Published in final edited form as:
Memory. 2008 October ; 16(7): 773–787. doi:10.1080/09658210802261124.

Working Memory Capacity for Spoken Sentences Decreases with Adult Aging: Recall of Fewer, but not Smaller Chunks in Older Adults

Amanda L. Gilchrist, **Nelson Cowan**, and **Moshe Naveh-Benjamin**
University of Missouri

Abstract

Previous studies show that older adults have poorer immediate recall for language but the reason is unknown. Older adults may recall fewer chunks from working memory, or may have difficulty binding words together to form multi-unit chunks. We examined these two hypotheses by presenting 4 types of spoken sentences for immediate free recall, differing in the number and length of chunks per trial: 4 short, simple sentences; 8 such sentences; 4 compound sentences, each incorporating two meaningful, short sentences; and 4 random word lists, each under a sentence-like intonation. Older adults recalled words from (accessed) fewer clauses than young adults, but there was no aging deficit in the degree of completion of clauses that were accessed. An age-related decline in working memory capacity measured in chunks appears to account for deficits in memory for spoken language.

A fundamental hypothesis in cognitive psychology is that the working memory system is capacity-limited in terms of the number of chunks that can be stored or maintained at once (Miller, 1956; Cowan, 2001). Prior research has demonstrated that both the number and size of chunks that are concurrently stored in working memory can be estimated from task performance (e.g., Cowan, Chen, & Rouder, 2004). It is possible to ask, then, whether the number and/or size of chunks changes with age in adulthood. Naveh-Benjamin, Cowan, Kilb, and Chen (2007) recently provided evidence from the serial recall of word lists that the number of chunks that can be held in working memory decreases considerably in adult aging, and that the ability to retain multi-word chunks also decreases somewhat. The present research investigates similar processes in natural language, making use of the idea that the coherence of language does result in multiword chunks in memory (cf. Tulving & Patkau, 1962). However, in order to determine how capacity limits affect working memory we present more than one such chunk and we vary the effective length of a chunk (by presenting lists of random words, lists of one-clause sentences, and lists of two-clause sentences).

To situate the current study theoretically, we review the phenomenon of chunking and its relation to capacity limits in working memory and then discuss aging and its effects on memory, with an emphasis on how such effects might relate to chunk formation in language processing.

Working Memory and Chunking

Following Miller's (1956) seminal work on “the magical number seven plus or minus two,” subsequent research has provided further evidence for a basic capacity limit in working memory, although the limit is only approximately three to four unitary items or chunks (Broadbent, 1975; Cowan, 2001). For example, a normal young adult can recall a list of at least

Address correspondence to: Nelson Cowan Department of Psychological Sciences 210 McAlester Hall University of Missouri Columbia, MO 65211 E-mail: CowanN@missouri.edu Phone: (573) 882−4232.

three unrelated items reliably, without error or hesitation (Broadbent, 1975). Cowan (2001) reviewed a great deal of further evidence, based on tasks in which items presumably cannot be grouped together to form higher-level chunks and cannot be phonologically rehearsed. He suggested that the capacity limit reflects how many items can be held in the focus of attention at once.

Miller (1956) emphasized that more items could be recalled when they were organized into superordinate groups on the basis of pre-existing knowledge or associations, a process he called chunking. However, he did not consider other processes that might allow more items to be recalled than would be expected on the basis of a core capacity limit. The items might be grouped through the rapid learning of inter-item associations (Cowan, 2001), or they might be covertly rehearsed in a repeating phonological sequence (Baddeley, 1986). These extra processes may account for the different estimates of immediate memory capacity suggested by Miller versus Broadbent (1975) and Cowan.

An early study of chunking in verbal free recall (Tulving & Patkau, 1962) made use of pre-existing linguistic knowledge to examine capacity limits for chunks much longer than isolated words. Participants were presented with lists of words that approximated English text to varying degrees. The lower levels of approximation had plausible transitions from one word to the next but each of these multi-word passages as a whole was ungrammatical and nonsensical. Participants could recall the words in the list in any order, but the authors defined an "adopted chunk" as a group of items that were recalled in the correct sequential order. A limit of about 4 to 6 adopted chunks was observed across all levels of approximation to English, providing further evidence for a basic capacity limit in working memory. The more closely the presented words approximated English text, thus increasing in meaningfulness and grammaticality, the larger the adopted chunks became on average. Similar findings of a capacity limit for coherent multi-word sequences, close to the core capacity limit of 3 or 4 chunks identified by Broadbent (1975) and Cowan (2001), were also obtained in other studies (Glanzer & Razel, 1974; Simon, 1974). Cowan et al. (2004) obtained similar results for lists comprising learned pairs of words. It appears that inter-word associations influence the sizes of recalled chunks but not capacity, i.e., the number of chunks an individual can recall.

Thus, capacity appears to remain roughly constant across studies, with larger chunks recalled when covert phonological rehearsal and/or grouping are possible. Covert phonological rehearsal appears to be limited to materials that can be pronounced in about 2 s and is especially useful for serial recall (e.g., Baddeley, 1986; Chen & Cowan, 2005).

Despite this convergence of results, it could be argued that the available information about the chunks formed in recalled spoken language is only approximate. For a fair comparison across age groups, we operationally defined chunks as structures that were assumed to be stored with internal associations, similar to a previous study (Naveh-Benjamin et al., 2007). These operationally- defined chunks were, however, words or learned word pairs within lists in Naveh-Benjamin et al. but clauses or sentences within lists in the present linguistic study. Constancy in capacity across list lengths can be used as evidence on the aptness of the operational definition. . Previous work on the effects of aging on working memory for language helps to set expectations for our task, and will now be considered.

Aging Effects on Working Memory for Language

List recall has served as a simplifying technique, within which the number and size of chunks were observed in a previous study of aging effects. A great deal of additional work helps to define expectations for why chunk formation ability might be affected by aging. There also is research providing a description of how the coherence of language might moderate any effects of age on the sizes of chunks that can be formed. These areas of background will be described in turn.

Age deficits in list recall

A previous study has indicated that the number of chunks that can be maintained in working memory declines with age. Naveh-Benjamin et al. (2007) obtained estimates of the number and size of formed chunks for young and older adults by examining rates of chunk access and completion for lists of word pairs composed of words that had been presented either as singletons, or in the same pairings that were used in the lists. A chunk was said to be accessed when at least one item of a word pair was recalled, and chunk completion was taken as the conditional probability that the remaining word in a pair was recalled, given that the pair was accessed. By these measures and a derived model, capacity was constant across materials and young adults recalled considerably more chunks than older adults, and recalled somewhat larger chunks.

Age differences in chunk formation

The observed age-related decline in chunk formation, specifically in chunk size estimates as observed by Naveh-Benjamin et al. (2007), may be related to binding deficits found to occur with age. Whereas recognition for a particular feature parallels recognition performance in young adults, older adults often encounter deficits in binding of multiple features of objects during short-term encoding (Mitchell, Johnson, Raye, Mather, & D'Esposito, 2000; Cowan, Naveh-Benjamin, Kilb & Saults, 2007) or when two objects must be associated into a single unit in long-term memory (Naveh-Benjamin, 2000; Naveh-Benjamin, Hussain, Guez, & Bar-On, 2003; Naveh-Benjamin, Guez, Kilb, & Reedy, 2004; Naveh-Benjamin, Guez, & Shulman, 2004; Castel & Craik, 2003; Light, Patterson, Chung, & Healy, 2004; Bastin & Van der Linden, 2006). Naveh-Benjamin (2000) proposed the associative deficit hypothesis to account for the above findings, stating that, although long-term memory for component objects or features is relatively unaffected by aging, the ability to form or retrieve associations between features or objects significantly declines with age in adulthood.

