,99) = 18.82$, $P < .001$] and subordinate targets [$F_1(1,239) = 8.61$, $P < .01$; $F_2(1,99) = 12.73$, $P < .01$]. Significant lexical level facilitation for subordinate bias sentences was not seen for moderate or high skill readers. In addition, there were no significant interactions between sentence bias and target type within any reading skill group, thus failing to demonstrate sentence level effects.

Age versus Reading Skill Analyses

Not surprisingly, the results of reading skill analyses were similar to age group analyses because of the high correlation between reading skill and age. We could not reliably examine reading skill differences within each age group because of the relatively small number of participants at each age group. There were three similar findings between the age and readers skill analyses. First, low skill readers (and 9-year-olds) but not moderate skill readers (and 10-year-olds) or high skill readers (and 12-year-olds) exhibited lexical level facilitation in accuracy. Second, low skill readers (and 9-year-olds) and moderate skill readers (and 10-year-olds) exhibited lexical level facilitation in reaction time. Third, only high skill readers (and 12-year-olds) showed sentence level facilitation in reaction time. The main difference between the age and reading skill analyses is that high skill readers, but not 12-year-olds, showed reliable sentence level inhibition in reaction time.

Discussion

This study asked children (9-, 10- and 12-year-olds) to read aloud written sentences that were ambiguous or that biased either the dominant or subordinate meaning of a sentence final homonym. We measured error rates and naming latencies to target words that were presented 1,000 ms after the sentence final homonym. Some targets were either related to the dominant or subordinate meaning of the homonym. We compared accuracy and naming latency of related targets to those of control words that were unrelated to the homonym (see Table 2). We also measured children's reading skill so we could examine reading skill as well as age differences in sentence and lexical level context effects (see Table 3). Sentence level facilitation was defined as a greater difference between the related (and consistent with sentence context) and control target in the dominant or subordinate bias sentences as compared to the ambiguous bias sentences. Sentence level inhibition was defined as a smaller difference between the related (but not consistent with sentence context) and control target in the dominant or subordinate bias sentences as compared to the ambiguous bias sentences. Lexical level context effects were defined as no difference between the related and control targets in the ambiguous bias sentences as compared to either the dominant or subordinate bias sentences. By these definitions, sentence level effects are thereby specific to the context of the sentence, whereas lexical level effects are specific to the meanings of the homonyms.

The first main result of our study was that only 9-year-olds or low skill readers showed lexical level context effects in accuracy (see Tables 5 and 7), and only the 9- and 10-year-olds or low and moderate skill readers showed lexical level context effects on reaction time (see Tables 4 and 6). The 12-year-olds did not show lexical level context effects for either accuracy or reaction time. These findings are consistent with previous studies and computational models that show developmental and skill decreases in lexical level semantic priming (Plaut & Booth, 2000). These results are also consistent with many studies that have examined context effects in children (see references in Table 1). However, as reviewed in the introduction, these past studies confounded lexical level and sentence level context effects.

Our study was unique because we were able to separate sentence and lexical level context effects. The second main result of our study was that only 12-year-olds or high skill readers showed sentence level context effects (see Tables 4 and 6, Figs. 1 and 2). In particular, 12-year-olds exhibited sentence level facilitation for target words consistent with sentence context, whereas high skill readers exhibited sentence level facilitation as well as sentence level inhibition for target words inconsistent with sentence context. Our results for 12-year-olds or high skill readers are similar the findings in Vu et al. (1998). In that study, adults showed priming for both dominant and subordinate targets following ambiguous sentences. However, they found adults showed priming only for dominant targets following dominant bias sentences and only for subordinate targets following subordinate bias sentences. The inhibition for the high reading skill children in our study is also consistent with adult studies that show comprehension skill differences in suppression (Gernsbacher & Faust, 1991, Gernsbacher & Robertson, 1995; Gernsbacher et al., 1990). These studies show that lower skill comprehenders activate all meanings of homonyms and are less able than higher skill comprehenders to inhibit meanings that are inconsistent with sentence context. Finally, the inhibition for high skill children is also consistent with a developmental study of single word priming that shows inhibition for 12-year-old children, but not 9-year-old children (Simpson & Forster, 1986). Together with our results, this pattern suggests that older or higher skill readers are better able than younger or lower skill readers to use sentence level context to facilitate or inhibit homonym meanings.

