THE RELATIONSHIP BETWEEN VISION AND MEMORY IN OLDER ADULTS

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by

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Abstract

In older adults, a relationship has been found between the cognitive, visual, and auditory performance. Three hypotheses proposed to explain this relationship are: the Common Cause Hypothesis, the Speed Hypothesis, and the Information Degradation Hypothesis. In the present study, adults aged 58 to 85, completed visually presented tests of free recall word lists, forward and backward digit span, vocabulary, and speed of processing. Hearing and vision were also tested. Vision was expected to be a stronger predictor for unrelated than related free recall lists, due to increased demands of the task. Contrast sensitivity, but not visual acuity, was related to free recall performance. Hearing correlated with forward and backward digit span performance. These results offer partial support for the Information Degradation and Common Cause hypotheses, but not the Speed Hypothesis and demonstrate that the impact of sensory decline may depend on the demands of the task.

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THE RELATIONSHIP BETWEEN VISION AND MEMORY IN OLDER ADULTS

For many people, aging is a process accompanied by declines in vision, hearing, and memory. Significant positive correlations have been reported between decreased sensory functioning and short-term memory deficits in older adults (Anstey, Butterworth, Borzycki, & Andrews, 2006; Baltes & Lindenberger, 1997; Salthouse, Hambrick & McGuthry, 1998; Zekveld, Deijen, Goverts, & Kramer, 2007). Some research suggests that sensory variables and memory may share a relationship not directly accounted for by age. This research often utilizes variance partitioning techniques in creating variables and drawing conclusions.[1] The present study examined the relationship between contrast sensitivity, visual acuity, low-contrast visual acuity, auditory acuity, and some aspects of cognition in older adults. In the current paper, the term "cognition" refers to measures of short-term memory and speed of processing tests, though its use in other research is based on a variety of measures outlined below.

While relationships have been reported between memory performance and a number of sensory functions, vision and hearing typically account for the most variance in age-related cognitive decline. For example, Anstey, Luszcz, and Sanchez (2001) found 79% of the age-related variance in cognition to be shared with vision and hearing. Lindenberger and Baltes (1994) used 14 extensive tests of cognitive functioning to create a composite variable called "Intellectual Functioning" and found that 93% of the age-related variance in this variable could be accounted for by vision and hearing, more than could be accounted for by health or education combined. While the data show a definite link among age-related changes in vision, hearing, and cognition, the cause of this relationship is not so clear. Three general theoretical explanations have been proposed to account for the relationship between sensory and cognitive functioning in older adults: the Common Cause Hypothesis, the Speed Hypothesis, and the Information Degradation Hypothesis. Predictions of each hypothesis were explored by tests performed in the current study.

The Common Cause Hypothesis

The Common Cause Hypothesis states that the physical results of aging simultaneously cause declines in both the cognitive and sensory systems. In addition to visual acuity and hearing, some types of motor physiological deficits, such as grip strength, upper leg strength, and blood pressure, have been found to correlate with both cognitive decline and age (Anstey, Lord, & Williams, 1997). The Common Cause Hypothesis suggests that the large amount of age-related variance accounted for by vision is mediated by general neural deterioration. A testable assumption of the Common Cause Hypothesis is that the noticeable symptoms (e.g., vision and memory loss) do not have to show a systematic relationship with each other, other than that accounted for by the common cause. For example, if an individual suffers from widespread deterioration and has the noticeable symptoms of vision loss and cognitive decline, his or her memory should be no worse for visual information than it is for auditory information. This is because vision is not directly having an impact on memory performance. Rather, vision loss and cognitive decline are both driven by the common cause.

Much of the research supporting the Common Cause Hypothesis comes from longitudinal correlational studies. For example, Anstey, Hofer, and Luszcz (2003) examined three age groups of older adults over an eight-year period and found a significant moderately sized association between rates of change in memory and vision after statistically controlling for effects of age, gender, education, self-rated health, medical conditions, and depressive symptoms. In addition, a modest association was found between hearing and memory loss, but disappeared after controlling for age and gender. The researchers suggested that the modest association between hearing and memory loss was a result of a commonality between age and hearing loss, such that removing one removes the unmeasured biological variance they share. It appeared that the relationship between hearing loss and memory loss was confounded by their shared relationship with age. Vision loss, however, was still associated with memory loss even after age was controlled for. These results suggest that, unlike the relationship between changes in hearing and memory, the relationship between changes in vision and memory is not confounded by age.

Anstey, Lord, and Williams (1997) tested adults 60 to 87 years old and found lower-limb strength, visual contrast sensitivity, and reaction time to be important predictors of performance on measures of reasoning and cognition. After controlling for lower-limb strength, visual contrast sensitivity, and reaction time, age no longer explained a significant proportion of the variance in measures of reasoning. Another study found that sensorimotor and physiological variables accounted for nearly all of the age differences in performance on reaction-time tasks (Anstey, 1999a). In fact, after controlling for grip strength, forced expiratory volume, and vibration sense (measured by the level at which a participant can tell that a vibration on their skin stops), vision was no longer a significant predictor of reaction time. This showed that for the variable of reaction time, non-cognitive sensory predictors were equally effective in predicting the results as vision.