The relevance of associative binding to a short-term list recall task is that a chunk can be considered a type of binding or association between items, perhaps with an additional binding to the current temporal context. In the case of presented word pairs, as was used in Naveh-Benjamin et al. (2007), this binding may take place between words in a presented pair. Older adults should encounter difficulty in binding two words together into a cohesive unit, resulting in the observed decline in chunk size estimates. Age differences in binding are often greatest for novel associations or bindings; as meaningfulness increases between items through repeated pairing or greater semantic associations, age differences in binding typically decline (Hay & Jacoby, 1999; Naveh-Benjamin et al., 2003; 2007; Taub, 1974).

Some previous studies examining aging effects on chunking have suggested instead that there may be no age differences in the ability to form chunks out of meaningless strings of items, even when influential grouping is involved (Allen & Coyne, 1988, 1989; Allen & Crozier, 1992). These studies, however, contained a small number of stimuli (e.g., six letters or numbers) that may not greatly tax working memory or provide a need to chunk items together.

Age differences in recall of coherent language

The presence of increased meaningful semantic and syntactic associations in linguistic materials should ease binding deficits (e.g., Naveh-Benjamin et al., 2003; Taub, 1974). Nevertheless, recall of coherent language requires holding in mind multiple pieces of information (e.g., various syntactic and semantic structures that comprise linguistic materials) that cannot all be reduced to a single chunk. Specifically, as linguistic materials exceed working memory capacity limits, prior research has often found that age-related deficits dramatically increase. Craik and Masani (1967) noted that although older adults improved in recall of discourse as it approximated English, there was a relative age decrement that further increased when materials surpassed working memory span (also see Kausler, 1994).

Exceeding capacity may also affect otherwise unimpaired language processing in older adults. Older adults generally perform as well as young adults on comprehension measures, but their verbatim recall declines as information increases, leading to a greater reliance upon gist interpretations, holistic properties of verbal materials, and surface features (Backman & Nilsson, 1985; Stine-Morrow, Gagne, Morrow, & DeWall, 2004; Stine & Wingfield, 1987). Given age-related declines in working memory capacity, some researchers have proposed that working memory has minimal involvement in creating online gist interpretations in cases of little cognitive load (Radvansky, Copeland, Berish, & Dijkstra, 2003; Radvansky & Dijkstra, 2007; DeDe, Caplan, Kemtes, & Waters, 2004; Waters & Caplan, 2005). In contrast, as the above studies show, working memory is necessary for retaining information offline. However, it can be difficult to quantify where online processing ends and offline processing begins in a task. Prior research has found that as information presented in text increasingly taxes working memory beyond capacity, the likelihood of retaining quality gist interpretations markedly declines (Cohen, 1979; Wingfield, Wayland, & Stine, 1992), leading to greater recall of information that is irrelevant to a passage's central theme (Wingfield & Stine-Morrow, 2000). If aging is accompanied by a reduced working memory capacity, as Naveh-Benjamin et al. (2007) found, the number of items needed to exceed that capacity will also be reduced, making deficits in cognitive processes more likely. The consequences can include greater difficulty in chunking information (Craik, Morris, & Gick, 1990), particularly when chunk organization is not predetermined, offsetting some of the benefits to chunking that linguistic materials provide.

Cowan (2001) suggested that in order to chunk items together, they first must co-exist in working memory. The implication is that, if one's working memory capacity is relatively small, the size of chunk that one can form in a single processing episode should be relatively small. Accordingly, effects of age on chunk size may be secondary to the effects of age on capacity. When strategies to group verbal stimuli into smaller chunks are examined across young and older adults, older adults often process chunks that are smaller in size (Kemper, 2006). Fallon, Kuchinsky, and Wingfield (2006) presented both young and older adults with spoken passages containing alternating one-clause and two-clause sentences that abruptly stopped; participants were instructed to recall words in their correct serial order, leading up to the interruption (see Jarvella 1970, 1971 for more about this paradigm). Older adults were less likely to recall two consecutive clauses, and were more likely to recall less than a full clause (Fallon et al., 2006). Such findings could result from a reduced number of chunks, reduced chunk size, or both.

In sum, the literature clearly indicates that older adults have a deficit in memory for coherent linguistic materials, but the existing evidence is indecisive as to whether the key factor underlying this age difference is in working memory capacity, the size of chunks recalled, or both factors operating together.

Current Study

We examined the effects of age on working memory for lists of coherent sentences, both to understand better the role of working memory in changes in language processing with aging, and to help address issues about working memory and aging that were left unresolved by Naveh-Benjamin et al. (2007) in their study of list recall. There is the issue of whether the findings obtained with unrelated word pairs as stimuli can be generalized to other materials. As words in a pair had no pre-existing associations with each other, a strategy was needed for meaningful encoding and recall. A participant might have needed to create an association between items where one did not exist, which is what the authors intended. Although the word pairs were certainly more meaningful and easier to encode than random shapes or numbers, the stimuli may still have been too difficult for older adults with depleted resources to accomplish such encoding as well as young adults. Specifically, previous research suggests that those with higher working memory capacity are more likely to engage in effortful, strategic processing during encoding and retrieval (e.g., Rosen & Engle, 1997; Cokely, Kelley, & Gilchrist, 2006). As capacity declines with age, older adults may therefore be less likely to take advantage of such processing.

The current study should provide an important extension of the findings of Naveh-Benjamin et al.(2007). Lists of unrelated English sentences were used as stimuli in this study, which may ease task difficulty due to the syntactic and semantic associations that are often present in natural language, as older adults are often helped by pre-existing or predetermined associations (Hay & Jacoby, 1999; Naveh-Benjamin, Craik, Guez, & Kreuger, 2005).

The use of sentence stimuli also creates a situation that is likely to emphasize chunk capacity and chunk size differences with aging, as opposed to age differences in the limit in the phonological length of stimuli that can be recalled. The latter should be important according to the phonological loop account (e.g., Baddeley, 1986) and is known to underlie age differences in word list recall (Kynette, Kemper, Norman, & Cheung, 1990). Baddeley, Thomson, and Buchanan (1975) found that recall for verbally presented items was generally limited to what participants could rehearse in 2 s, providing support for a time-limited capacity. It was attributed to a decaying trace combined with a rehearsal process capable of reactivating items only if they had not yet decayed, which was supposed to occur in about 2 s. If capacity limits in working memory are due to time constraints within a phonological loop, it is to be expected that recall for sentences exceeding this time limit should be very poor; otherwise, an alternative account for these capacity limits will be necessary. In any case, the lengths of sentences we used presumably preclude the use of Baddeley's 2-s loop for more than one sentence in most instances (Glanzer & Razel, 1974).

An aim of this study was to investigate further the effects of aging upon qualitative and quantitative aspects of the use of chunking in recall. The critical manipulation for this study involved the length and grouping of the stimuli. Participants were presented with one of four types of spoken lists: (1) lists of four unrelated long sentences, each made of two meaningfully conjoined, coordinate clauses (e.g., *Turn the block over and place it by the toy*); (2) lists of four random “sentences,” each comprising words from various sentences mixed together in random, nonsyntactic order,(e.g., *the soon help sauce starts*) but with a sentence intonation; (3) lists of four unrelated short sentences, each with a single clause (e.g., *Turn the block over*); and (4) lists of eight unrelated short sentences. The 1-s period between sentences was presumably too short to allow much semantic elaboration of the material, which seemed haphazard within a trial (e.g., in one trial with four short sentences: don't scare your brother; we took pictures as a gift; I upset my mother; answer every question).

As illustrated in Table 1 and detailed in Appendix A, no participant received the same content in more than one condition. Importantly, the two clauses making up a long sentence for one participant group could be separated to form two short sentences for the other participant group, and they were presented to that other group within different trials. Therefore, even though the 1-clause sentences were quite varied in structure, we could observe the effects of conjoining these short sentences to form longer ones.