Our study is not consistent with the Simpson et al. (1994) study reviewed in the introduction. Although Simpson et al. (1994) could not examine facilitation versus inhibition because they did not use ambiguous sentences, their results suggested greater sentence context effects in younger than older children. The discrepancies of this study with ours may be explained by differences in methodology. First, Twilley et al. (1994) used shorter SOAs (0, 300 and 700 ms), whereas the current study used a longer SOA (1,000 ms) possibly allowing for stronger context effects. Second, the Simpson et al. (1994) dominant and subordinate targets were based on older association norms (Nelson, McEvoy, Walling, & Wheeler, 1980), whereas our stimuli were based on more recent norms (Twilley et al., 1994). Indeed, nearly 50% of the dominant and subordinate targets in the Simpson et al. (1994) study do not occur as free associates in the Twilley et al. (1994) homonym norms. Third, there were only 8 participants per age group in the Simpson et al. (1994) study (SOA and sentence bias was manipulated between participants) limiting the generality of the findings. Our study employed a larger number of subjects per age or reading skill group ($N = 25$).

Interpretation of Results Based on the Distributed Attractor Model

Our results are consistent with an interactive model of homonym processing that suggests preceding context can affect the activation levels of the different meanings for these word forms. Kawamoto (1993) has formulated a computational model of homonym processing (Kawamoto, 1993) that employs these interactive principles and provides an elegant account for our observed developmental/skill differences. His computational model employs a distributed attractor network that learns by adjusting connection weights through error correction that minimizes the discrepancy between the activation level in the network and the input. Lower energy results from activation levels of units that are systematically related and which have a strong connection with each other. For example, lower energy would result from two units with high activation levels having a strong connection weight. In metaphorical terms, low energy states correspond to valleys and basins in a landscape. When input is presented to the network, activity of the network changes so as to move down the energy gradient. A point of any given landscape represents the activation levels of the units in the system. When a local minimum or basin is reached, the network's activation does not change further and the network is said to be in a stable state. The slope of the landscape and the distance between the initial and stable state determines how long the system takes to settle.

More frequent dominant meanings of homonyms have a wider and deeper basin of attraction than less frequent subordinate meanings (see Fig. 3a) because dominant representations are encountered more frequently. The ridge separating the basins for the two meanings is further from the dominant meaning because the basin is wider for dominant meaning. In a neutral context, the initial state of the network is equidistant from the two states corresponding to the dominant and subordinate meaning of the homonym. Because the ridge is further from the dominant meaning, the network will more likely settle into the basin for the dominant meaning, and therefore, results in homonym frequency effects. Homonyms with equiprobable meanings have similar basins for the two meanings. Therefore, there is a similar probability of settling into the basin for either meaning because the initial state of the network will more likely be on the horizontal portion of the ridge separating the two basins. Furthermore, the network changes less rapidly when the energy landscape is horizontal, leading to longer reaction times for equiprobable homonyms as compared to the dominant meaning of polarized homonyms.

As mentioned above, the initial state of the network is equidistant from each meaning basin when no context is present. Prior context determines the initial state of the network. When context is present, the initial state of the network is closer to the basin corresponding to the meaning biased by context. Furthermore, a stronger context has an initial state closer to the bottom of the basin than a weaker context resulting in a stronger context effect. For polarized homonyms, even a weak context for the dominant meaning will almost always result in the initial state being on the dominant side of the energy landscape. In contrast, a strong context for subordinate meanings is necessary to result in the initial state being on the subordinate side of the energy landscape for polarized homonyms (see Fig. 3b). For equiprobable homonyms, a weaker context is enough to cause the initial state of the network to be in either the "dominant" or "subordinate" basins. Therefore, the effect of context on processing is greater for equiprobable "subordinate" meanings than for polarized subordinate meanings.