In another study, Anstey and Smith (1999) used biomarkers of visual acuity, hearing, grip strength, and vibration sense to create a latent variable called BioAge. BioAge explained virtually all of the age-related variance in cognition (i.e., tests of intelligence, perceptual speed, spatial ability, and working memory performance) in a group of 180 participants aged 60 to 90. This suggested not only that sensory function was related to cognition separately from aging, but also that non-cognitive sensory variables could explain changes in cognitive functioning.

Although relationships have been reported between cognition and variables such as grip strength and vibration sense, other reports suggest that most of the variance in cognitive performance is accounted for by vision and hearing alone. A large scale study by Baltes and Lindenberger (1997) compared individuals aged 25 to 103 years on visual and auditory acuity, along with 14 cognitive tasks assessing overall intellectual functioning. Individual differences in intellectual functioning related to sensory functioning accounted for 11% of the variance in those aged 25 to 69 and 31% of the variance for those aged 70-103. In addition, an average of 93% of the predictive variance in vision and hearing was shared with age. The researchers attributed the relationship between vision, hearing, and age as support for the Common Cause Hypothesis, since vision and hearing did not appear to be significant predictors in younger adults. The common cause, which is brought on by age, could explain why younger adults did not display a strong relationship between sensory and intellectual functioning. Even so, the authors acknowledged that specific experimental research would be necessary before refuting alternative hypotheses. It is possible that the limited variance in sensory functioning in younger adults led to the weaker relationship between sensory and intellectual functioning in this age group.

Despite the correlational evidence supporting the Common Cause Hypothesis, there is much it does not explain. The Common Cause Hypothesis does not specify the exact mechanism by which the "cause" acts, or whether the cause is just a wide-spread deterioration. In addition, much of the evidence supporting the Common Cause Hypothesis comes from longitudinal studies, which are susceptible to a number of threats to internal validity. For example, Lane and Zelinski (2003) repeatedly tested memory of adults aged 55 to 87, over a 19 year period, and found that returning participants showed better initial scores than dropouts, indicating that longitudinal samples might not be representative of the population from which they are drawn. As with all longitudinal research, it is also impossible to rule out all other factors as causing the change that is attributed to the common cause. Most importantly, longitudinal studies, as well as cross sectional studies comparing older to younger adults, leave aging as an active, confounding variable. It is not enough to declare that the passage of time causes declines in physical and mental resources. To study the relationship between age-related sensory and cognitive decline scientifically, the underlying cause must be separated from age itself and identified.

Salthouse (1999) criticized the Common Cause Hypothesis for leaving age as a causal factor, noting that causal explanations are required to explain the relationship between aging and changes in the quantity and the quality of resources. Craik and Salthouse (2000) thoroughly examined the literature surrounding the Common Cause

Hypothesis, and concluded by rejecting rejected the Common Cause Hypothesis as the primary explanation of the relationship between age-related sensory and cognitive decline. Rather, they argued that while vision and hearing loss, as well as cognitive decline, may be symptoms of the common cause, they also share an additional relationship outside of it. For example, reduced visual functioning could result in a poor trace of an encoded stimulus, causing an already strained memory even greater difficulty at recall. Vision and hearing cannot be separated from cognition as they are the means through which most sensory information about the world is encoded, and their dysfunction can affect the quality of any encoded information.

The Speed Hypothesis

An alternative to the Common Cause Hypothesis focuses on the speed at which information is encoded. According to the Speed Hypothesis, a general, age-related, physical slowing causes longer encoding times, which is why older adults generally are slower than younger adults at cognitive tasks. The prediction made by the Speed Hypothesis is similar to that made by the Common Cause Hypothesis, however the Speed Hypothesis predicts a causal rather than correlational relationship between sensory degradation and cognitive performance. For example, someone with poor vision may have to strain his or her eyes while reading, causing longer encoding times. Longer encoding times would result in less time to rehearse the encoded information. Therefore, an older adult with worse vision would perform slower than an older adult with better vision. It should be noted that while the literature addresses the Common Cause and Speed Hypothesis exclusively, an argument can be made that their predictions overlap in some ways (Anstey, 1999b).

The Speed Hypothesis has been examined in a number of correlational designs. In a review, Luszcz and Bryan (1999) critically examined the most popular hypotheses regarding age-related memory loss and concluded that the evidence supporting the Speed Hypothesis was the strongest. Anstey (1999a) found that sensory functioning explained more variance in speed measures than in accuracy measures, suggesting that speed might be more sensitive to the effects of aging than accuracy.

In variance partitioning models, speed of processing often emerges as the central factor, mediating all age-related variance in memory (Luszcz & Bryan, 1999). However, the mediational approach used to support the Speed Hypothesis has been highly criticized. Sliwinski and Hofer (1999) warned that variance partitioning and mediating variables (i.e., variables claimed to mediate a relationship) can be misleading when used in an explanatory context. They stated that, "…the percentage of age-related variance accounted for by a mediator is a complex function of the shared and not necessarily age-related variance between the dependent and mediator variables" (p. 352). Sliwinski and Hofer (1999) also stated that the amount of evidence supporting a theory is not as important as the strength of that evidence, and longitudinal tests of the Speed Hypothesis have not shown that within-person declines in speed mediate declines in memory.

