Published in final edited form as:
J Speech Lang Hear Res. 2008 August ; 51(4): 1042–1054. doi:10.1044/1092-4388(2008/076).

Attentional modulation of word recognition by children in a dual-task paradigm

Introduction

Short-term memory (STM) plays a crucial role in processing speech (Baddeley & Hitch, 1974; Baddeley, 1986; Pisoni & Sawusch, 1975). Limitations in STM can interfere with perceptual processing and learning of speech. For instance, STM deficits have been linked to language impairments in children (Gathercole & Baddeley, 1990).

Increased STM capacity is required in adults when listening to speech in noise (Rabbitt, 1968). However, children's STM is limited in comparison to adults as measured by both memory span (Gathercole, 1998; 1999) and dual-task performance (Irwin-Chase & Burns, 2000; Karatekin, 2004; Manis, Keating, & Morrison, 1980). Thus, in situations that require increased processing demands, children may experience performance limitations due to STM constraints more frequently than adults in situations that require increased processing demands. In addition, children have less access to linguistic knowledge and automated processes that may alleviate some of the demands on STM capacity (Elliott, 1979; Nittrouer & Boothroyd, 1990). Adult/child differences may become even more apparent in challenging listening conditions. It has been well documented that children's speech perception is more susceptible to noise than adults (Elliott, 1979; Elliott, Connors, Kille, Levin, Ball, & Katz, 1979; Fallon, Trehub, & Schneider, 2002; Hall, Grose, Buss, & Dev, 2002; Johnson, 2000). Thus, children may not have the capacity necessary to accommodate these added demands and as a result, may be more adversely affected by noise than adults.

STM and speech perception in noise exhibit somewhat parallel age trends. STM span (defined as an ability to retain information for brief periods of time) increases rapidly during childhood and adolescence (Gathercole 1998;1999) becoming more adult-like by the age of twelve. However, complex working memory (defined as the ability to manipulate and store material simultaneously) shows a steep developmental slope up to the age of sixteen (Gathercole, 1999). Children's speech perception in noise follows a similar trajectory. Elliott tested children between nine and seventeen years of age using the SPIN (Speech Intelligibility in Noise) test (Kalikow, Stevens, and Elliott, 1977). The task was to repeat the last word in high-predictability sentences presented in babble at a 0 dB signal-to-noise ratio (SNR). Nine-year olds performed more poorly than 11-year olds while11- and 13-year olds performed more poorly than 15- and 17-year olds. Johnson (2000) measured the identification of consonants presented at a 13-dB SNR to children (6- to 15-year olds) and adults (18- to 30- year olds). Mean consonant scores for adults and 14 to15-year old children were not significantly different from each other, but both were significantly higher than the scores of 6 to 7-year olds. Stuart (2005) reported similar age-associated improvement in the recognition of words presented in steady-state and fluctuating noise. Children in the 6 to 11-year age range showed poorer performance than adults, whereas the 12 to15-year olds performed at an adult level. Similarities in the development of STM and speech perception in noise may be more than coincidental. As STM increases with age, children may be better able to meet the capacity demands required for auditory processing when listening to speech in noise. To date, the relationship between STM capacity and speech perception in noise in normally developing children has not been established.

To measure the capacity demands required for speech processing in adults, serial recall tests or dual-task paradigms have been commonly used. Serial recall of auditorily presented items requires both processing of acoustic information and subvocal rehearsal for memory retention. Without rehearsal, phonological information quickly fades after two seconds (Baddeley, 1986). Since perceptual processing and rehearsal share the same STM resources, if one process requires more capacity, trade-offs must occur (Baddeley and Hitch, 1974). For example, Rabbitt (1968) presented a series of numbers auditorily in both quiet and noise. When items to be recalled were presented in noise, perceptual processes required more capacity for acoustic-phonetic encoding, leaving fewer resources for rehearsal and resulting in a reduction in recall accuracy. This is a specific case of a more general paradigm of presenting two tasks that compete for a general limited capacity (Kahneman, 1973), known as a dual-task paradigm.

In typical environments, children do not always listen to speech under optimal listening conditions. For example, classrooms that are often filled with unwanted background noise and reverberation may not provide an optimal acoustical environment for learning (Knecht, Nelson, Whitelaw, & Feth, 2002). Learning includes multiple, simultaneous, and sequential tasks that compete for a limited processing capacity. Children are bombarded with new information every day and often are faced with multiple tasks. Considering the limited STM capacity in children, noisy listening conditions can degrade learning due to the additional STM demands required for auditory processing of the speech signal. Determining how much STM capacity is required for children to understand speech in noise and how these demands impact performance during simultaneous tasks may provide insight into the extent to which noise is harmful in a learning situation.

The current study investigates an account of limited STM capacity for children's speech perception in noise. A dual-task paradigm was used to measure the STM demands required for word recognition in noise while children performed a competing memory (serial digit recall) task. Capacity models of attention (Kahneman, 1973; Navon & Gopher, 1979; 1980; Wickens, 1991) propose that limitations in performance occur when two tasks compete for the same processing capacities. In the current study, a memory preload technique (Baddeley and Hitch, 1974) was used to create competition for STM capacity. A serial recall task was chosen to compete with word recognition because both tasks presumably require processing capacity in phonological STM (Baddeley, 1986). When the two tasks put excessive demands on processing resources, one should witness a decrement in performance relative to the tasks in isolation. It was predicted that the dual-task decrement would be greatest for the youngest children as they have the smallest STM capacity and the least access to linguistic experience that may lead to efficient listening strategies. For older children, it was predicted that dual-task decrements would persist but be substantially reduced compared to the younger cohorts.