In order to explain our observed reading skill (and developmental) differences in context effects, we made three additional assumptions regarding the distributed attractor network model (see Fig. 3). Our first assumption was that lower skill readers representations have an energy landscape with relatively shallow basins that result from weak and widespread neural connections. In other words, the representational landscape of lower skill readers has higher energy because units that are related in

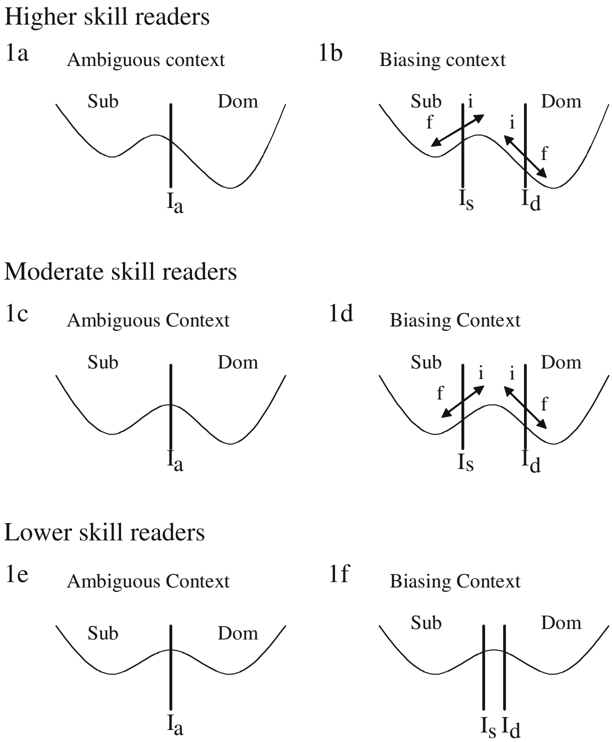

Fig. 3 Hypothesized energy landscapes for higher skill readers (adults), moderate skill readers (older children) and lower skill readers (younger children) for polarized homonyms. Lower energy corresponds to the basin of attraction in the landscape. Although semantics representations are multidimensional, only one dimension of the landscape is represented here for ease of presentation. The ambiguous bias context represents lexical level context effects of homonyms on targets. The initial state (I) of the network with ambiguous bias context is reliably in the dominant basin for higher skill readers (1a) resulting in a larger lexical level context effect for dominant than subordinate homonyms. In contrast, the initial state of the network is often near the ridge separating the basins for moderate and lower skill readers (1c, 1e) resulting in a similar lexical level context effect for dominant and subordinate meanings in ambiguous bias context. The initial state of the network with a sentence level context is reliably in the appropriate dominant or subordinate basin for higher and moderate skill readers (1b, 1d) resulting in sentence level context facilitation (f) for related targets and inhibition (i) for unrelated targets. Inhibition or hysteresis occurs because the state of the network must be changed from the inappropriate basin to appropriate basin (Plaut & Booth, 2000). In contrast, the weak sentence level context effects for lower skill readers result in the initial state of the network being near the ridge separating the dominant and subordinate meanings. Thus, there is little or no sentence level context effect for lower skill readers