Anstey (1999b) criticized the Speed Hypothesis, arguing that speed of processing shared too much variance with cognition in its attempt to explain age-related memory loss. Scores on speed of processing tests are a product of both sensory input (typically visual) and cognitive functioning. Instead, Anstey (1999b) promoted a focus on non-cognitive sensory variables (e.g., grip strength) to minimize the presence of confounding variables and circular arguments.

For the Speed Hypothesis, as well as Working Memory, and Executive-Functioning hypotheses, there is also the problem of construct validity. Most psychological data are provided by measures intended to represent a theoretical variable, but these measures are not equivalent to this variable (e.g., the Intelligence Quotient is meant to represent intelligence, but cannot be said to be equivalent to intelligence). Salthouse (1999) elaborates by stating that, "…at the present time there is relatively little evidence for discriminant and convergent validity of most cognitive constructs, and consequently it is seldom clear exactly what is meant by these terms, and whether different operationalizations really refer to the same construct" (p. 346). Indeed, the broad, causal statements used in most correlational research are generally not well-founded.

The measures used to examine speed are subject to test-retest reliability issues unique to older adults. Ferrer, Salthouse, and McArdle (2005) tested adults, 30 to 80 years of age, and found that while age-related memory decline correlated with processing speed, this relationship decreased at retest. The authors offered the possibility that correlations between variables such as memory and processing speed may differ depending on the components of retest. For example, older adults who are unfamiliar with using a computer may perform worse on computer-based memory and speed of processing tests than younger adults who are more familiar with using computers. When returning for the retest, however, they may show increased performance due to practice and familiarity, making changes in scores on computer-based memory tasks a poor representation of true changes in memory for older adults. Older adults are also a population high in between- and within-subject variance, making retest effects very important to consider when comparing them to younger adults (Salthouse, 2000).

Finally, the mediational and variance partitioning research that supports the Speed Hypothesis is not always consistent. In a large-scale study using adults aged 70 to 98, Anstey et al. (2001), defined "cognition" as including tests of memory, speed of processing, and verbal ability. Age, speed, vision, and hearing all shared a large proportion of the variance in cognition, but further variance remained. Neither the effects of age nor sensory function on cognition were fully mediated by speed, suggesting it was not the only important variable.

While structural models have been used to support the Speed Hypothesis (e.g., Luszcz & Bryan, 1999), they have also revealed evidence suggesting speed of processing is not the best predictor of cognitive functioning. As outlined above, Lindenberger and Baltes (1994) found that visual acuity explained 41% and auditory acuity 35% of the total variance in intellectual functioning. Combined, vision and hearing accounted for 49% of the total and 93% of the age-related variance. Put into a structural model, vision and hearing fully mediated age differences in intellectual functioning and were more powerful predictors of any negative age differences than speed. Given that the Speed and Common Cause hypotheses both predict a general slowing, it is difficult to determine if the relationship between sensory and cognitive decline can be attributed to speed of processing, or if general slowing is just another symptom of the common cause. Finally, it is possible that reduced speed of processing is brought on not by age itself, but solely by reduced sensory capabilities.

The Information Degradation Hypothesis

The Information Degradation Hypothesis states that sensory deficits brought on by age reduce the quality of encoding and representation of an item, making discrimination between items at recall difficult. According to the Information Degradation Hypothesis, older adults, who generally have reduced vision compared to younger adults, should show particular decrements in memory for detail and context (i.e., surrounding stimuli and information not essential to meaning). For example, an older adult with reduced vision who might strain to read a road sign, might remember the important information (e.g., town name) but may not recall the colour of the sign. Indeed, age differences between older and younger adults are significantly larger when to-be-remembered stimuli are of a contextual rather than conceptual nature (Spencer & Raz, 1995). For example, Smith (1977) found that older adults were more successful recalling a target word (e.g., apple) when cues were meaningfully related to the target word (e.g., fruit) than when they were the first letter of the target word (e.g., A). Age-differences in performance between older and younger adults were also significantly reduced when cues were meaningful rather than detail specific (Smith, 1977).

To compensate for decreased memory ability, an effective strategy for older adults would be to focus more on meaningful information than specific details. Focusing on meaningful information would allow older adults to encode a select, representative sample of the stimuli, rather than trying to remember as much as possible. This strategy is known as gist-based processing, and is very commonly used by older adults, even when it is not beneficial to the test conditions (Tun, Wingfield, Rosen, & Blanchard, 1998). Memory in older adults appears to be impaired by inefficient encoding of target items.

When adults aged 63-to-75 were encouraged to scrutinize items at encoding and retrieval, false recognition caused by gist-based processing was reduced (Koustaal, Schacter, Galluccio, & Stofer, 1999). It is possible that one of the reasons older adults rely on gist-based and semantic processing is to compensate for reduced visual or auditory functioning. If straining to focus on contextual stimuli causes longer latencies than normal conditions, it may be more efficient to take the gist or meaning of the information.