The four trial types were designed to allow some critical comparisons among conditions and age groups. (1) The four- and eight-short-sentence conditions could be compared to determine the effects of the total memory load. If each short sentence forms a single chunk in working memory, the number of such sentences is the memory load on that trial. We were interested in whether older adults could handle an increasing memory load as well as young adults could. (2) The eight-short- and four-long-sentence conditions could be compared to determine the effects of linguistic coherence. Both of these sentence types contained approximately the same material and were approximately of the same length (the only difference being the conjoining words such as *and*, *but*, *so*, and *as*). They differed, though, in that the coherent meaning and overarching structure across the clauses of a long sentence might at least sometimes allow the entire long sentence to become a single chunk in working memory. We wondered if older adults could bind clauses within a long sentence, and thereby take advantage of the potential reduction in memory load, as well as young adults could. (3) The four-long-sentence condition also could be compared to the four-short-sentence condition. If performance is limited by the number of chunks that can be retained and if each long sentence were encoded as a single chunk, one would expect twice as many short clauses to be recalled within the four-long-sentence condition, because each chunk would include two clauses instead of just one. We do not expect such ideal encoding of long sentences in either age group, but this comparison helps to assess the success of that encoding in each age group. (4) Finally, the four-short-sentence and four-random-sentence conditions can be compared to determine the contribution of linguistic coherence within a short sentence. These sentence types were of equal length but differed dramatically in linguistic coherence. We expected that this coherence might be more critical for performance in older adults because they would be less able to retain the unconnected material of random sentences using phonological rehearsal (Kynette et al., 1990).

The recall measures described have previously been applied to lists of unrelated words or word pairs. It may be argued that extending these measures to lists of unrelated sentences in the present study oversimplifies the stimuli. As mentioned earlier, comprehension of linguistic materials typically involves multiple levels of representation, such as a surface level that retains syntax or deeper levels that maintain semantic information (e.g., Sachs, 1967). Applying these measures to verbatim recall may fail to take into account richer processing beyond the surface structure of the sentence stimuli. To examine this possibility, we examined the frequency with which items were replaced by synonyms. Primarily, though, our approach was to include various levels of linguistic structure in an undifferentiated fashion to determine whether the age difference in recall occurs between structures (e.g., in how many of the unrelated sentences can be accessed) or within structures (e.g., in how complete the recall of each clause or sentence is, once it is accessed).

Method

Participants

Participants were 24 University of Missouri undergraduates and 24 older adults (7 males and 17 females in each age group) recruited from the Columbia, Missouri community, who reported normal or corrected-to-normal vision and hearing. All were randomly assigned to testing groups. An additional male young adult and female older adult were excluded because they did not follow the experimental directions. Young adults had a mean age of 18.37 years (SD = .49) and a mean education level of 13.00 years (SD = 0); the mean age for older adult participants was 70.95 years (SD = 4.56), with a mean education level of 14.02 years (SD = 1.47). Undergraduates received course credit in exchange for participation, while older adults received monetary compensation.

Materials

Stimuli were created through the computer program Audacity. These sentences were verbally presented in a female voice through headphones from 45 to 70 dB. Both the experimental procedure itself and recording of sound data from participants were administered through the computer software program Revolution 2.6.1, which also provided a graphical interface for the experiment in addition to randomizing and presenting sentence stimuli. Participants responded by speaking through a microphone. Responses were converted into sound files and saved by the computer program. Spoken sentences included words taken from age of acquisition norms via the MRC psycholinguistic database (http://www.psy.uwa.edu.au/mrcdatabase/uwa_mrc.htm), with age of acquisition ratings from 100 to 350 serving as the parameters.

Each trial included a list of short, long, or random sentences. Short sentences contained two words from the norms, and were 3 to 5 words long (e.g., *Don't scare your brother*). Long sentences were composed of two short sentences that were connected, and were 8 to 11 words long (e.g., Don't scare your brother because the screaming bothers me). Random sentences were similar to simple sentences in that each contained two words from the norms and were 3 to 5 words long. However, the words were in a non-grammatical, haphazard order (e.g., *aunt jersey cooked almost*) albeit in a usual sentence intonation.

Design

Four different conditions were formed to compare the number of chunks and the total length of those chunks (here, the number of words) across stimuli types. The material to be remembered in a trial included one of the following: (1) 4 short sentences, (2) 4 long sentences, (3) 8 short sentences, or (4) 4 random sentences. For example, 4 long sentences and 8 short sentences were equivalent in overall length; in terms of the number of chunks, 4 long sentences were equivalent to 4 short sentences if perfect chunking is assumed. There were two trials in each of these four conditions, and the order of these eight trials was randomized across participants.

An illustration of how sentences were reassigned to different trial conditions to achieve counterbalancing is included in Table 1; for additional details on the stimuli, trials, and presentation order, refer to Appendix A. The sentences used for short and long sentence trials were equated and counterbalanced across subjects, so any differences in performance that occurred could not be attributed to the selection of materials. Sentences that were a part of long sentence conditions for half of the participants were presented as short sentences for the remaining half. As an example, participants in Group 1 were presented with the long sentence *Play in the park but expect rainy weather later*. For participants in the second group, this sentence was deconstructed into two smaller sentences (*Play in the park* and *Expect rainy weather later*), and these were placed into different conditions (either the four- or eight-short-sentence conditions). Likewise, long sentences that were presented to the second group of participants were deconstructed into short sentences to be presented to the first group.

Short sentences that would be connected in a long-sentence condition were placed in different short-sentence conditions to reduce sentence-specific effects. Using the above example, *Play in the park* was placed in the first trial of the eight-short-sentence condition; *Expect rainy weather later* was placed in the second trial of eight short sentences. In a similar fashion, short sentences could be combined to form a long sentence, or combined with other short sentences to form random sentences. For example, the sentence *We took pictures as a gift* was deconstructed and combined with other short sentences to form the random sentences *the struck pictures your sting* and *gift building a as* for half of the participants.

Procedure

All participants were tested one at a time, in quiet rooms. Testing sites were equipped with a computer to run the experiment program, headphones for listening to stimuli, and a microphone for recording spoken responses. After completing necessary informed consent and demographic forms, participants were instructed to listen carefully to the stimuli and, when cued, verbally recall what they had just heard in any order. Each of the eight trials began with a 1000-ms fixation on the computer screen (the word "Ready") to alert participants. The spoken stimuli were then presented through the headphones. Each sentence in a trial condition was separated by a pause of 1000 ms. At the end of the set of sentences and a final pause of 1000 ms, a 500-ms, 400 Hz tone was presented as the cue for participants to verbally recall the stimuli. Participants provided their answers by speaking through a microphone. This free recall period had a maximum duration of 1 minute, though participants were free to terminate recall before that time by pressing a key. Another key press started the next trial. All responses were converted into sound files and saved by the computer program.

Analyses

All participant responses were verbally transcribed by the experimenter. Three different measures were used to examine age differences in recall of the different trial conditions: total words recalled, clause access, and clause completion. *Total words recalled* simply involved the number of words correctly recalled from each condition. If more than one instance of a word was present (e.g., if "the" appeared twice), each occurrence in recall was counted as a separate word recalled. *Clause access* referred to access to the groups of information provided, and was measured as the number of clauses in a sentence condition from which at least one word was recalled. A clause was measured as one short sentence; how this was adapted for long and random sentences is discussed below. The assumption regarding clause access was that multiple words recalled from the same clause or 1-clause sentence are considered, tentatively at least, to form part of the same chunk in working memory. On the basis of a similar assumption about access to learned word pairs, Naveh-Benjamin et al. (2007) found a roughly constant working memory capacity across learning conditions and a decrease in capacity (fewer pairs accessed) for older adults than for young adults, and we wanted to see if that result would generalize to sentence materials.