activation levels are not necessarily connected by strong weights. In contrast, moderate and higher skill readers have lower energy landscapes with relatively deep basins due to strong and selective connections. This proposed difference as a function of skill parallels early versus late learning in Kawamoto's (1993) computational model of homonym processing. Our second assumption was that lower skill readers have similar representations for the dominant and subordinate meanings of polarized homonyms. In other words, lower skill readers representations for polarized homonyms are similar their representations for equiprobable homonyms. This assumption is consistent with the behavioral research discussed above that suggests older participants are more sensitive than younger participants to homonym meaning frequency (Marmurek & Rossi, 1993; Simpson et al., 1994). Our third assumption was that sentence level context is weaker for lower skill than higher skill readers. Lower skill readers have lower comprehension and therefore are less able to use the subtle cues in sentence contexts to bias the processing of individual lexical items (Gernsbacher et al., 1990). These three additional assumptions for the distributed attractor network model predict no sentence level context effects for lower skill readers (see Fig. 3f), but equal facilitation and inhibition for dominant and subordinate bias contexts for moderate skill readers (see Fig. 3d). These predictions of the model match our experimental results for children. Also according to this model, adults or very high skill readers should show larger context effects for dominant than subordinate meanings (see Figure 3b) due to their greater sensitivity to homonym frequency. Although we did not see this for our older or higher reading skill children, they may not have been skilled enough to demonstrate differences in context effects for dominant versus subordinate meanings.

Predictions Based on the Distributed Attractor Model

Future developmental studies should systematically examine the effect of SOA between the sentence final homonym and the target word to determine the time course of contextual influences on homonym processing. Our study used only a 1,000 ms SOA, and therefore, we could not examine the time course of activation of dominant versus subordinate meanings. Many studies with adults have found that homonym effects are modulated by SOA (Simpson & Krueger, 1991, Tanenhaus et al., 1979). Although the only developmental study to examine SOA differences in the effect of sentence context on homonym processing did not find significant effects, this may be due to lack of power (Simpson et al., 1994). Because increasing SOA effectively increases the time that context can operate, longer SOAs may increase the strength of the context, especially in children who are slow information processors (Kail, 1993, Kail & Hall, 1994). Kawamoto (1993) has shown that, in a weak context, both dominant and subordinate meanings increase in activation following a consistent or inconsistent context, although the increase is stronger and more rapid for the consistent context. In a strong context, however, there is strong activation for consistent meanings and little activation for inconsistent meanings. In other words, neither dominant meanings following a strong subordinate context nor subordinate meanings following a strong dominant context produce much activation. Our study found younger children or lower skill readers showed lexical level facilitation for dominant and subordinate meanings regardless of biasing context, whereas older children or high skill readers showed no lexical level, but reliable sentence level facilitation for targets consistent with the sentence context. In addition, high skill readers showed sentence level inhibition for targets inconsistent with the sentence context. Based on Kawamoto (1993) model of homonym processing, increasing SOA for younger children or lower skill readers should increase the strength of the context, and therefore, may produce sentence level facilitation or inhibition.

The effect of contextual strength on developmental differences in the processing of homonyms also needs to be examined. Several studies with adults have found that the strength of context affects homonym processing (Dixon & Twilley, 1999; Martin et al., 1999; Twilley & Dixon, 2000, Vu et al., 1998). Our study used sentence contexts that were strongly biased toward the dominant or subordinate meaning, or sentence contexts that were ambiguous, so we could not examine developmental differences in the effect of contextual strength. Kawamoto's (1993) model of homonym processing predicts, for example, that a weak subordinate bias sentence for higher skill readers should be sufficient to put the initial state of the network in the basin for subordinate meanings. Thus, there should be context effects for subordinate targets, but not for dominant targets in subordinate bias sentences. However, for lower skill readers, a weak subordinate bias sentence should not reliably put the network in the basin for subordinate meanings. A strong subordinate bias sentence for lower skill readers should be required to reliably put the initial state of the network in the basin for subordinate meanings.