Many of the studies supporting the Information Degradation Hypothesis use auditory stimuli. For example, Rabbitt (1991) created age-matched groups of normal hearing and below-average hearing 50-to-82 year olds. Before performing a memory task, both hearing groups correctly repeated words heard at the same intensity levels as the to-be-remembered stimuli. When performing an auditory memory test for lists of words, the normal hearing group recalled more words than the below-average hearing group. Additionally, the group with below-average hearing recalled visually presented words as well as the normal-hearing controls. The finding that recall was related only to the sense required at encoding (i.e., hearing) is evidence against the Common Cause Hypothesis. Rabbitt theorized that older adults with mild hearing loss have to allocate additional processing resources in order to identify the spoken stimuli, reducing the available resources that might have supported encoding the materials. This theory offers an explanation as to why the encoded signal would be less well remembered.

Surprenant (1999) tested recall of young adults on nonsense syllables heard in different amounts of auditory noise. In addition, they were tested on their ability to recognize the syllables over the different amounts of auditory noise. Although stimuli were recognizable under all noise levels, recall was significantly worse when stimuli were presented with high amounts of noise than when stimuli were presented with low amounts of noise. Surprenant explained these data in terms of a dual-code theory, such that when the physical trace is distorted and rendered less useful, more reliance is placed on the abstract trace of an item. Because it is an abstract representation of an item rather than its physical trace that is being recalled, discrimination of this item from other items in memory would be difficult.

A recent study examined how hearing loss could affect memory for the trace of an item. McCoy, Tun, and Cox (2005) presented normal hearing participants and participants with a hearing loss 15-word auditory lists that were stopped at random points. All words were presented at the same amplitude. Participants were asked to recall the three words preceding the stopping point. Although participants with normal hearing and participants with a hearing loss all showed excellent recall for the last word, recall of the two words before it was significantly worse for those with a hearing loss than for those with normal hearing. The researchers suggested that the auditory trace of earlier words was less distinct for the group with a hearing loss than the group with normal hearing, possibly as a result of a degraded input.

Across a number of experiments, Murphy, Craik, Li, and Schneider (2000) examined the relationship between background noise and memory for words in both older and younger adults. All participants showed worse recall under noise conditions than under quiet conditions. Younger adults listening to words with background noise did not differ from older adults listening to the words in silence. Even so, when noise was added to the stimuli read by younger adults so they were equated on perceptual thresholds, younger adults still recalled more words. While hearing was related to recall of auditory stimuli, it could not alone account for all of the age differences in the recall of auditory stimuli.

Because the Common Cause Hypothesis predicts that any association between sensory and cognitive deficits is a result of a general deterioration, the specific type of stimuli to be remembered should not be relevant to performance. In fact, Anstey, Butterworth, Borzycki, and Andrews (2006), found visual degradation related to age in 60-to-87 -year-olds to be associated with an overall slower encoding of information. The researchers found that lower contrast of stimuli resulted in longer latencies compared to higher contrast of stimuli. Additionally, the researchers found an overall moderate-to-strong association between visual contrast sensitivity and cognitive performance. Age and visual contrast sensitivity both explained larger proportions of variance in all of the tasks when stimuli was presented under lower contrast sensitivity than under a normal level of contrast sensitivity (Anstey et al., 2006). The relationship between cognitive decline and the perceptual demands of a task supports predictions made by the Information Degradation Hypothesis.

Zekveld, Deijen, Goverts, and Kramer (2007) found that hearing loss was not associated with performance on visually presented cognitive tests (i.e., visual pattern recognition memory, sustained visual attention, or spatial working-memory). Other studies (e.g., Rabbitt, 1991) have found hearing loss to be associated with decreased memory performance on auditory but not visual stimuli. The findings of Zekveld et al. (2007) and Rabbitt (1991) suggest the relationship between sensory and cognitive deficits may be modality specific. In addition, research has found that people wearing glasses that partially obscured their vision had increased difficulty recalling visually presented stimuli at a later time (Craik & Salthouse, 2000). Finally, most evidence demonstrates a significant age-related decline in speed and memory abilities, but not in verbal abilities (Anstey, Hofer, & Luszcz, 2003). If cognitive deficits result from a general deterioration, an explanation should be provided as too why verbal abilities are preserved. The research shows a stimulus-specific relationship between sensory decline and performance on memory tests, in line with the predictions of the Information Degradation Hypothesis.

Critique of the Literature

A number of problems exist with the research examining age-related changes in cognitive and sensory functioning. The variance partitioning techniques often used involve creating concepts (e.g., "Cognition") by combining tests (e.g., digit span, recall, etc) thought to measure that particular variable. There are no standardized rules for which cognitive tests should be included in a Cognition variable, or which visual tests should be included in a Visual variable, making conceptual variables difficult to compare across studies. Zelinski and Burnight (1997) showed that different cognitive tests were differentially affected by aging. To load different cognitive tests onto the same factor (e.g., Intelligence) is not an accurate way of examining age-related changes.