Attention allocation is determined by the capacity demands of the task imposed by activities in which the person is engaged and their goals. When more attention is allocated to a task, more STM is available for processing information. These allocation decisions are presumed to be under control of the individual. Therefore, if, in the current task, attention is primarily given to word recognition, children may show little or no decrement in word recognition, but a substantial decrement in serial recall (secondary task). The decrement in the secondary task will be proportional to the amount of STM resources allocated to the primary task. In other words, the decrement in secondary-task performance provides information about the capacity demands of the primary task. In line with predictions above, one would expect a greater decrement in serial digit recall (in the dual task versus isolation) for younger children. On the other hand, if primary attention is given to the serial recall task, a dual-task decrement should be shown for word recognition. Primary and secondary task determination was manipulated in this experiment through instruction. This manipulation allows examination of the ability of children to control allocation of their processing resources and to note any developmental changes in this ability.

Methods

Subjects

Sixty-four children between the ages of 7 and 14 years participated in the present study. The children were assigned to two experimental groups of 32 subjects based on their instructions for the dual-task condition. It should be noted that subjects in Group 1 were also completing additional tasks for a separate study[1]. Within each experimental group, equal numbers of children were assigned to four age-groups (7-8, 9-10, 11-12, & 13-14 years). Age and gender (16 males & 16 females) were matched between the two experimental groups (See Table 1). All subjects spoke American English as their first language. None had a diagnosed history of speech, language, or hearing problems. All subjects had normal hearing (< 15 dB HL from 250-8000 Hz). Phonological STM was assessed using the Digit Span subtest from the Wechsler Intelligence Scale for Children-III (WISC-III, 1991), and receptive vocabulary was assessed using the Peabody Picture Vocabulary Test—Third Edition (Dunn & Dunn, 1997). Only participants whose standard scores on both tests fell above -2 standard deviations (SD) of age-appropriate norms were included. Means and SD for age, raw PPVT, and raw Digit Span scores are summarized in Table 1.

Stimuli

Word recognition—Stimuli were phonetically balanced kindergarten (PBK) monosyllabic words (Haskins, 1949) recorded by a female talker with a general American English dialect[2]. PBK list 3 was used for baseline measures of word recognition in the single-task condition, and 25 words randomly selected from the 100 words in lists 1 and 4 were used for word recognition in the dual-task condition[3]. The stimuli were equated at 65 dB RMS amplitude across the entire word using Level 16 (Carrell, 1998), and digitally mixed with speech-shaped noise at +8 dB SNR using Audition 1.5 (Adobe Systems, 2003). The noise always began 50 milliseconds before the beginning of the word and lasted for at least 50 ms after the end of the word. The beginning and the end of 50-ms noise were linear-amplitude-ramped to prevent misperception of noise as a stop consonant due to abrupt change in amplitude.

Digit recall—Stimuli were sets of 3 or 5 digits randomly generated by a computer. Familiar digit sequences such as local area codes and zip codes were removed from the cohorts. Ascending or descending patterns of consecutive digit sequences also were removed.

Experimental tasks and Procedures

All experiments were conducted at Boys Town National Research Hospital in a singlewalled sound booth (Acoustic Systems) meeting ANSI S3.1-1999 (ANSI, 1999). Participants were

[1]Children in Group 1 were seen for two visits on separate days. During their first visit, children completed hearing screening, digit span, single digit recalls and word recognition tasks in addition to recalling nonsense words presented in a short story. During this visit, digit-recall tasks in isolation were completed first. During their second visit, the children first completed dual tasks and then an additional listening task for a different study. Children were provided with frequent breaks and tangible rewards to help maintain their motivation throughout the session.

[2]Recording was extracted from the Speech Audiometry Materials CD (Harris & Hilton, 1991). Sampling rate and amplitude resolution of the original recording were 44.1 kHz and 16 bits respectively.

[3]List 2 was not used in this experiment due to the lack of list equivalency with other lists. However, lists 1, 3, and 4 have been found to be equivalent in behavioral results (in % correct scores) (Haskins, 1949), and in computation analysis of word frequency, neighborhood density and frequency (Meyer & Pisoni, 1999).

recruited through the Human Research Subjects CORE database[4] and paid for their participation. The average duration of an experimental session was 1 ½ hours.

Word recognition (Single-task)—Two lists, each comprised of 25 monosyllabic words from PBK list 3 were used to measure single-task (baseline) performance for word recognition in speech-shaped noise at 8 dB SNR. This SNR was used based on the results from a pilot study. Specifically, this SNR was found to provide an appropriate level of difficulty (avoiding both ceiling and floor effects) for the age group tested. The two half lists (words 1 through 25 and words 26 through 50) were determined to be equivalent and phonetically balanced and thus were counterbalanced across subjects within each age group. Words were played through a 24-bit CardDeluxe, amplified and routed to Sennheiser headphones (HD 250) and presented binaurally at 65 dB SPL. The random presentation of stimuli was controlled by a Windows-based experimental program Behavioral Auditory Research Tests (BART; BTNRH Computing Core, 2006). Children's articulation was screened using Bankson and Bernthal Quick Screen of Phonology (1990). As long as articulation errors were consistent and speech was intelligible, children with mild articulation problems were included. Children were told that they would hear a word in the middle of a "/sh/ sounding noise." They were instructed to ignore the noise and repeat the word loudly and clearly and were encouraged to guess if they were unsure of a word. Verbal responses were scored online by the experimenter. Only correct repetitions of the entire word were scored as correct.

Serial digit recall (Single-task)—Strings of 3 or 5 digits were visually presented in the center of a computer screen using PowerPoint (Microsoft Office 2003). Prior to the display of digits, a warning picture appeared on the screen along with an audible command ("Look at the numbers"). The 5-digit sets were displayed on the screen for 3 seconds, and the 3-digit sets were displayed for 2 seconds. Subjects were instructed to remember the numbers in the exact order they were presented on the screen, and encouraged to keep rehearsing the numbers quietly as many times as possible until they were asked to say the numbers. After 10 seconds of silence, subjects were asked to recall the numbers. All subjects were tested with 5 digits in the first block. Each block consisted of 5 sets of digits. If a subject scored 100% in 5-digit recall, the 3-digit recall task was not administered, and their ability to recall 3 digits was assumed to be 100%. Subjects who did not score 100% in the 5-digit recall task also completed the 3-digit recall task. Digits were scored using the conservative method described by Gillam, Cowan & Day (1995). Specifically, each digit was treated as an individual item and only digits that were recalled in exact serial position were scored as correct. If insertion of a non-target item or omission of a target item occurred, the remaining items were counted incorrect even if they were recalled in the correct sequence. For example, if the target was '23456' and the response was '3456', the score was 0 percent correct.