Future developmental studies should also examine age differences in processing polarized versus equiprobable homonyms. Several studies with adults have shown processing differences between polarized and equiprobable homonyms (Carpenter & Daneman, 1981, Hogaboam & Perfetti, 1975, Simpson & Burgess, 1985). We argued above that the energy landscape of polarized homonyms for lower skill readers resembles the energy landscape of equiprobable homonyms for higher skill readers. In other words, we suggest that lower skill readers have shallow landscapes for all homonyms, whereas higher skill readers may have shallow landscapes only for equiprobable homonyms. This is consistent with the demonstration of greater sensitivity to homonym meaning frequency in older as compared to younger children (Marmurek and Rossi, 1993; Simpson, Krueger, Kang, & Elofson, 1994). Although our study did not examine equiprobable homonyms, Kawamoto's (1993) model of homonym processing has shown that the "dominant" and "subordinate" meanings of equiprobable homonyms have similar activation levels following a consistent context. In contrast, activation of dominant meanings was larger than subordinate meanings for polarized homonyms following a consistent context. Based on this model, we suggest that lower skill readers will show little difference in the effect of context on processing equiprobable versus polarized homonyms. In contrast, higher skill readers will show reliable differences between equiprobable and polarized homonyms because of their more differentiated semantic representations for dominant and subordinate meanings for polarized homonyms.

Conclusion

The main conclusion of our study is that younger children or lower skill readers show lexical level facilitation and not sentence level context effects. In contrast, older children or higher skill readers show sentence level facilitation and inhibition. These findings are important because previous developmental research that has shown greater context effects for younger children or lower skill readers has not distinguished between lexical and sentence level context effects. Although more research needs to be conducted on the effect of context on homonym processing (e.g. the effect of SOA, context strength and homonym frequency), the results of the current study are consistent with distributed attractor network models of lexical processing.

Acknowledgements This research was funded in part by National Institute of Child Health and Human Development grant 5-F32-HD08255-02, by National Institute of Deafness and Other Communication Disorders grant 5-R01-HD23998, and by National Institute of Mental Health grant

5-T32-MH19102. We would like to thank the students, teachers, and administrators at Christ Lutheran School for participating in our study. We would also like to thank Patricia J. Brophy for comments on earlier versions of this manuscript.

References

Adams, M. J., & Huggins, A. W. F. (1985). The growth of children's sight word vocabulary: A quick test with educational and theoretical implications. *Reading Research Quarterly, 20*, 560–568.

Backscheider, A. G., & Gelman, S. A. (1995). Children's understanding of homonyms. *Journal of Child Language, 22*,(1), 107–127.

Booth, J. R., & Hall, W. S. (1994). Role of the cognitive internal state lexicon in reading comprehension. *Journal of Educational Psychology, 86*, 413–422.

Booth, J. R., & Hall, W. S. (1995). Development of the understanding of the polysemous meanings of the mental-state verb know. *Cognitive Development, 10*, 529–549.

Booth, J. R., Hall, W. S., Robinson, G. C., & Kim, S. Y. (1997). Acquisition of mental state verbs by 2- to 5-year old children. *Journal of Psycholinguistic Research, 26*, 581–603.

Briggs, P., Austin, S., & Underwood, G. (1984). Effects of sentence context in good and poor readers: A test of Stanovich's interactive compensatory model. *Reading Research Quarterly* (Fall), 54–60.

Carpenter, P. A., & Daneman, M. (1981). Lexical retrieval and error recovery in reading: A model based on eye fixations. *Journal of Verbal Learning and Verbal Behavior, 20*(2), 137–160.

Cohen, J. D., MacWhinney, B., Flatt, M., & Provost, J. (1993). PsyScope: An interactive graphic system for designing and controlling experiments in the psychology laboratory using Macintosh computers. *Behavior Research Methods, Instruments, and Computers, 25*, 257–271.

Cramer, P. (1983). Homonym understanding and conservation. *Journal of Experimental Child Psychology, 36*(2), 179–195.

Crystal, D. (1992). *An encyclopedic dictionary of language and languages*. Cambridge, MA: Blackwell.

Dixon, P., & Twilley, L. C. (1999). Context and homograph meaning resolution. *Canadian Journal of Experimental Psychology, 53*(4), 335–346.

Duffy, S. A., Morris, R. K., & Rayner, K. (1988). Lexical ambiguity and fixation times in reading. *Journal of Memory and Language, 27*, 429–446.