Variance partitioning techniques also do not reveal a causal relationship. As Sliwinski and Hofer (1999) note, "Evidence supports the Speed Hypothesis, the Common Cause Hypothesis...as well as innumerable process-specific hypotheses. All appear to be tenable, which is all this method can tell us" (p. 352). Variance partitioning studies have been useful in leading to the development of competing theories, which can now be tested by looking at differences among specific stimuli. Like many age-related cognitive theories, the Common Cause, Speed, and Information Degradation hypotheses are not mutually exclusive. To differentiate and disprove any of these theories, cognitive and sensory tests should be examined for their individual relationships. For the reasons listed above, the current study will not use a variance-partitioning strategy and load cognitive or sensory tests onto one factor, but rather will examine how performance on certain types of cognitive tests relates to vision and hearing.

Although vision consistently correlates with age-related changes in cognition in studies using variance partitioning techniques (e.g., Anstey et al., 2006; Lindenberger & Baltes, 1994), many of the studies examining group differences on specific stimuli (e.g., lists of nonwords) examine hearing instead (e.g., Rabbitt, 2001; Surprenant, 1999). When vision is examined, it is often visual acuity that is tested (e.g., Anstey, Luszcz, and Sanchez, 2001). Visual acuity provides a measure of distance vision and can be moderately corrected with lenses or surgery, while contrast sensitivity refers to the ability to perceive differences between objects and their background. Visual acuity and contrast sensitivity are influenced by different factors and show different rates of decline (Anstey et al., 2006). The current study will use multiple tests of contrast sensitivity and visual acuity to determine the relationship between each type of vision and different tests of cognition, for the reasons listed above.

Another problem with much of the previous research on aging and cognitive decline is the use of university undergraduates as the comparison group for older adults. University undergraduates and community dwelling older adults differ in a number of ways not easily controlled for. For example, younger and older adults have different circadian rhythms (Hasher, Zacks, & Rahhal, 1999). Often, both younger and older adults are tested in the afternoons, which is the optimal time for younger, but not older adults

(Hasher et al., 1999). Hasher et al. demonstrated that while 7% of college students are morning-types and 40% evening types, 75% of older adults are morning types. It has been shown that memory performance is better at optimal times than non-optimal times. Additionally, performing at non-optimal times can lead to an increase in the size of age differences, compared to performing at optimal times, particularly those relating to speed of processing (Hasher et al., 1999). For the reasons listed above, the current study tested only older participants (see below) and tested them only in the mornings.

Another reason it is ineffective to compare groups of older and younger adults is that samples of younger adults often use quite a limited age range, often from 18 to 25 years of age. Conversely, samples of older adults can range anywhere from 60 to 100+ years of age. It is important to acknowledge that aging is a continuous process, and the large age range of the group labelled "older adults" would naturally result in large between-subject variance. The current study tested only older adults and looked at age as a continuous rather than categorical variable. Because there was a limited age range, an effect of age was not predicted. Many studies have confirmed that declines in cognitive performance correlate with age, so instead, the current study examined older adults as a group and specifically at the variance in cognitive performance accounted for by each sensory variable.

Finally, there is some evidence that the performance of older adults on digit-span tasks, often used as a memory construct, can be greatly affected by proactive interference (Salthouse, 1991). Older adults have more difficulty suppressing old information when presented with new information, which can be very problematic in tasks that involve series of lists. The current study used both forward and backward digit-span tasks, which are differentially susceptible to proactive interference (Salthouse, 1991).

In summary, the current student will differ from the previous research by examining each variable individually rather than use variance partitioning techniques, by testing both contrast sensitivity and visual acuity, by comparing older adults to each other rather than university undergraduates, by only testing in the mornings to increase optimal performance, and by testing both forward and backward digit span.

The Current Study

The current study looked specifically at the relationship between hearing, vision, and certain aspects of cognition. Each participant completed tests of visual contrast sensitivity, visual acuity, low contrast visual acuity, and auditory acuity. Forward digit span (FDS), backward digit span (BDS), speed of processing (SOP), and vocabulary tests provided information about the cognitive functioning of the sample, while a general questionnaire was used to assess demographic and health characteristics. Participants also completed recall tests for visually presented lists of categorically related words (e.g., types of birds) and unrelated words.

In addition to regression analyses, which explored how sensory variables were able to predict performance on cognitive tests, analyses of variance (ANOVAs) were also performed. A median split on each test of vision created Low and High Vision groups. This allowed the extremes in performance (i.e., participants who consistently scored perfect and those who consistently performed poorly) to be directly compared. Although the scores were also examined as continuous variables, the aim of comparing Low and High vision groups was to determine whether the half of participants who had better vision, would perform better on cognitive tests than the half with worse vision. Age was examined as a confounding variable. A median split was not performed on the auditory acuity test because it was a screening instrument, and because the aim of the current study was to examine vision specifically.

If older adults with sensory degradation are encoding a poor signal, the target representation is more likely to be confused with other representations in memory. It was predicted that all participants would perform worse with lists of unrelated items than related items because they would be less able to use meaningful processing (e.g., Smith, 1977). Increased reliance on meaningful processing when visual functioning is reduced would be demonstrated if visual functioning predicted a greater percentage of the variance in the unrelated than in the related lists. Additionally, this would be shown if the Low Vision groups showed a greater difference in performance between the unrelated and the related lists than the High Vision groups. This would support the theory that reliance on meaningful processing is a coping strategy for poor stimulus encoding related to sensory degradation and support the Information Degradation Hypothesis.