In the case of four long sentences, each long sentence was made up of two smaller clauses, resulting in eight total clauses (as in the 8-short-sentence condition). We did not know if clauses were truly adjoined into long sentences and the only way to find out was to consider pairs of clauses as both a single sentence and as separate clauses, to see whether either measure would yield constant capacity across stimulus types. We expected that short, 1-clause sentences that were connected into a long sentence would be easier to recall than they would be if presented separately, as was done in the four- and eight-short-sentence conditions; but possibly not sufficiently easy to recall to conclude that long sentences were consistently integrated into a single, meaning structure.

For the scoring of four random sentences, each one was considered a clause, with a maximum of four clauses that could be accessed. Similar to the measure of chunk completion used by Naveh-Benjamin et al. (2007), *clause completion* was measured as the proportion of words recalled for a given clause, conditional on access to the clause. This scoring essentially treated the four-random-sentence condition as a control to contrast with the use of sentence structure in the four-short-sentence condition.

Results

Means and standard errors for the measures explained above were calculated for each age group across sentence condition, and can be found in Table 2. The results for each of the measures will be discussed in turn.

Words Recalled per Trial

A repeated-measures ANOVA for the mean number of words recalled per trial included age group as a between-subjects factor and sentence condition as a within-subjects factor. There was a significant main effect of age group, F(1, 46) = 9.03, $\eta_p^2 = .164$, p <.01, with young adults recalling more words (*M* = 10.81, *SD* = 2.48) than older adults (*M* = 8.66, *SD* = 2.48). There was also a significant effect of condition, F(3, 138) = 112.12, $\eta_p^2 = .709$, p < .001, with the greatest number of words recalled for four long sentences (*M*= 14.02, *SD* = 4.52), followed by four short (*M* = 10.52, *SD* = 2.68), eight short (*M* = 9.67, *SD* = 3.52), and four random sentences (*M* = 4.73, *SD* = 1.83). Figure 1 shows that, as the number of words increased in sentences, and as the amount of coherence increased, recall performance was generally higher (i.e., number of words recalled was highest for four long sentences and lowest for the condition termed four random sentences, which are half as long and have no linguistic coherence).

The main effects were qualified by a significant age group × condition interaction, F(3,138) = 4.23, $\eta_p^2 = .084$, p <.01. Post-hoc Newman-Keuls tests provided more information about the above findings. For young adults, recall followed the pattern: four long > four short = eight short > four random. For older adults, the pattern was slightly different: four long > four short > eight short > four random The difference is that four short and eight short sentences produced equivalent numbers of words recalled in young adults, but the larger number of sentences diminished recall in older adults. Young adults recalled roughly the same number of words from both conditions, which may indicate a capacity limit. In contrast, older adults recalled more information from four short than from eight short sentences, suggesting that older adults may not be able to avoid interference from additional material after their capacity limit has been exceeded.

Independent-sample, 1-tailed t-tests (summarized in Table 3) were considered a priori comparisons to examine, with maximum power, age differences in words recalled separately for each condition. As shown in Figure 1, older adults recalled significantly fewer words than young adults in all except the four-short-sentence condition. We carried out power analyses using G-Power 3 (Faul, Erdfelder, Lang, & Buchner, 2007), which indicated that we had a .8 power to detect effects of at least .73 for this measure. By comparison, the observed size of the non-significant effect for the four-short-sentences condition was only d=0.12.

A more conventional manner of analyzing the same data is the proportion of words correct, which was not emphasized because it cannot reveal constant capacity across conditions with materials of different length. The proportions are provided in Figure 1 above the frequency bars. In an ANOVA, all of the same effects were obtained as in the total words recalled measure. Young adults recalled a greater proportion of words (*M* = .42, *SD* = .10) than older adults (*M* = .35, *SD* = .10). The largest proportion of words recalled was for four short sentences (*M* = .60, *SD* = .15), followed by four long (*M* = .37, *SD* = .11), eight short (*M* = .29, *SD* = .10), and four random sentences (*M* = .28, *SD* = .11).

It was possible that the differences in performance were due to strict scoring of items at recall. As previous research has suggested that older adults are more reliant upon gist interpretations in comprehending language (see above), it is possible that older adults recalled items that reflected semantically correct recall without being scored as correct (e.g., recalling the word “clutched” in place of “gripped”). We examined all transcribed responses for instances in which a synonym of a presented word was recalled in a given trial. Participants tended to recall very few synonyms overall (less than 1 per trial), and older adults were no more likely than young adults to respond with a synonym during recall, F(1, 46)<1, $\eta_p^2 = 0.00$. We had a power of .8 to detect an effect size of at least $\eta_p^2 = 0.06$, a small effect (Faul et al., 2007).

On average, individuals produced the highest number of synonyms in the four-long-sentence condition (*M* = 0.47 per trial, *SD* = 0.44), and progressively fewer for eight short sentences (*M* = 0.26, *SD* = 0.37), four short sentences (*M* = 0.14, *SD* = 0.22), and four random sentences (*M* = 0.05, *SD* = 0.19), a significant difference, $F(3, 138) = 15.49$, $p<.001$, $\eta_p^2 = 0.25$. Newman-Keuls tests indicated that there were more synonyms produced in the four-long-sentence condition than in any other condition, and more in the eight-short-sentences condition than in the four-random-sentence condition. There was no significant interaction, $F(3, 138) < 1$, $\eta_p^2 = 0.02$. We had a power of .8 to detect an effect size of at least $\eta_p^2 = 0.05$, a small effect.

In sum, the results from this analysis indicate that the differences in performance across age groups did not depend upon the use of strict verbatim scoring.

Clauses Accessed per Trial

For the following two measures, we defined chunks as the most coherent units presented (here, clauses, or sets of isolated words within a clause intonation in the random condition). For the number of clauses accessed per trial, a repeated measures ANOVA produced a significant effect of age group, $F(1, 46) = 12.41$, $\eta_p^2 = .212$, $p <.001$. Young adults accessed a greater number of clauses (*M* = 3.27, *SD* = 0.65) than older adults (*M* = 2.60, *SD* = 0.65). There was also an effect of condition, $F(3, 138) = 81.40$, $\eta_p^2 = .638$, $p <.001$, with the greatest number of clauses accessed for four long sentences (*M* = 4.08, *SD* = 1.12), followed by four short (*M* = 3.02, *SD* = 0.63), eight short (*M* = 2.84, *SD* = 1.05), and four random sentences (*M* = 1.81, *SD* = 0.69).These effects were qualified by a significant age group × condition interaction, $F(3, 138) = 3.71$, $\eta_p^2 = .074$, $p <.05$. Consistent with the measure of the number of words recalled, Figure 2 suggests that young adults generally accessed more clauses than older adults. The significant interaction for the access measure occurred because the age effect appeared to be attenuated in the case of four short sentences, which differed from other conditions in including a relatively small number of short, coherent clause units.

Newman-Keuls tests clarify the difference between age groups in clause access. Young adults displayed the pattern of four long > four short = eight short > four random. Older adults showed a different pattern: four long > four short > eight short > four random. Both young and older adults were able to take advantage of the structure of long sentences, leading to higher access rates than for the shorter sentences. However, whereas young adults showed similar access rates for the four-short and eight-short sentence conditions, access declined with eight sentences in older adults. Again, this suggests that older adults were impaired when the number of clauses greatly exceeded working memory capacity.

T-tests examining age differences in access for each sentence condition (see Table 3) provided support for the above findings. Significant age differences were found in the eight short, four long, and four-random-sentence conditions, with older adults accessing fewer clauses in each. For four short sentences, the actual non-significant effect size was only d=.25, in comparison to our ability to detect a change of at least d=.73 with a power of .8.