Durkin, K., & Shire, B. (1991). Primary school children's interpretations of lexical ambiguity in mathematical descriptions. *Journal of Research in Reading, 14*(1), 46–55.

The Educator's Word Frequency Guide (1996). Brewster, NY: Touchstone Applied Science Associates, Inc.

Gernsbacher, M. A., & Faust, M. E. (1991). The mechanism of supression: A component of general comprehension skill. *Journal of Experimental Psychology: Learning Memory and Cognition, 17*, 245–262.

Gernsbacher, M. A., & Robertson, R. R. W. (1995). Reading skill and suppression revisited. *Psychological Science, 6*, 165–169.

Gernsbacher, M. A., Varner, K. R., & Faust, M. E. (1990). Investigating differences in general comprehension skill. *Journal of Experimental Psychology: Learning, Memory, & Cognition, 16*(3), 430–445.

Glucksberg, S., Kreuz, R. J., & Rho, S. H. (1986). Context can constrain lexical access: Implications for models of language comprehension. *Journal of Experimental Psychology: Learning, Memory, & Cognition, 12*(3), 323–335.

Hogaboam, T. W., & Perfetti, C. A. (1975). Lexical ambiguity and sentence comprehension. *Journal of Verbal Learning and Verbal Behavior, 14*, 265–274.

Kail, R. (1993). Processing time decreases globally at an exponential rate during childhood and adolescence. *Journal of Experimental Child Psychology, 56*(2), 254–265.

Kail, R., & Hall, L. K. (1994). Processing speed, naming speed, and reading. *Developmental Psychology, 30*(6), 949–954.

Kawamoto, A. H. (1993). Nonlinear dynamics in the resolution of lexical ambiguity: A parallel distributed processing account. *Journal of Memory and Language, 32*, 474–516.

Kintsch, W., & Mross, F. (1985). Context effects in word identification. *Journal of Memory and Language, 24*, 336–349.

Marmurek, H. H. C., & Rossi, M. (1993). The development of strategic processing of ambiguous words: Riddles versus neutral context. *Journal of Genetic Psychology, 154*(4), 475–486.