Although it was likely that there would be an interaction between age and quality of vision (i.e., the oldest participants would have poorer vision than the youngest participants), this relationship was expected to be minimalized by only testing older adults. Age was examined as a confounding variable, but not as the central independent variable in this study for the reasons described by Salthouse (1999) and on pages five-to-six and fifteen-to-sixteen of the current paper.

Summary of Predictions

The present study tested three main hypotheses relating to memory in older adults. First, it was predicted that visual performance would correlate with performance on memory tests, a finding that could be explained by the Common Cause, Speed of Processing, and Information Degradation Hypotheses. Second, it was predicted that vision would account for more variance in the unrelated lists than in the related lists, indicating specific, not general degradation. Likewise, it was predicted that the Low Vision groups would perform worse on the unrelated than the related lists to a greater degree than the High Vision groups. This would support only the Information Degradation Hypothesis, because the Common Cause and Speed of Processing hypotheses do not predict differences between specific stimuli. Third, it was predicted that vision would be the best sensory predictor on all tests because the stimuli were of a visually presented nature. This would support the Information Degradation Hypothesis and also be explainable by the Speed Hypothesis, but go against the predictions of the Common Cause Hypothesis. The effects of sensory and non-sensory variables on forward and backward digit span and speed of processing were also examined.

Method

Participants

A total of 53 adults (49.1% female) were recruited from the St. John's community through advertisements in newspapers, senior magazines, and events for older adults. Initially, 65 participants were recruited, but twelve were eliminated from the data due to not returning to the second session or for being in poor physical health. Participants were aged 58-85 ($M = 68.70$, $SD = 6.36$). There was a slight positive skew regarding age, with the majority of participants close to the mean of 69.59 years, but a few much older.

Participants were asked to indicate the highest level of education they had completed. Eight had some high school, four had a high school diploma, twelve had completed community college or trade school, sixteen had some university, six had completed a university bachelor's degree, and seven had completed a university master's degree or higher. No participants indicated taking any medications known to affect cognitive functioning. Participants rated their health in relation to same-age peers on a seven-point scale with one meaning extremely poor, four meaning average, and seven meaning excellent. The average rating was 5.42 ($SD = .97$). All participants rated their health between four and seven on the seven-point scale. Most participants (94%) wore corrective lenses, which remained on during all tests, including vision tests. Of those who wore corrective lenses, sixteen were near-sighted, twenty-one were far-sighted, seven wore bifocal lenses, and six were not sure of their prescription. Sixteen participants had undergone eye surgery, of which fourteen were for cataract removal, one was to correct double vision, and one was to correct a detached retina. All participants were compensated $7.50, $8.00, or $8.50 per session hour. The different compensation levels reflect fluctuation in provincial minimum wage throughout the study.

Vision groups. Participants were split into Low and High vision groups according to each visual measure: Rabin, Rabin Glare, FACT, and Landolt C (all tests described in more detail below). A median split was used to divide the groups. In situations where the two median numbers were identical, the split was performed before or after this series of numbers, so as to keep these numbers together while still aiming for even sample sizes between groups. For this reason, some groups have different sizes.

Materials

General questionnaire. The general questionnaire inquired about the participants' physical and mental activity levels as well as their general health (Appendix

A). Most questions were rated on a seven-point scale, though some involved choosing particular answers and others were open answer. The questionnaire was written in size 16, Times New Roman font to reduce strain on individuals with poor vision and promote comprehension.

Distance visual acuity. The Landolt C was used to test distance visual acuity (Landolt, 1899). Sitting three meters from the lit chart, in a dark room, the participants identified the orientation of the letter "C", as left, right, up, or down. Each line had multiple letter Cs, which became smaller as the lines progressed. Testing continued until two mistakes were made, at which point at logMAR value was recorded. The score was the log of the minimum angle of resolution for the last line on which the participant made no more than two mistakes. Scores were taken for each eye and a mean was calculated. The Landolt C test is reversed scored, with high scores representing poor visual acuity.

Low-contrast visual acuity. The Functional Acuity Contrast Test (FACT) was used to assess low-contrast visual acuity (Stereo Optical Company, Inc., 2008). The FACT is a sine-wave grating chart that tests nine levels of contrast and five spatial frequencies. In full lighting, binocularly, participants identified the orientation of lines within circles as straight, left, or right. Contrast decreased horizontally, with the lines becoming more faded, while acuity decreased vertically, with the lines becoming smaller. When participants erred in identifying the lines horizontally, the number correct was recorded and they moved onto the next row. There were nine figures in each of the five rows, and the last number they read correctly before erring (one to nine) was recorded for the five different degrees of contrast. A mean was then taken as their overall actual contrast sensitivity (CS) score.