Dual-Task—Digit recall and word recognition were combined to create a dual task. A memory preload technique (Baddeley and Hitch, 1974) was used to increase processing load in phonological STM and to create competition for attentional resources. Each trial began with the display of digits on the screen. The removal of digits from the computer screen was followed by auditory presentation of 5 monosyllabic words randomly selected from PBK Lists 1 and 4. After repetition of five words, the subject was asked to recall the preloaded digits. A line drawing of dual-task (Panel A) and the sequence of a dual-task trial (Panel B) are depicted in Figure 1. The random presentation of digits and words was controlled by a Windows-based experimental control program specifically developed for this dual-task paradigm. Although two different software programs were used for the single- and dual-task conditions, the same sound card and headphones were used and the stimulus levels were equivalent (65 dB SPL)

[4]The human subject database was developed by BTNRH Computing Core supported by NIH grant P30-DC004662.

across the single and dual-task conditions. All subjects completed two blocks of dual tasks: word recognition with a competing 3-digit recall task and word recognition with a competing 5-digit recall task. The order of 3- and 5- digit competing task conditions was counterbalanced within each age group. Prior to the experiment, all children were given a practice session consisting of 2 dual-task trials.

To examine the effects of task priority on speech recognition, the children in Group 1 were instructed to place their primary attention on word recognition and the children in Group 2 were told to exert more effort to remember the digits. To encourage children to pay primary attention to their directed task, subjects were told that they would get points for both repeating words and remembering digits, but they would get extra points for their primary task. Recall that subjects in Group 1 also were completing tasks for another study. For that reason, they received the single-tasks on the first day of a two-day visit and the dual-task on the 2nd day. The time gap between the 1st and the 2nd day visits varied from a minimum of one day to a maximum of 2 weeks. Group 2 completed the single- and dual-tasks in a one-day visit. However, independent group T-tests revealed no group difference in word recognition [$t(1, 62) = 1.867$, $p > .066$], 3-digit recall [$t(1, 62) = -.073$, $p > .94$], or 5-digit recall [$t(1, 62) = .833$, $p > .38$]. In addition, correlation analysis revealed that neither the task order nor the time interval between single and the dual-tasks correlated with any of the measures of task performances (see Table 6). Therefore, the difference in the task order between Group 1 and Group 2 did not affect children's performance significantly.

Results

Development of STM and word recognition in noise

STM capacity was measured by both the Digit Span Test and the 3- and 5- digit serial recall tasks in the single-task conditions. Children in both groups showed an increase in digit span (Table 1) and 5-digit serial recall (Table 2) with age. Performance on the 3-digit recall task was >97% regardless of age, suggesting that children had little difficulty with this task. However, scores decreased and subject variability (SD) increased for the more difficult 5-digit recall task. Age effects also were statistically significant for both the digit span [$F(3, 56) = 4.6$, $p < .007$] and 5-digit recall [$F(3, 56) = 10.1$, $p < .003$]. No statistically significant group differences were found in STM span for either the 3- or 5-digit serial recall task. As can be seen in Table 2, word recognition in noise in the single-task condition improved with age and these age effects were found to be significant [$F(3, 56) = 5$, $p < .005$]. Finally, a significant correlation was found between age & word recognition in noise [$r = .363$, $p < .003$]. Although Group 1 achieved slightly higher scores than Group 2 [$F(1, 56) = 4.1$, $p < .05$], both groups showed similar age-related trends for word recognition in noise.

STM demands for word recognition in noise

In order to measure children's limitations in STM capacity for processing speech in noise, dual-task word recognition in noise was measured in the presence of a competing digit recall task. STM demands for word recognition in noise were measured in two different levels of attention allocation: primary and secondary. Given the logic of the dual-task paradigm, it was expected that limitations in capacity demands required for the primary task would result in decreased performance in the secondary task. Recall that the magnitude of the decrement in the secondary task (relative to baseline) was expected to be roughly proportional to the capacity demands required for processing the primary task. Since the children in Group 1 were told to focus on the word recognition task, a decrement in dual-task digit recall was expected. Alternately, the children in Group 2 were told to focus on digit recall, which would be expected to result in decreased word recognition scores. For the remainder of this paper, the term "decrement" will be used to refer to a reduction in performance for the dual-task condition relative to the single-task (baseline) condition.

Figure 2 shows mean percent correct scores for word recognition (left) and digit recall (right) in the single- and dual-task conditions as a function of task priority. Two separate twoway mixed ANOVAs were conducted. The dependent variables were percent correct digit scores and word recognition, and the independent variables were group and task (single vs. dual). When the children were told to give priority to the word recognition task (Group 1 = words priority in Figure 2), no decrement in word recognition was observed, but a significant decrement in digit recall was observed for both the 3- and 5-digit conditions [$F(1, 31) = 51.6$, $p < .0005$, $F(1, 31) = 467$, $p < .0005$, respectively]. Dual-task decrements in digit recall in the presence of a competing word recognition task were predicted in accordance with a limited capacity account. Thus, decrements in digit recall suggest that processing speech in noise is a capacity-demanding task. Unexpectedly, dual-task improvements in word recognition in noise were observed, and the improvements were statistically significant in both the 3- [$F(1, 31) = 17.5$, $p < .0005$] and 5-digit conditions [$F(1,31) = 9.4$, $p < .01$]. Although little or no decrement in dual-task word recognition was expected when the primary attention was on word recognition, *improved* dualtask word recognition is contradictory to a limited capacity model.