A further analysis clarifies the basis of the age difference in clause access for four long sentences. We asked what proportion of the accessed clauses was part of a recall protocol in which both clauses of the long sentence were accessed. That proportion was .68 (*SD* = .22) of accessed clauses in young adults and .58 (*SD* = .28) of accessed clauses in older adults. The proportions did not differ significantly, $t(46) = 1.44$, d=0.41. We also looked at a complementary statistic, the proportion of long sentences accessed. This proportion was .64 (*SD* = .16) for young adults and .56 (*SD* = .17) for older adults, which again failed to reach significance, $t(46) = 1.66$, d=0.49. Therefore, it appears that the age difference in clause access for long sentences was not systematically due to one of these factors alone; it was related to the access of multiple clauses, partly within a long sentence and partly across long sentences.

Clause Completion

Clause completion was defined as the proportion of words recalled from a given clause, provided that it was accessed (i.e., at least one content word was recalled from it). A repeated-measures ANOVA indicated no significant effect of age upon mean clause completion, $F<1$, $\eta_p^2 = .01$, in contrast to the finding of a modest age difference in chunk completion that Naveh-Benjamin et al. (2007) observed for studied word pairs. Power analyses showed that we could detect an effect of $\eta_p^2 = .09$ with a power of .8. Figure 3 illustrates the absence of age group differences on clause completion rates, and this absence of age effects held within each sentence condition (see Table 3). For these conditions, $-.19<d<0$, whereas we could detect $d=.73$ or greater with a power of .8.

There was, however, a main effect of condition, $F(3,111) = 17.22$, $\eta_p^2 = .317$, $p <.001$. The greatest proportion of clause completion occurred for eight short sentences (*M* = .83, *SD* = .16), followed by four short sentences (*M* = .81, *SD* = .11), four long sentences (*M* = .73, *SD* = .12), and four random sentences (*M* = .65, *SD* = .20) respectively. The interaction between age group and condition was not significant, $F<1$, $\eta_p^2 = .01$. Power analyses showed that we could detect an effect of $\eta_p^2 = .05$, a small effect, with a power of .8.

Discussion

The present data provide a portrait of aging effects in memory for lists of coherent sentences. The outcome appears to be that there is a clear age difference in the number of chunks that can be held in working memory at once, at least as indexed by the number of clauses accessed in recall (Figure 2), a conclusion in keeping with the results of Naveh-Benjamin et al. (2007) for lists of associated word pairs. However, unlike that previous study, for linguistic materials the number of words recalled per clause, or clause completion, was remarkably similar across age groups (Figure 3). The absence of an age effect in clause completion suggests that although older adults may have a reduced working memory capacity in chunks, for the present linguistic materials the integration of related elements into chunks did not differ from young adults.

The effects of age can be further understood in light of the informative pattern of results that was obtained for both age groups. Thus, that pattern will be examined first.

Effects of Linguistic Materials Across Age Groups

Several findings provide insight into which types of language stimuli young and older adults will be more likely to recall, as well as where aging deficits might be found using the measures described above. It was expected that sentences that were more meaningful in terms of their coherence would be better recalled than those sentences that had little or no coherence. We found that participants were indeed more likely to recall words from these meaningfully constructed sentences than pseudo-sentences that were haphazard in their structure. For coherent sentences, participants tended to access a greater number of clauses and were more likely to complete a previously accessed clause. This is consistent with previous studies in which increases in stimuli meaningfulness led to improvement in chunk formation and recall (e.g., Tulving & Patkau, 1962; Glanzer & Razel, 1974).

Patterns of clause access and completion suggested that words recalled from a particular clause were not recalled in isolation. Participants tended to recall sentences in terms of integrated clauses, similar to findings by Fallon et al. (2006). This was especially the case for short sentences, in which average proportion completion of an accessed clause was approximately .80 for both age groups. The results suggest that, at least for those sentence conditions containing coherent stimuli, a one-clause sentence typically served as a chunk unit during recall. This assumption is supported by young adults' performance for the four- and eight-short-sentence conditions, inasmuch as the number of words recalled and number of clauses accessed were comparable across these conditions, and thus constrained by a limited capacity. Although it is still possible that some of these unrelated short sentences were grouped together to form larger chunks, there is no apparent mechanism for conjoining unrelated sentences (other than perhaps noticing unplanned, haphazard semantic connections between them). At any rate, such multi-sentence chunking would not be expected to change the conclusions about age effects, only the specific capacity estimates.

For lists of long sentences, connecting two short sentences together into one larger sentence allowed participants to increase the amount of information present within a sentence. Although combining two short sentences thus provided some benefits compared to lists of unrelated short sentences, the number of clauses accessed was much less than doubled for lists of long compared to lists of short sentences. The semantic connections between clauses of a long sentence were thus not always well-encoded and remembered. There is a limit to the extensiveness of semantic and linguistic integration.

Effects of Aging

An examination of the mean number of words recalled in each condition by each age group (Figure 1) shows that the largest difference between age groups occurred in the four-long-sentences condition. These findings replicate and extend the result of Craik and Masani (1967), who noted that when the capacity limit of working memory is exceeded, the use of linguistic structure to minimize the information overload becomes more efficient in young adults than in older adults, despite benefits that occur from such connection.

We operationally defined chunks according to the units that were provided in the stimuli, and recall of a chunk was taken as access to that chunk sufficient to recall one word from it. The result of this measure, the mean number of clauses accessed (Figure 2), was similar to the number of words recalled, with the largest aging deficit occurring with four long sentences. Moreover, the difference in access came primarily from the larger number of long sentences that young adults could access, with no age difference in the likelihood of accessing both clauses within a long sentence provided that at least one such clause was accessed. Along with this finding, we observed that the number of words recalled from each accessed clause (Figure 3) was remarkably similar across age groups.

These findings clarify the results with number of words recalled overall. They show that the aging deficit is in retaining multiple unrelated units (in this case, long sentences) when there is a lot of linguistic material, not an age difference in completing a long sentence once it or its clauses have been accessed. It thus appears to reflect consequences of a basic working memory capacity decline with age (e.g., Naveh-Benjamin et al., 2007). The finding that the age difference for four long sentences was somewhat accentuated compared to 8 short sentences (Figures 1 and 2) would seem to suggest that the use of the linguistic tie between clauses within long sentences was effortful to some extent, and was accomplished at the expense of accessing fewer of the clauses compared to young adults.

We did not find across-the-board age differences in either words recalled or clause access; both of these measures failed to show age differences for four short sentences. The apparent discrepancy between sentence conditions may suggest that, as the need to form chunks increased, either because of the overall long duration of the memoranda or because of the large number of presented sentences, self-initiated strategies to retain or retrieve information became increasingly necessary. These strategies are more resource-demanding for older adults than for young adults (Craik, 1983, 1986; Naveh-Benjamin et al., 2005), and this may have placed the former group at a disadvantage during more demanding sentence conditions. Although any such strategy worked well for older adults in the four-short-sentences condition, it proved less than optimal overall. In particular, there was an absolute decrease in the number of words recalled and in the number of chunks accessed in the eight-short-sentences condition, compared to the four-short-sentences condition, for older adults (cf. Figures 1 and 2).

Older adults have worse verbatim recall than young adults and tend to employ greater reliance upon gist interpretations (e.g., Backman & Nilsson, 1985). Yet, it is worth noting once more that the present task required verbatim recall. It is quite possible that if only gist recall were required, the difference in capacity observed here would be eradicated. Although the present work can only give a partial picture of the effects of the aging process on recall, it does point to a basic structural difference that can be used to help explain the vulnerability of older adults to information overload in language processing (e.g., Backman & Nilsson, 1985; Cohen, 1979; Stine-Morrow et al., 2004; Stine & Wingfield, 1987; Wingfield et al., 1992; Wingfield & Stine-Morrow, 2000). There is an age difference in working memory capacity for sentential materials and there is a strong theoretical and practical need to explore its nature using analytic methods, in the spirit of the present study.

Acknowledgements

This research was conducted with support from NIH Grant R01-HD21338 and a Roger S. Williams Research Award from the University of Missouri. We thank Melissa Knipe for assistance, Scott Saults for programming, and Elizabeth Stine-Morrow and Gerry Tehan for comments on an earlier draft.