Martin, C., Vu, H., Kellas, G., & Metcalf, K. (1999). Strength of discourse context as a determinant of the subordinate bias effect. Quarterly *Journal of Experimental Psychology. A, Human Experimental Psychology, 52A*(4), 813–839.
Neill, W. T., Hilliard, D. V., & Cooper, E. A. (1988). The detection of lexical ambiguity: Evidence for context sensitive parallel access. *Journal of Memory and Language, 27*, 279–287.
Nelson, D. L., McEvoy, C. L., & Schreiber, T. A. (1998). The University of South Florida word association, rhyme, and word fragment norms.: http://www.usf.edu/FreeAssociation/
Perfetti, C. A., & Roth, S. (1981). Some of the interactive processes in reading and their role in reading skill. In A. Lesgold & C. Perfetti (Eds.), *Interactive processes in reading*. Hillsdale, NJ: Erlbaum.
Perfetti, C. A., Goldman, S. R., & Hogaboam, T. W. (1979). Reading skill and the identification fo words in discourse context. *Memory and Cognition, 7*, 273–282.
Plaut, D. C., & Booth, J. R. (2000). Individual and developmental differences in semantic priming: Empirical findings and computational support for a single-mechanism account of lexical processing. *Psychological Review, 107*(4), 786–823.
Raduege, T. A., & Schwantes, F. M. (1987). Effects of rapid word recognition training on sentence context effects in children. *Journal of Reading Behavior, 19*, 395–414.
Schwantes, F. M. (1981a). Effect of story context on children's ongoing word recognition. *Journal of Reading Behavior, 13*, 305–311.
Schwantes, F. M. (1981b). Locus of the context effect in children's word recognition. *Child Development, 52*, 895–903.
Schwantes, F. M. (1982). Text readability level and developmental differences in context effects. *Journal of Reading Behavior, 14*, 5–12.
Schwantes, F. M. (1985). Expectancy, integration, and interactional processes: Age differences in the nature of words affected by sentence context. *Journal of Experimental Child Psychology, 39*, 212–229.
Schwantes, F. M., Boesl, S. L., & Ritz, E. G. (1980). Children's use of context in word recognition: A psycholinguistic guessing game. *Child Development, 51*, 730–736.
Simpson, G. B. (1981). Meaning dominance and semantic context in the processing of lexical ambiguity. *Journal of Verbal Learning & Verbal Behavior, 20*(1), 120–136.
Simpson, G. B., & Burgess, C. (1985). Activation and selection processes in the recognition of ambiguous words. *Journal of Experimental Psychology: Human Perception & Performance, 11*(1), 28–39.
Simpson, G. B., & Forster, K. I. (1986). Lexical ambiguity and children's word recognition. *Developmental Psychology, 22*, 147–154.
Simpson, G. B., & Krueger, M. A. (1991). Selective access of homograph meanings in sentence context. *Journal of Memory and Language, 30*, 627–643.
Simpson, G. B., Krueger, M. A., Kang, H., & Elofson, A. C. (1994). Sentence context and meaning frequency effects in children's processing of ambiguous words. *Journal of Research in Reading, 17*(1), 62–72.
Spieler, D. A. & Balota, D. H. (2001). Word Naming Corpus: 2870 Single Syllable Words and Associated Naming Latencies (http://elexicon.wustl.edu/).
Stanovich, K. E., Nathan, R. G., West, R. F., & Vala-Rossi, M. (1985). Children's word recognition in context: Spreading activation, expectancy, and modularity. *Child Development, 56*, 1418–1428.
Stanovich, K. E., West, R. F., & Freeman, D. J. (1981). A longitudinal study of sentence context effects in second grade children: Tests of the interactive-compensatory model. *Journal of Experimental Child Psychology, 32*, 185–199.
Swinney, D. A. (1979). Lexical access during sentence comprehension: Reconsideration of context effects. *Journal of Verbal Learning and Verbal Behavior, 18*, 645–659.
Tanenhaus, M. K., Lieman, J. M., & Seidenberg, M. S. (1979). Evidence for multiple stages in the processing of ambiguous words in syntactic contexts. *Journal of Verbal Learning and Verbal Behavior, 18*, 427–440.
Twilley, L. C., & Dixon, P. (2000). Meaning resolution processes for words: A parallel independent model. *Psychonomic Bulletin & Review, 7*(1), 49–82.
Twilley, L. C., Dixon, P., Taylor, D., & Clark, K. (1994). University of Alberta norms of relative meaning frequency for 566 homographs. *Memory and Cognition, 22*, 111–126.
Van Petten, C., & Kutas, M. (1987). Ambiguous words in context: An event-related potential analysis of the time course of meaning activation. *Journal of Memory and Language, 26*, 188–208.
Vu, H., Kellas, G., Metcalf, K., & Herman, R. (2000). The influence of global discourse on lexical ambiguity resolution. *Memory & Cognition, 28*(2), 236–252.
Vu, H., Kellas, G., & Paul, S. T. (1998). Sources of sentence constraint on lexical ambiguity resolution. *Memory & Cognition, 26*(5), 979–1001.

West, R. F., & Stanovich, K. E. (1978). Automatic contextual facilitation in readers of three ages. *Child Development, 49*, 717–727.

West, R. F., & Stanovich, K. E. (1988). How much of sentence priming is word priming? *Bulletin of the Psychonomic Society, 26*, 1–4.

West, R. F., Stanovich, K. E., Freeman, D. J., & Cunningham, A. E. (1983). The effect of sentence context on word-recognition in second-and sixth-grade children. *Reading Research Quarterly, 19*, 6–15.

Woodcock, R. W. (1987). Woodcock Reading Mastery Tests - Revised. Circle Pines, MN: American Guidance Service.