When children were told to focus on the digit recall task (Group 2 = digits priority in Figure 2), dual-task decrements in word recognition were expected. Contradictory to this prediction, however, significant *improvements* in word recognition were found in both the 3-digit [$F(1, 31) = 13.8$, $p < .005$] and 5-digit; $F(1,31) = 8.5$, $p < .01$] conditions. Similarly, although little or no decrement in dual-task digit recall was predicted, significant *decrements* were observed for both the 3-digit [$F(1,31) = 30.8$, $p < .0005$] and 5-digit conditions [$F(1,31) = 370.8$, $p < .0005$]. In other words, regardless of task priority (words vs. digits), the children in both groups showed the same pattern in the dual-task conditions (i.e., improvement in word recognition and decrement in digit recall). This suggests that children in the 7- to 14-year age range may not have developed top-down controlled attention allocation based on task priorities. In both groups, word recognition in noise significantly interfered with both 3-digit recall and 5-digit recall. This indicates that processing words in noise is a high-capacity task for children, even at relatively good SNRs.

Age effects on STM demands for word recognition in noise

Since there was no group difference in dual-task performance due to task priority, the data were collapsed across groups to examine the effects of age on STM capacity demands for speech perception in noise. Based on a limited capacity model, dual-task decrements were expected to diminish with age. Mean percent correct scores (+/-1 SD) for word recognition and digit recall are plotted as a function of age group in Figure 3. Single and dual-task word recognition scores are summarized in Table 3. Four separate one-way repeated measures ANOVAs were conducted for each age group to determine if there were significant differences across single and dual-task conditions for word recognition in noise. Dual-task word recognition with 3- and 5-digit recall was compared with the baseline performance (single-task word recognition) as a within-group factor (See Table 3). The Bonferroni method for multiple hypothesis tests was used to adjust α-levels (.05/4 = .0125). Improvements in word recognition in noise were significant for the 7-8-year in the 3-digit condition [$F(1, 15) = 13.1$, $p < .005$] and for the 9-10-year olds in both the 3-digit [$F(1, 15) = 12.6$, $p < .005$] and 5-digit conditions [$F(1,15) = 17.1$, $p < .005$: with 5-digit], but not for the 11- to 12 or 13- to 14-year olds. Because these older children performed at very high levels for baseline measures, there was relatively little room for improvement. As a result of improved word recognition in the dual-task conditions for the younger children, the performance gap between younger and older children was reduced and the age effects apparent for single-task word recognition in noise disappeared in the dual-task conditions

Dual-task digit recall decreased significantly compared to single-task digit recall for all age groups (see the right panel of Figure 3). Again, separate repeated measures ANOVAs were conducted for each age group (Bonferroni adjusted α was used). As before, single task performance was used as the baseline. The observed decrement in digit recall in the dual-task conditions was significant [$p < .0125$] for all age groups (Table 4).

To determine if there was an age-associated decrement in digit recall, two separate oneway ANOVAs were conducted for the 3- and 5-digit recall decrements (absolute differences in performance between the single- and dual-task conditions, see Table 5). The decrement in 3-digit recall differed by age group [$F(3, 60) = 9.258$, $p < .009$] with the 7-to-8 year-old group showing the greatest decrement (35.2%). Posthoc tests (unequal variance assumed and Games-Howell adjustments used) revealed that the decrement in 3-digit recall for the youngest group was significantly different from both the 9- to 10-year olds [$p < .011$] and the 13- to 14-year olds [$p < .009$], suggesting that 7 to-8 year-old children require greater STM capacity to recognize words in noise compared to older children. For the more challenging 5-digit recall condition, a one-way ANOVA revealed no statistically significant age-associated differences in dual-task decrements. This finding is partially due to unequal variance between the groups and small sample size (n=8). In general, for all age groups it appears that the competing word recognition task significantly interfered with dual-task digit recall.

Confounding and latent variables for word recognition

Dual-task improvements are not typically observed in split attention tasks. It is possible that confounding effects of uncontrolled variables may have contributed to this unusual finding. This possibility was assessed by examining the correlations between improved word recognition and five potentially confounding variables. Specifically, it is possible that the subjects with better STM (as measured by either the Digit Span Test or the 5-digit recall task) performed better than those with poorer STM. Alternatively, a larger vocabulary (PPVT) may have facilitated word recognition. Finally, task order (dual task 1^{st}, single-task 2^{nd} or vice versa) or differences in word list difficulty may have influenced results. As can be seen in Table 6, no significant correlations were found between improvements in word recognition in the dual-task conditions and any of these potentially confounding variables.

Discussion

In general, an account of limited capacity in STM for children's poor speech perception in noise was partially supported. The following predictions were made in the current study based on the hypotheses of limited capacity and developmental STM deficit:

1. Dual-task deficit was expected in both tasks due to capacity limit. However, children showed decrements in dual-task performance relative to single-task for digit recall, but not for word recognition in noise. Therefore, the hypothesis for dual-task decrement due to limited capacity was partially supported.
2. The magnitude of dual-task decrement was expected to vary by age of listener due to developmental changes in STM capacity. This age trend is observed only in digit recall during dual-tasks. Dual-task decrement in 3-digit recall decreased with age. However, dual-task decrement in 5-digit recall did not significantly differ with age.
3. Changing the primary task (or task priority) was expected to alter the attention allocation pattern as evidenced by a shift in which task demonstrated the greatest dual-task decrement. However, most children in our study did not demonstrate top-down

controlled attention allocation based on task priority. Speech processing appeared to receive preferential allocation regardless of priority instructions.

An additional finding, which was not predicted, was the fact that significant improvements in word recognition in noise were observed during dual-tasks compared to the single-task condition for the youngest two groups.