Appendix A

Stimuli used for each group and trial type. Stimuli within each trial were presented in the order below; trials were randomized.

Trial Type	Stimuli
Group 1	
4 long, trial 1	Turn the block over and place it by the toy. Grandmother warmed the oven and she baked a fudge cake. I tripped over the rug and I smashed the vase. The drink tumbled down and my shirt was stained.
4 long, trial 2	Play in the park but expect rainy weather later. She locked the door and then she walked to school. The woman heard footsteps so she gripped her bag. Our neighbor sells vegetables but he also makes fruit juice.
4 random, trial 1	Go jar she flag. A close football your cheese. The soon help sauce starts. Prepared uncle and cookie.
4 random, trial 2	Girls find cut your. Is my breakfast firewood. Can chicken please finished. Aunt cooked jersey almost.
4 short, trial 1	Don't scare your brother. We took pictures as a gift. I upset my mother. Answer every question.
4 short, trial 2	Take your paper and pencil. I lied about the money. The teacher enjoys photographs. The screaming bothers me.
8 short, trial 1	Hold the hive still. Add some salted butter. The yellow dog howled. Flashes rattled the sky. Thieves took the painting. My feelings get hurt. We welcomed the family. The worm wiggled below.
8 short, trial 2	The birds circled above. We rested before supper. My temper causes trouble. Dad saw them leave.

Trial Type	Stimuli
	Lightning struck the building. The witch kicked him. Give the crab flavor. Bees sting when surprised.
Group 2	
4 long, trial 1	My temper causes trouble when my feelings get hurt. We welcomed the family and we rested before supper. Give the crab flavor and add some salted butter. The birds circled above as the worm wiggled below.
4 long, trial 2	Don't scare your brother because the screaming bothers me. The yellow dog howled as the witch kicked him. I upset my mother when I lied about the money. Thieves took the painting and Dad saw them leave.
4 random, trial 1	Took when pencil and surprised. Gift building a as. The struck pictures your sting. Lightning paper we bees take.
4 random, trial 2	The hold sky hive. Answer the still flashes. Photograph teacher every. Enjoys the rattled question.
4 short, trial 1	Then she walked to school. My aunt cooked chicken. I smashed the vase. The woman heard footsteps.
4 short, trial 2	She gripped her bag. I tripped over the rug. She prepared a cheese sauce. She locked the door.
8 short, trial 1	Please find your jersey. The drink tumbled down. Place it by the toy. Play in the park. Go and help your uncle. Our neighbor sells vegetables. She baked a fudge cake. Breakfast is almost finished.
8 short, trial 2	Close the cookie jar. Grandmother warmed the oven. He also makes fruit juice. Girls can cut firewood. Expect rainy weather later. Turn the block over. My shirt was stained. Flag football starts soon.

References

Allen PA, Coyne AC. Age differences in primary organization or processing variability? Part I: An examination of age and primary organization. Experimental Aging Research 1988;14:143–149. [PubMed: 3234455]

Allen PA, Coyne AC. Are there age differences in chunking? Journal of Gerontology, Psychological Sciences 1989;44:P181–P183.

Allen PA, Crozier LC. Age and ideal chunk size. Journal of Gerontology, Psychological Sciences 1992;47:P47–P51.

Backman L, Nilsson LG. Prerequisites for lack of age differences in memory performance. Experimental Aging Research 1985;11:67–73. [PubMed: 4092720]

Baddeley, A. Working memory. Clarendon Press; Oxford, England: 1986.

Baddeley AD, Thomson N, Buchanan M. Word length and the structure of short-term memory. Journal of Verbal Learning & Verbal Behavior 1975;14:623–629.

Bastin C, Van der Linden M. The effects of aging on the recognition of different types of associations. Experimental Aging Research 2006;32:61–77. [PubMed: 16293569]

Broadbent, DE. The magic number seven after fifteen years.. In: Kennedy, A.; Wilkes, A., editors. Studies in long-term memory. Wiley; New York: 1975. p. 3-18.

Castel AD, Craik FIM. The effects of aging and divided attention on memory for item and associative information. Psychology and Aging 2003;18:873–885. [PubMed: 14692872]

Chen Z, Cowan N. Chunk limits and length limits in immediate recall: A reconciliation. Journal of Experimental Psychology: Learning, Memory and Cognition 2005;31:1235–1249.

Cohen G. Language comprehension in old age. Cognitive Psychology 1979;11:412–429. [PubMed: 487746]

Cokely ET, Kelley CM, Gilchrist AL. Sources of individual differences in working memory: Contributions of strategy to capacity. Psychonomic Bulletin & Review 2006;13:991–997. [PubMed: 17484424]

Cowan, N. An embedded-processes model of working memory.. In: Miyake, A.; Shah, P., editors. Models of working memory: Mechanisms of active maintenance and executive control. Cambridge University Press; Cambridge, U.K.: 1999. p. 62-101.

Cowan N. The magical number 4 in short-term memory: A reconsideration of mental storage capacity. Behavioral and Brain Sciences 2001;24:87–185. [PubMed: 11515286]

Cowan N, Chen Z, Rouder JN. Constant capacity in an immediate serial recall task: A logical sequel to Miller (1956). Psychological Science 2004;15:634–640. [PubMed: 15327636]

Cowan N, Naveh-Benjamin M, Kilb A, Saults JS. Life-span development of visual working memory: When is feature binding difficult? Developmental Psychology 2006;42:1089–1102. [PubMed: 17087544]

Craik FIM. On the transfer of information from temporary to permanent memory. Philosophical Transactions of the Royal Society of London 1983;302:341–359.

Craik, FIM. A functional account of age differences in memory.. In: Klix, F.; Hagendorf, H., editors. Human memory and cognitive capabilities: Mechanisms and performances. Elsevier Science Publishers; New York: 1986. p. 409-421.

Craik FIM, Masani PA. Age differences in the temporal integration of language. British Journal of Psychology 1967;58:291–299. [PubMed: 5586653]

Craik, FIM.; Morris, RG.; Gick, ML. Adult age differences in working memory.. In: Vallar, G.; Shallice, T., editors. Neuropsychological impairments of short term memory. Cambridge University Press; New York: 1990. p. 247-267.

DeDe G, Caplan D, Kemtes K, Waters G. The relationship between age, verbal working memory, and language comprehension. Psychology and Aging 2004;19:601–616. [PubMed: 15584786]

Fallon M, Kuchinsky S, Wingfield A. The salience of linguistic clauses in young and older adults' running memory for speech. Experimental Aging Research 2006;30:359–371. [PubMed: 15371100]

Faul F, Erdfelder E, Lang A-G, Buchner A. G*Power 3: A flexible statistical power analysis program for the social, behavioral, and biomedical sciences. Behavior Research Methods 2007;39:175–191. [PubMed: 17695343]

Glanzer M, Razel M. The size of the unit in short-term storage. Journal of Verbal Learning & Verbal Behavior 1974;13:114–131.

Hay JF, Jacoby LL. Separating habit and recollection in young and older adults: Effects of elaborative processing and distinctiveness. Psychology & Aging 1999;14:122–134. [PubMed: 10224637]

Jarvella RJ. Effects of syntax on running memory span for connected discourse. Psychonomic Science 1970;19:235–236.

Jarvella RJ. Syntactic processing of connected speech. Journal of Verbal Learning & Verbal Behavior 1971;10:409–416.

Jennings JM, Jacoby LL. Automatic versus intentional uses of memory: Aging, attention, and control. Psychology & Aging 1993;8:283–293. [PubMed: 8323731]

Kausler, DH. Learning and memory in normal aging. Academic Press; San Diego, CA, U. S.: 1994. Long-term episodic memory: Discourse.; p. 276-305.