Contrast sensitivity. The Rabin Contrast Sensitivity test was used, with each eye tested separately (Precision Vision, Inc). Sitting three meters away from the test, participants identified letters presented in a light box in a dark room. There were five letters per line, which remained the same size for each line. As lines descended, log CS reduced .25 steps per row (0.05 log CS/letter). The total number of letters accurately identified was recorded and an associated score was taken. The Rabin test was also completed with a glare screen over the light box, which reduced contrast further. Total log CS means for both eyes were recorded for both the Rabin and Rabin Glare forms of the test.

Auditory acuity. Due to time constraints, only a brief auditory acuity screening test was performed. Participants indicated whether they could hear certain tones at 500 Hz, 1000 Hz, and 2000 Hz. The frequencies were tested in an ascending order at different magnitudes. If a participant could hear 500 Hz at 20 decibels (dB), they were assigned a score of 20 for 500 Hz. If participants could not hear anything at 20 dB, they were tested at 25 dB, and if they could not hear at 25 dB, they were tested at 30 dB. If they were unable to hear anything up to 45 dB, they were assigned a score of 50 dB. If participants could not hear a signal, it was repeated multiple times to ensure they did not hear it. The examiner stood behind the participant in order to ensure that the participant could not see when the signal was being pressed, nor to which ear it was directed. The participant was asked to raise the hand associated with the ear the signal was heard in, to ensure that the tone was heard at the right time and guessing did not occur. Scores for both ears were recorded for each participant and a mean was calculated.

Free recall. Categorical norms were obtained from 56 categories that were compiled by Battig and Montague (1969). The Battig and Montague categorical norms were retested by Yoon, Feinbug, Hall, Gutchess, Hedden, Chen, Hu, Jin, Cui, and Park (2004) to determine which were appropriate across age and culture. Only those categories deemed appropriate for North American older adults were used in the present study.

All free recall lists were presented visually. There were two types of free recall lists, one in which the words were categorically related to another (FRR) and the other a mix of words from different categories that were unrelated (FRU). For the unrelated lists, no two words in any list shared an obvious category. For both the related and unrelated lists, no two words in any list shared a first letter, and all words were between four and eight letters. Lists did not significantly differ according to frequency, imagery, familiarity, or concreteness ratings. There were ten words per list. The stimuli can be found in Appendix B.

Digit span. Both forward and backward digit span tests were presented visually, as black numbers on the white background of a computer screen. Participants clicked the numbers in the forward or backward order in which they had seen them presented. List lengths started at three digits. If the correct numbers were clicked in the correct order, the list length increased by one. If an error was made, the list length decreased by one. Twenty of lists of digits were presented for both forward and backward digit span. The maximum list length that was correctly recalled was recorded, along with a mean of successful lists. For all analyses, the digit span means were used to represent performance.

Vocabulary. In the brief vocabulary test, twenty words were presented individually, each alongside four alternative words. The task required the participant to indicate which word was either the synonym or antonym of the central word. The words were presented in blocks of ten synonyms and ten antonyms. The measure was a computerized version of the vocabulary test created by Salthouse (1993).

Speed of processing. The speed of processing measure was taken from the WAIS-R (Wechsler, 1981) and consisted of two subtests. In the first, participants had three minutes to cross out the five figures that were identical to the target figure in each row. In the second, participants circled the two numbers that were identical in each row, again with a three minute time limit. On both tests, the total number of rows correctly completed was tallied and an overall mean was taken.

Procedure

Over two one-hour sessions, participants had their visual and auditory abilities tested using the instruments described above. Participants also completed tests of free recall, digit span, speed of processing, vocabulary, and a demographic questionnaire. Order of task (e.g., free recall, digit span, speed of processing), order of free recall memory tests (i.e., related or unrelated), order of digit span tests (i.e., backward or forward) and order of items within a list were randomized over all participants. The speed of processing measure was completed at a desk using a pen and paper.

Free recall memory tests began with two practice trials, using words that did not appear on the target lists. Data were recorded for practice trials but not used in the final analysis. Participants saw four lists of ten words, related by category or unrelated, for two seconds per word. At the end of the list, there was a pause, followed by the word "GO!", also visually presented. When participants saw the word "GO!", they were to write down all the words they could remember, in any order, on a piece of paper in front of them. While there was no time limit, participants were encouraged to move on to the next list when they had remembered all they felt they could. Lists were always presented in the same order, with the first two lists of each type used only for practice. Items within a list were always presented in random order. Recall lists were marked for accuracy. Lists were administered using E-Prime (Psychological Software Tools, 2002).

The written questionnaire was completed on a desk using a pen and paper, with no time limit. If participants did not wish to answer a question, they had the option of leaving it blank. Some participants experienced difficulty using the computer mouse (e.g., right clicking instead of left clicking, or clicking off the screen), focusing their attention, or following task instructions when completing the computerized tasks. If there were any problems that could jeopardize a participant's score, his or her result was not recorded for the task in which the problem occurred, as this would not be a true representation of his or her ability to perform that cognitive task. Tasks where problems occurred were not repeated, so as to prevent an advantage due to practice. For the reasons listed above, certain task scores have different sample sizes.

Older adults generally display optimal cognitive performance early in the day, so testing occurred between 8:00 am and 2:00 pm (Hasher et al., 1999). Participants were able to choose their own slot between 8:00 and 2:00 pm, allowing for an individual optimal performance time. Participants were fully debriefed as to the purpose of the study at the end of the second session.