STM and speech processing in noise

An account of the development of children's speech perception in noise based on a similar age-associated increase in STM capacity was examined. Both STM capacity and word recognition in noise improved with age. There was also a significant (but weak) correlation between STM capacity and single-task word recognition in noise. However, the age-associated difference in word recognition in noise disappeared in the dual-task conditions as a result of improved word recognition by the younger children (7-8 & 9-10 year olds). This improvement in word recognition by younger children came at the expense of decreased digit recall in the dual-task conditions. Dual-task decrements in digit recall decreased with age. Therefore, age-associated differences in word recognition in noise were traded off for age-associated decrements in digit recall in the dual-task conditions. This suggests that younger children may require greater STM capacity to process speech in noise at performance levels comparable to those of older children. However, the improvement in word recognition during dual tasks (where capacity demands are higher) suggests that limited capacity in STM may not fully account for younger children's generally poorer speech perception in noise. Limited STM capacity may be only one of many factors that contribute to the developmental changes that are often reported for speech perception in noise tasks. In the current study, it appears that a greater amount of STM capacity was allocated to process speech in noise in the presence of a competing task.

Attentional modulation and speech perception

Improved word recognition in noise during dual tasks was unexpected and contradictory to a limited capacity model. Factors such as STM, vocabulary, task order, and word list effects did not explain this unusual finding. Although the current results would not be predicted from limited capacity models, previous work in attention may allow us to speculate on possible mechanisms underlying this effect.

One possibility is that children may have allocated more resources to the word recognition task when the overall task (i.e., the combination of tasks) became more difficult. Urbach and Spitzer (1995) reported improved visual discrimination in adults when a sample stimulus and a test stimulus had different orientations relative to a condition where both stimuli had identical orientations. Presumably the increased demands of the initial task led to recruitment of additional attentional resources. It is possible that in the current experiment children may have increased attentional resources during the dual-task to meet the increased processing demands of competing tasks. However, this explanation is challenged by improved word recognition during dual-tasks even when the priority of attention allocation was given to the digit recall tasks.

Another possible mechanism for improved word recognition is a result of reduction or suppression of interference from irrelevant information that is mediated by increased processing load in a relevant task. According to Lavie's theory of attention (1994; 1995), the extent of perceptual processing of irrelevant information is dependent on the processing load required for a relevant task (Rees, Frith, & Lavie, 1997). Since the processing load was higher during the dual-task compared to the single-task, irrelevant information to word identity (e.g., acoustic features related to talker identity) may not have been processed fully. This may have made word recognition more efficient and less prone to errors. In line with this suppression of interference account, Kim, Kim and Chun (2005) recently demonstrated a reduction of Stroop interference during a dual-task when the type of concurrent working memory load overlapped with distractor processing. Specifically, in a color comparison Stroop task, the relevant task was to determine whether the color of a printed word was the same as the color of a patch. Subjects performed this task while simultaneously remembering a random set of seven nonsense monosyllables. The verbal processing of the distractor (the semantic content of the printed word) was limited by concurrent memory load of verbal information, which resulted in less interference with the primary task. In the present experiment, split attentional resources also may have limited the processing of distracting irrelevant acoustic features.

A third mechanism that may account for improved recognition under limited capacity is shifts in phonetic cue weighting. Gordon, Eberhardt, and Rueckl (1993) demonstrated changes in the relative importance of acoustic cues for phonemic labeling when attention was divided by a competing arithmetic task (deciding whether the difference between two pairs of numbers was identical or not). It was found that in the identification of /ba/ vs. /pa/, subjects' reliance on a weaker cue (F0-onset frequency) increased in the presence of a competing task while their reliance on a stronger cue (voice onset time) decreased. Children's phonetic cue weighting has been shown to differ from that of adults (Nittrouer, 2005; Sussman, 2001; Nittrouer, 1992). One may presume that child weighting patterns are less effective than mature weighting strategies. It is possible that dual-task demands resulted in shifts in children's weighting functions that were more optimal for this speech in noise task.

These underlying mechanisms are highly speculative and the current data do not support any one in particular. But they have in common the notion that children may bring sub-optimal processing strategies to word recognition in noise that may be ameliorated by forced attentional reallocation. This forced refocus of processing strategy is necessary because it is clear from the present study that voluntary allocation is limited in children.

Development of attention allocation

Children in the current study showed immature top-down controlled attention allocation according to task priority. Children in all age groups failed to maintain their baseline digit recall performance, and showed a significant dual-task decrement in digit recall even when task priority was given to the digits. The lack of difference in results across the two priority-instruction conditions suggests a major deficit in attentional control in children.

Immature attention allocation in the 7 to 14-year-old children in this study is somewhat consistent with previous findings, which suggests that attention allocation abilities begin to develop in late childhood. Schiff & Knopf (1985) studied the developmental changes in attention allocation in 9 year-old and 13 year-old children. Their dual tasks were detecting visually presented target symbols and recalling visually presented letters simultaneously. Nine year-old children did not show a change in the duration of fixation on a target in the dual-task condition compared to the single-task condition. However, 13 year-old children fixated for a shorter time on the target, but at the same time improved performance in recalling letters. The decrease in time spent on target symbol detection was interpreted as an improvement in attention allocation in accordance with task demands. Irwin-Chase and Burns (2000) compared children's attention allocation by varying task priorities for two visual detection tasks in both 8 and 11 year-old children. It was found that 11 year-old children could allocate attention according to task priority but 8 year-old children could not. In the present study, the majority of 11 to 14 year-old children did not show the mature ability to allocate attention by task priority. Karatekin (2004) measured pupillary dilation as an estimate of attentional effort in a study of attention allocation in 10 year-old children and young adults. Pupillary dilation was measured while subjects rehearsed increasing sequences of 4 to 6 to 8 digits while simultaneously pushing a button as soon as they saw a rock on a monitor. As the length of the digit string increased, pupillary dilation increased linearly in adults but not in children. This indicates that children have not necessarily developed the ability to voluntarily allocate or recruit extra attentional resources to meet increased processing demands by the age of 10.

Future directions and implications

Based on the findings from the current study, it is difficult to draw any conclusions regarding the underlying mechanisms for improved word recognition in the dual-task conditions. Further investigations are needed to test the validity of the possible mechanisms proposed here. In this study, only one aspect of STM capacity was investigated (STM span). Therefore, the development of complex STM and attentional control will need to be investigated in relation to children's speech perception in noise. In addition, in the current study speech perception was assessed at a single, relatively favorable SNR. To gain a clearer picture of the effects seen here, additional studies using multiple levels and different types of noise need to be conducted.