Kemper, S. Language in adulthood.. In: Bialystok, E.; Craik, FIM., editors. Lifespan cognition: Mechanisms of change. Oxford University Press; New York: 2006. p. 223-238.

Kynette D, Kemper S, Norman S, Cheung H. Adults' word recall and word repetition. Experimental Aging Research 1990;16:117–121. [PubMed: 2090462]

Light LL, Patterson MM, Chung C, Healy MR. Effects of repetition and response deadline on associative recognition in young and older adults. Memory & Cognition 2004;32:1182–1193.

Miller GA. The magical number seven plus or minus two. Some limits on our capacity for processing information. Psychological Review 1956;63:81–97. [PubMed: 13310704]

Mitchell KJ, Johnson MK, Raye CL, Mather M, D'Esposito M. Aging and reflective processes of working memory: Binding and test load deficits. Psychology & Aging 2000;15:527–541. [PubMed: 11014715]

Naveh-Benjamin M. Adult age differences in memory performance: Tests of an associative deficit hypothesis. Journal of Experimental Psychology: Learning, Memory and Cognition 2000;26:1170–1187.

Naveh-Benjamin M, Cowan N, Kilb A, Chen Z. Age-related differences in immediate serial recall: Dissociating chunk formation and capcity. Memory & Cognition 2007;35:724–737.

Naveh-Benjamin M, Craik FIM, Guez J, Kreuger S. Divided attention in young and older adults: Effects of strategy and relatedness on memory performance and secondary task costs. Journal of Experimental Psychology: Learning, Memory, and Cognition 2005;31:520–537.

Naveh-Benjamin M, Guez J, Kilb A, Reedy S. The associative deficit of older adults: Further support using face-name associations. Psychology and Aging 2004;19:541–546. [PubMed: 15383004]

Naveh-Benjamin M, Guez J, Shulman S. Older adults' associative deficit in episodic memory: Assessing the role of decline in attentional resources. Psychonomic Bulletin & Review 2004;11:1067–1073. [PubMed: 15875977]

Naveh-Benjamin M, Hussain Z, Guez J. Adult age differences in episodic memory: Further support for an associative-deficit hypothesis. Journal of Experimental Psychology: Learning, Memory, and Cognition 2003;29:826–837.

Radvansky GA, Copeland DE, Berish DE, Dijkstra K. Aging and situation model updating. Aging Neuropsychology and Cognition 2003;10:158–166.

Radvansky GA, Dijkstra K. Aging and situation model processing. Psychonomic Bulletin & Review 2007;14:1027–1042. [PubMed: 18229472]

Rosen VM, Engle RW. The role of working memory capacity in retrieval. Journal of Experimental Psychology: General 1997;126:211–227. [PubMed: 9281831]

Sachs JS. Recognition memory for syntactic and semantic aspects of connected discourse. Perception & Psychophysics 1967;2:437–442.

Simon HA. How big is a chunk? Science 1974;183:482–488. [PubMed: 17773029]

Stine-Morrow EAL, Gagne DD, Morrow DG, DeWall BH. Age differences in rereading. Memory & Cognition 2004;32:696–710.

Taub HA. Coding for short-term memory as a function of age. Journal of Genetic Psychology 1974;125:309–314.

Tulving E, Patkau JE. Concurrent effects of contextual constraint and word frequency on immediate recall and learning of verbal material. Canadian Journal of Psychology 1962;16:83–95. [PubMed: 13923055]

Waters G, Caplan D. The relationship between age, processing speed, working memory capacity, and language comprehension. Memory 2005;13:403–413. [PubMed: 15952262]

Wingfield, A.; Stine-Morrow, EAL. Language and speech.. In: Craik, FIM.; Salthouse, TA., editors. The handbook of aging and cognition. 2nd ed.. Lawrence Erlbaum Associates Publishers; Mahwah, NJ, U.S.: 2000. p. 359-416.

Wingfield A, Wayland SC, Stine EAL. Adult age differences in the use of prosody for syntactic parsing and recall of spoken sentences. Journal of Gerontology: Psychological Sciences 1992;47:350–356.

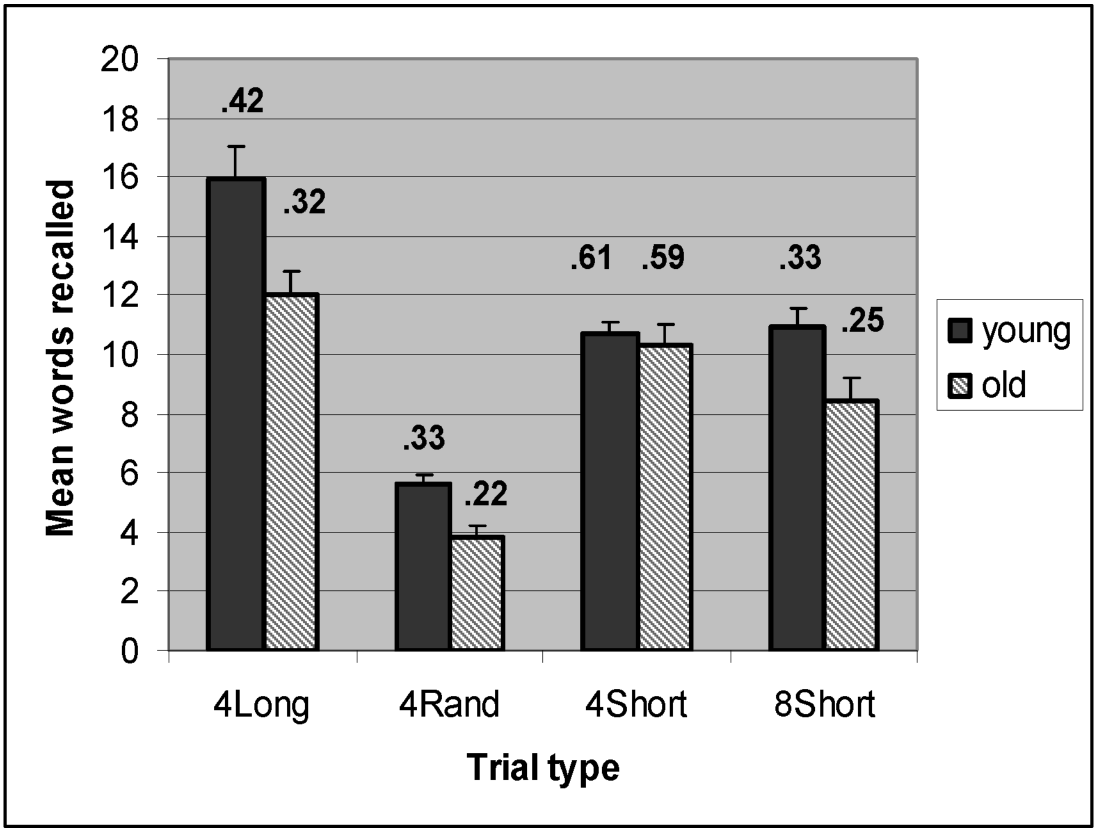

Figure 1.
Mean number of words recalled per trial in each condition for each age group (graph parameter), with mean proportion of words recalled reported above the frequency bars. Error bars are standard errors of the mean.

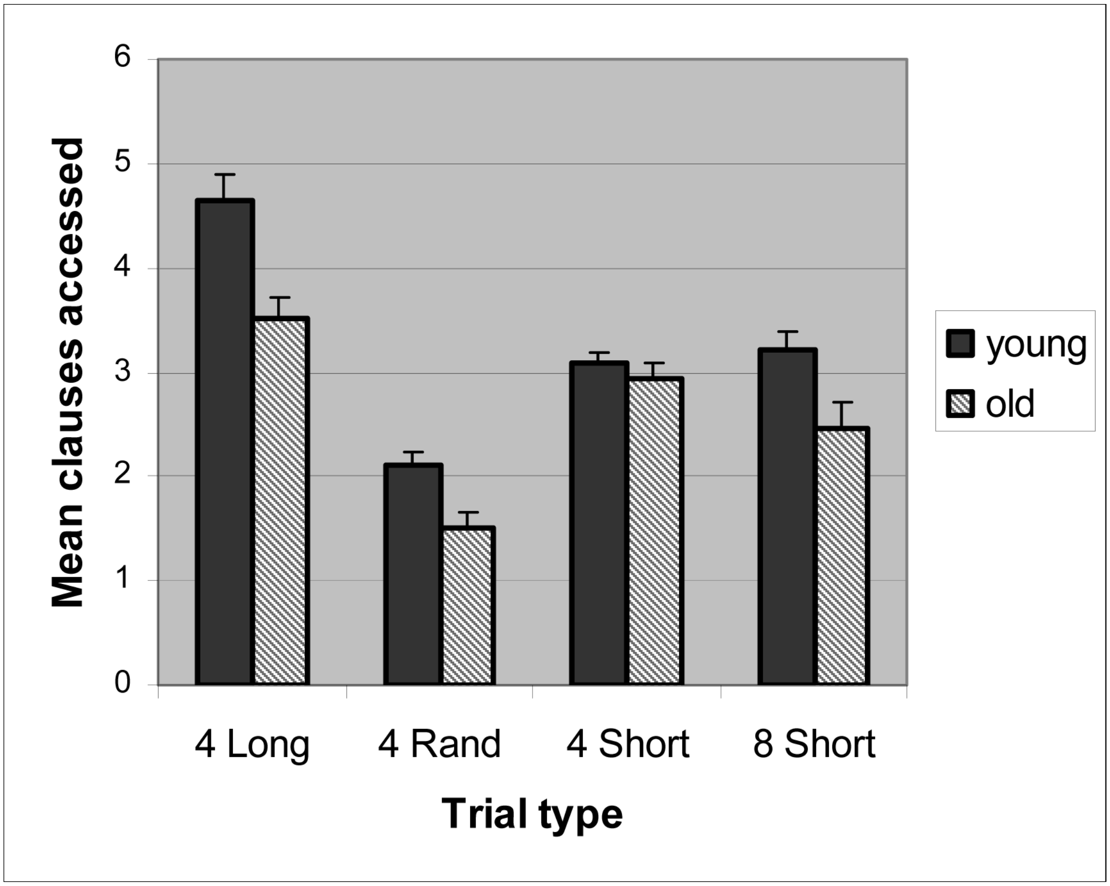

Figure 2.
Mean number of clauses accessed by condition for each age group (graph parameter). Error bars are standard errors of the mean.

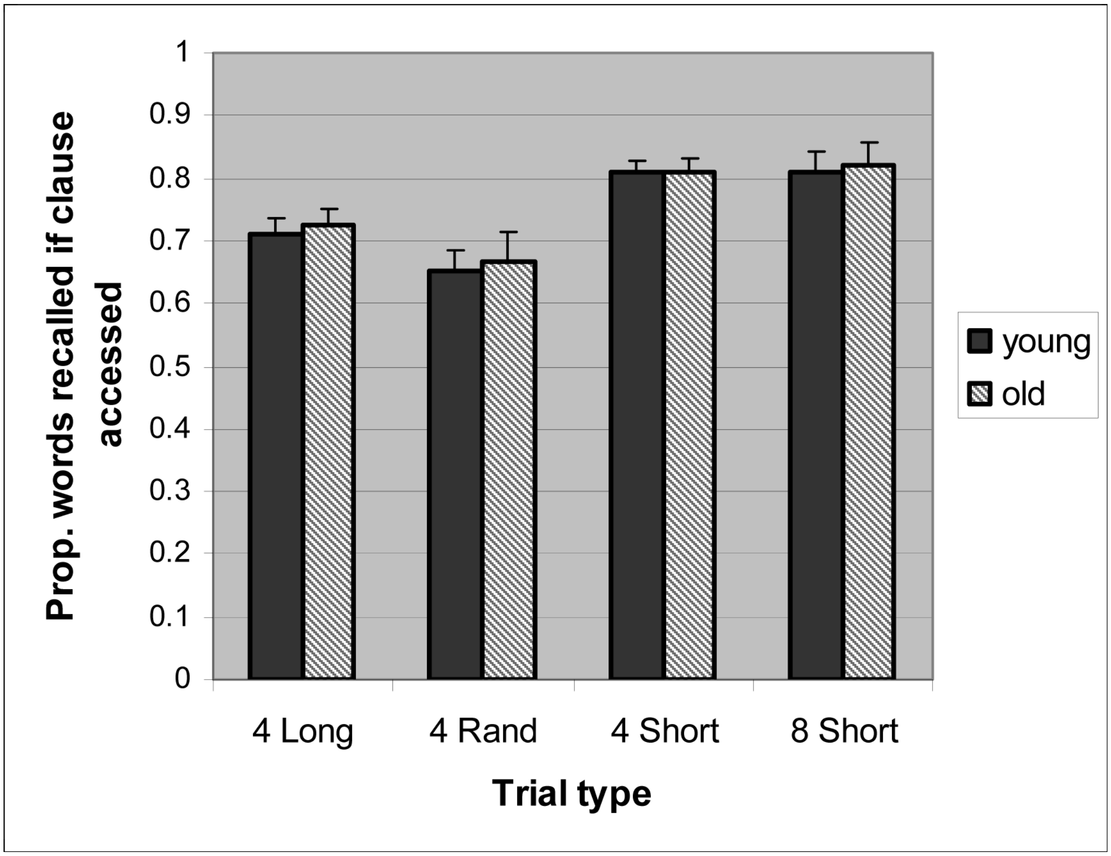

Figure 3.
Mean proportion of words recalled conditional on clauses that were accessed, for each age group (graph parameter). Error bars are standard errors of the mean.

Table 1

Reassignment of Group 1 stimulus materials to form Group 2 stimuli.

Group 1		Group 2
4 Long	divided among	4 Short, 8 Short
4 Random	divided among	4 Short, 8 Short
4 Short	divided among	4 Random, 4 Long
8 Short	divided among	4 Random, 4 Long

Note. Appendix A provides further details about the stimuli.

NIH-PA Author Manuscript

NIH-PA Author Manuscript

Table 2

Means and standard errors for total words, clause access, and clause completion across age groups and trial conditions

Age Group	Condition	Total Words	Clause Access	Clause Completion
Young adults	*Four Long*	15.97 (1.04)	4.64 (0.26)	.71 (.02)
	Four Random	5.66 (0.30)	2.12 (0.11)	.65 (.03)
	Four Short	10.68 (0.44)	3.10 (0.10)	.81 (.02)
	Eight Short	10.93 (0.66)	3.22 (0.17)	.81 (.03)
Older adults	*Four Long*	12.06 (0.79)	3.52 (0.19)	.73 (.03)
	Four Random	3.81 (0.43)	1.50 (0.16)	.67 (.05)
	Four Short	10.35 (0.64)	2.93 (0.15)	.81 (.02)
	Eight Short	8.41 (0.78)	2.45 (0.26)	.82 (.04)

Note. Standard errors are in parentheses.

NIH-PA Author Manuscript

NIH-PA Author Manuscript

Table 3

Results from independent sample t-tests examining age group differences by sentence condition for total words recalled, clause access, and clause completion

Condition	Total Words	Clause Access	Clause Completion
Four Long	2.99(46)*	3.46(46)*	−0.49(46)
Four Random	3.50(46)*	3.12(46)*	−0.27(40)
Four Short	0.43(46)	0.91(46)	−0.08(45)
Eight Short	2.48(46)**	2.52(46)**	−0.26(44)

Note. Degrees of freedom in parentheses.

* $p < .01$, 1-tailed.