The current results may have clinical implications in training children who exhibit difficulties processing auditory information. For example, children with language impairments exhibit difficulty in processing speech in noise and have difficulty extracting the relevant acoustic-phonetic features (e.g., temporal features such as formant transition) from speech. These children also can exhibit STM and attention deficits which can make their acoustic-phonetic representations more vulnerable to noise interference or irrelevant information. For these children, voluntary attention allocation to speech may be difficult. Dual-tasks may improve induced attention allocation by adding a competing task. When capacity limitation is induced by increasing a processing load with a competing task, processing of relevant and significant acoustic information may be facilitated by taking away the processing resources available for irrelevant information and reallocating these resources to a dual task due to the limitations in processing capacity. In addition, inappropriate cue-weighting strategies may be modified by reducing the amount of attention available for processing unimportant acoustic details to which children may attend. However, these concepts are highly speculative and would require systematic evaluation in additional studies to determine the feasibility of such an approach.

In summary, findings of the current study suggest that: 1) STM capacity and word recognition in noise increase with age over the age range tested in this study; 2) A positive, but weak correlation ($r = .363$, $p < .003$) exists between STM and word recognition at the favorable (8 dB) SNR used in this study; 3) In the presence of limitations in processing capacity (e.g., dual-task conditions), word recognition is not reduced by a competing task; 4) The mechanisms for younger children's improved word recognition in the dual-task conditions are unknown, but they do not appear to be related to a developmental deficiency in STM capacity; 5) Younger children's higher performance for word recognition in noise during dual-tasks is accompanied by a larger decrement in digit recall; 6) While STM capacity may be important for speech perception in noise, younger children's improvement in dual-task word recognition in the current study suggests that their insufficiency in speech perception may not be related to limitations in STM; 8) Children's top-down controlled attention allocation is not fully mature at least up to 14 years of age.

Acknowledgements

This work was supported by grants from the National Institute on Deafness and Other Communication Disorders, National Institutes of Health (R01 DC04300 and DC04662). We would like to thank Sandy Estee for assistance in recruiting participants and Chad Rotolo and Anthony Garot for software development. We would also like to thank the reviewers for comments and suggestions on an earlier version of the manuscript.

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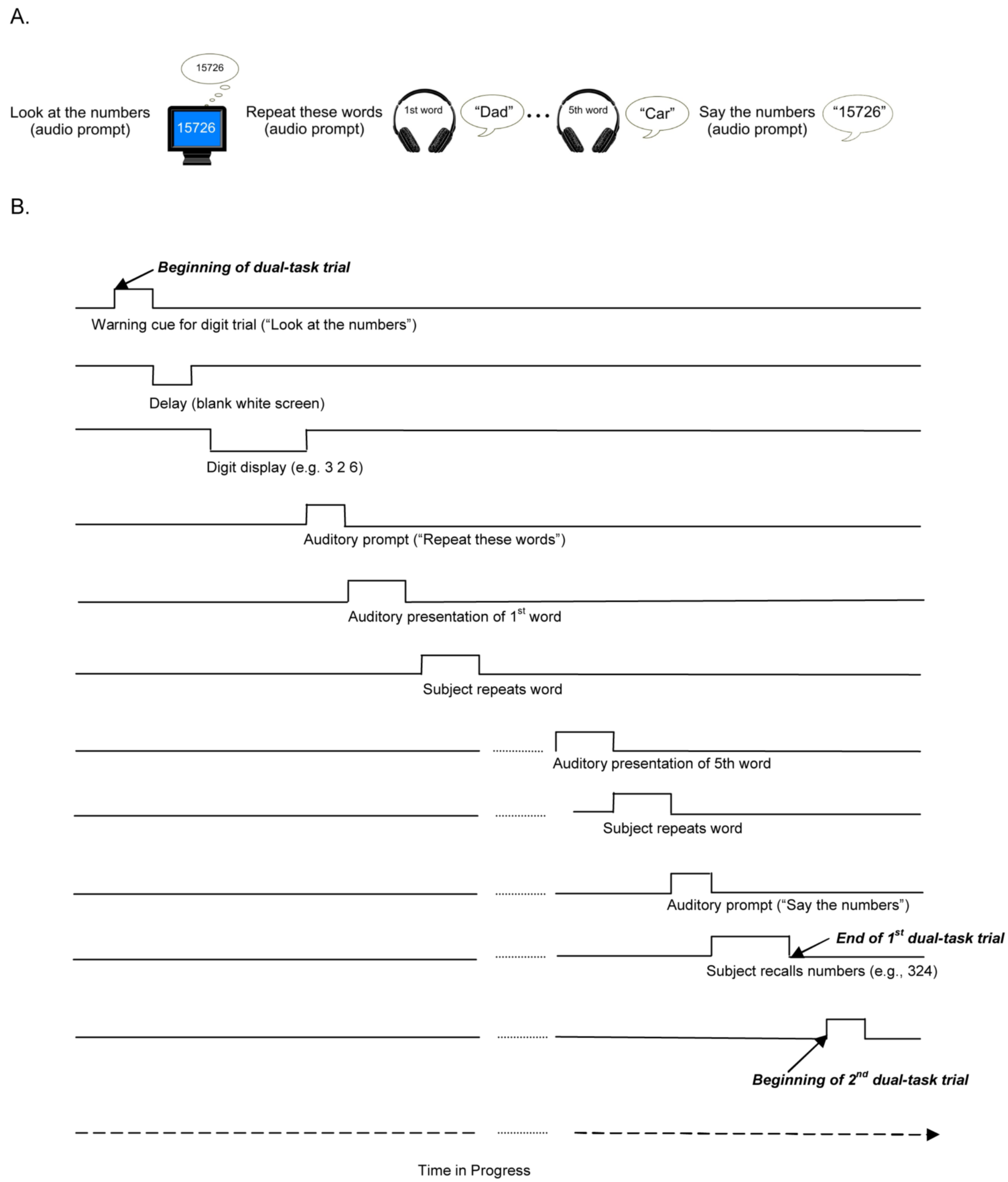
A.
15726
Look at the numbers
(audio prompt)
15726
Repeat these words
(audio prompt)
1st word
"Dad"
5th word
"Car"
Say the numbers
(audio prompt)
"15726"
B.
Beginning of dual-task trial
Warning cue for digit trial ("Look at the numbers")
Delay (blank white screen)
Digit display (e.g. 3 2 6)
Auditory prompt ("Repeat these words")
Auditory presentation of 1st word
Subject repeats word
Auditory presentation of 5th word
Subject repeats word
Auditory prompt ("Say the numbers")
End of 1st dual-task trial
Subject recalls numbers (e.g., 324)
Beginning of 2nd dual-task trial
Time in Progress

Fig 1.

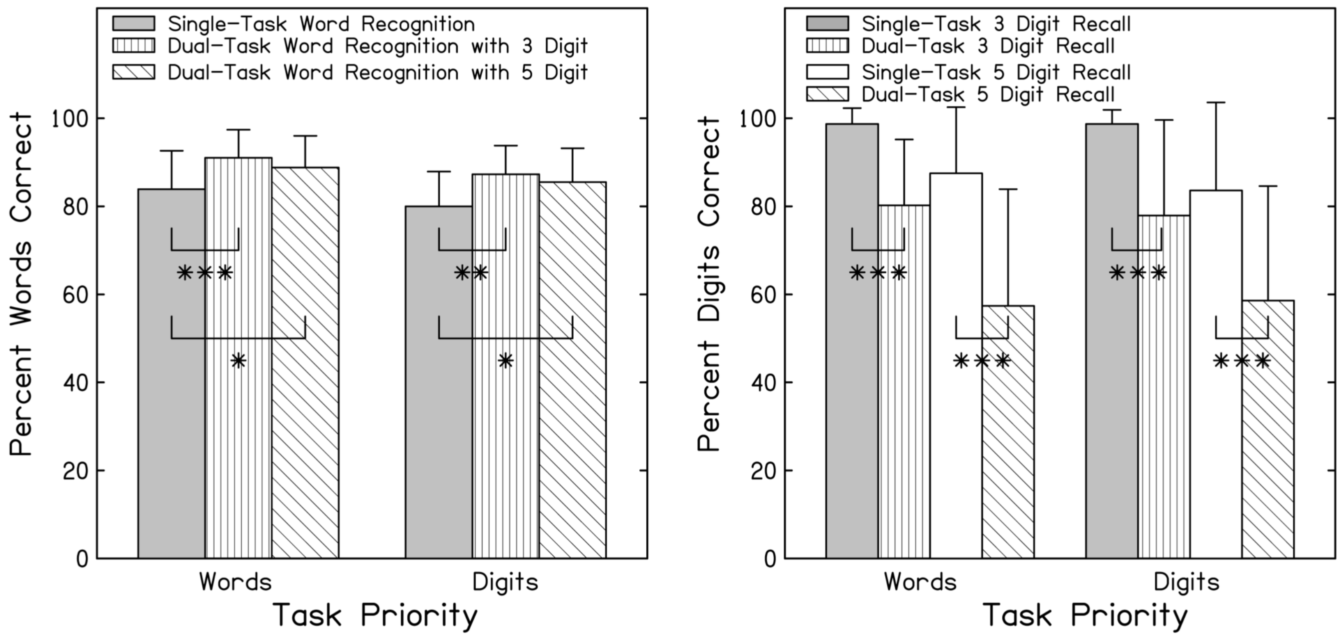
Single–Task Word Recognition
Dual–Task Word Recognition with 3 Digit
Dual–Task Word Recognition with 5 Digit
Percent Words Correct
100
80
60
40
20
0
***
*
**
*
Words
Digits
Task Priority
Single–Task 3 Digit Recall
Dual–Task 3 Digit Recall
Single–Task 5 Digit Recall
Dual–Task 5 Digit Recall
Percent Digits Correct
***
***
***
***
Words
Digits
Task Priority

Fig 2.

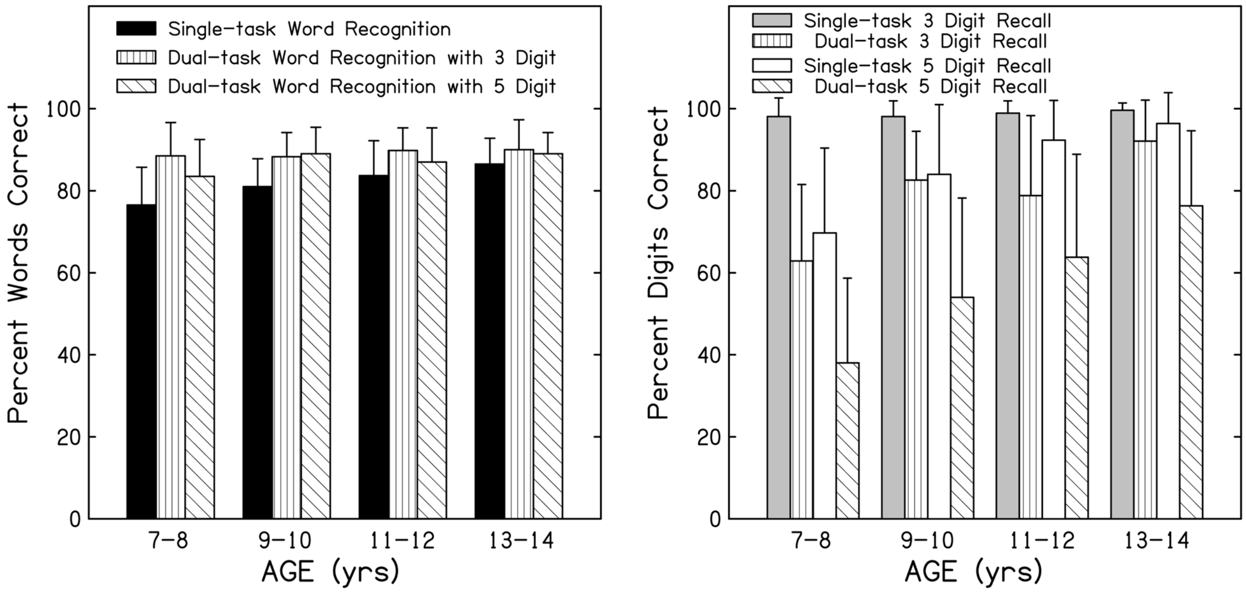
Single−task Word Recognition
Dual−task Word Recognition with 3 Digit
Dual−task Word Recognition with 5 Digit
Percent Words Correct
0
20
40
60
80
100
7−8
9−10
11−12
13−14
AGE (yrs)
Single−task 3 Digit Recall
Dual−task 3 Digit Recall
Single−task 5 Digit Recall
Dual−task 5 Digit Recall
Percent Digits Correct
AGE (yrs)

Fig 3.

Table 1

Means and SD (in parenthesis) of participants' profiles

Group	Age Group	Chronological Age	PPVT	Digit span	Gender		N
					M	F	
1	7-8	7.6 (0.5)	113.9 (21.4)	13.5 (2.0)	4	4	8
	9-10	10.2 (0.7)	150.4 (11.3)	15.5 (3.7)	4	4	8
	11-12	12 (0.4)	152 (20.3)	16.3 (3.3)	4	4	8
	13-14	13.5 (0.5)	167.3 (13.7)	18.1 (4.0)	4	4	8
Group 1 Total		10.8 (2.3)	145.63 (25.7))	15.8 (3.6)	16	16	32
2	7-8	7.6 (0.5)	114.5 (16.5)	13.6 (1.9)	4	4	8
	9-10	10.2 (0.7)	130.4 (17.1)	14.3 (3.4)	4	4	8
	11-12	12.1 (0.2)	155.4 (13.2)	15.1 (2.7)	4	4	8
	13-14	13.5 (0.5)	165.1 (10)	16.8 (2.4)	4	4	8
Group 2 Total		10.8 (2.3)	141.1 (24.7)	14.9 (2.8)	16	16	32
Overall Total		10.8 (2.3)	143.4 (25.1)	15.4 (3.2)	32	32	64

Table 2

Mean percent correct and SD (in parenthesis) for single-task digit recall and word recognition in noise

Age group	Group	3digit	5 digit	Word	N
7-8	1	97.1 (5.9)	68.9 (15.2)	77.5 (9.1)	8
	2	99.1 (2.5)	70.5 (26.1)	75.5 (9.9)	8
9-10	1	98.8 (2.6)	89.5 (8.5)	83.0 (7.6)	8
	2	97.5 (4.9)	78.5 (21.9)	79.0 (5.6)	8
11-12	1	98.8 (3.5)	93.0 (10.6)	88.0 (9.1)	8
	2	99.1 (2.5)	91.5 (9.4)	79.5 (5.4)	8
13-14	1	100 (0)	98.8 (2.4)	87.0 (6.0)	8
	2	99.1 (3.2)	94.0 (10.0)	86.0 (7.1)	8

Table 3

Single and dual-task word recognition scores and a repeated measure of ANOVA results within each age group (N=16, df = 1,15 and α=0.0125 for all comparisons)

Age Group	Single-task	Dual-task with 3 digit	Dual-task with 5 digit	ANOVA (Adjusted α=. 0125) Comparisons	F (P)
7-8 yrs	76.5	88.5	83.5	Single vs. Dual with 3	13. 2 (.0002)*
				Single vs. Dual with 5	5.4 (.034)
9-10 yrs	81.0	88.3	89.0	Single vs. Dual with 3	12.6 (.003)*
				Single vs. Dual with 5	17.1 (.001)*
11-12 yrs	83.8	89.8	87.0	Single vs. Dual with 3	7.1 (.018)
				Single vs. Dual with 5	1.5 (.24)
13-14 yrs	86.5	90.0	89.0	Single vs. Dual with 3	2.4(.14)
				Single vs. Dual with 5	1.6 (.22)

* Statistically significant at a Bonferroni adjusted α.

Table 4

Single and dual-task digit recall scores and a repeated measure of ANOVA results within each age group (N=16, df = 1,15 and α=0.0125 for all comparisons). All comparisons are statistically significant.

Age Group	Single 3-digit	Dual 3-digit	Single 5-digit	Dual 5-digit	ANOVA		
					Comparisons	*F*	*P*
7-8 yrs	98.1	62.9	69.7	38.0	3 digit	51.9	.003*
					5 digit	37	.002*
9-10 yrs	98.1	82.6	84.0	54.0	3 digit	29.7	.006*
					5 digit	25.6	.0001*
11-12 yrs	98.9	78.8	92.3	63.8	3 digit	20	.0004*
					5 digit	40.4	.001*
13-14 yrs	99.6	92.1	96.4	76.3	3 digit	9.2	.009*
					5 digit	25.6	.0001*

Table 5

Means and SD (in parenthesis) of the amount of decrement (=absolute difference in percent correct scores between the single-task and the dual-task.) in digit recall due to a competing word recognition task.

Age-group	3-digit decrement	5-digit decrement	N
7-8	35.2 (19.5)	31.7 (20.8)	16
9-10	15.6 (11.4)	30.0 (23.7)	16
11-12	20.2 (18.0)	28.5 (17.9)	16
13-14	7.5 (9.9)	20.1 (15.9)	16

Table 6

Pearson correlations (N=64) between the Improvement in word recognition in the dual-task Conditions and the confounding variables. None of the correlations was significant at α= .05.

	Word improvement in 3-digit condition	Word improvement in 5-digit condition
STM (Digit span)	−.199	−.2
STM (5-digit serial recall)	.184	−.109
PPVT	−.176	−.121
Task order	−.131	−.144
Word list	−.2	.067