Results

Descriptive Statistics

While most variables were normally distributed (FRR, BDS, speed of processing, vocabulary, self-rated health, auditory acuity, FACT, Landolt C, Rabin, Rabin Glare), FDS showed a negative skew, with the majority of participants scoring high, and a few scoring very low. Conversely, FRU showed a positive skew, with the majority of participants scoring low, and a few scoring very high.

Vision. Averages of all participants on vision measures are presented in Table 1 (page 27). The Landolt C was reverse scored, with higher log scores representing worse acuity and lower log scores representing better acuity. For all other tests, higher scores represented better accuracy and lower scores represented worse accuracy on the vision measurement. Participants were also divided into High and Low vision groups. Performance of High and Low vision groups on vision measures is presented in Table 2 (Page 28). Performance of High and Low vision groups on cognitive measures is presented in Table 3 (Page 29).

Cognitive tests. Vocabulary, free recall and digit span performance and ranges are presented in Table 1 (page 27).

Speed of processing. Speed 1 refers to the speed of processing measure in which participants crossed out five identical symbols per row. Speed 2 refers to the speed of processing measure in which participants circled two identical numbers. Scores on Speed 1 and Speed 2 were averaged to obtain the speed of processing score used in the analyses, and referred to in Table 1 as Speed Avg.

Table 1

Descriptive statistics for all measures

Test	N	Mean	SD	Minimum	Maximum
FRU	51	3.77/10	1.55	1	9
FRR	52	6.16/10	1.45	3	10
FDS avg	52	5.65/9	.93	2.5	7.17
FDS max	52	6.40/9	1.30	3	9
BDS avg	52	4.80/9	1.03	2.4	7.06
BDS max	52	5.92/9	1.74	2	9
Synonym	52	7.06/10	2.73	1	10
Antonym	52	5.35/10	2.80	0	10
Vocab. Avg	52	6.20/10	2.63	1.5	10
Speed 1	50	19.18/30	4.07	9	27
Speed 2	50	44.86/60	6.07	28	56
Speed Avg	50	41.61	6.27	26	54
Rated hearing	52	4.69/7	1.63	1	7
FACT	51	59.58	23.49	13.20	109.60
Rabin Chart	52	1.26	.34	.38	1.73
Rabin Glare	52	.91	.42	.03	1.58
Landolt C	52	.25	.17	-.05	.65

FRU: Free Recall Unrelated Lists, FRR: Free Recall Related Lists, FDS: Forward Digit Span, BDS: Backward Digit Span, Vocab. avg: Vocabulary Average, FACT: Functional Acuity Contrast Test.

Table 2

Performance on visual measures according to low or high vision group designation

Test	N	Rabin	SD	N	Rabin Glare	SD	N	Landolt C	SD	N	FACT	SD
Low Rabin	26	.97	.21	26	.59	.30	26	.36	.14	26	51.48	22.42
High Rabin	26	1.54	.15	26	1.23	.22	26	.14	.11	25	67.99	21.93
Low Rabin Glare	26	.98	.23	26	.57	.28	26	.36	.15	26	50.49	21.49
High Rabin Glare	26	1.53	1.73	26	1.25	1.89	26	.14	.11	25	69.02	22.04
Low Landolt C	28	1.04	.27	28	.65	.34	28	.37	.11	28	53.36	21.30
High Landolt C	23	1.50	.21	23	1.22	.26	23	.10	.08	23	67.15	24.25
Low FACT	26	1.09	.32	26	.73	.44	26	.30	.16	26	40.84	12.52
High FACT	25	1.41	.26	25	1.09	.31	25	.20	.17	25	79.06	14.50

Table 3

Performance on cognitive measures according to low or high vision group designation

Test	N	FRR	SD	N	FRU	SD	N	BDS	SD	N	FDS	SD	N	Speed	SD
Low Rabin	26	5.69	1.47	26	3.33	1.29	26	4.56	1.03	26	5.41	1.11	26	40.44	6.67
High Rabin	25	6.68	1.31	24	4.27	1.71	25	5.00	1.01	26	5.90	.64	24	42.88	5.67
Low R. Glare	26	5.69	1.39	26	3.38	1.28	25	4.64	.95	26	5.46	1.01	26	40.19	6.96
High R. Glare	25	6.68	1.40	24	4.21	1.75	26	4.91	1.11	26	5.85	.82	24	43.15	5.13
Low Landolt C	28	5.95	1.54	27	3.67	1.53	28	4.71	1.00	28	5.51	1.01	28	40.64	6.01
High Landolt C	23	6.46	1.36	23	3.91	1.63	22	4.77	1.00	23	5.86	.81	22	42.84	6.51
Low FACT	26	5.92	1.36	26	3.40	1.24	25	3.40	1.24	26	5.50	.90	25	40.22	7.05
High FACT	25	6.44	1.55	24	4.19	1.79	25	4.84	.95	25	5.84	.96	25	43.00	5.15

Note. Low R. Glare = Low Rabin Glare, High R. Glare = High Rabin Glare

Auditory acuity. The mean decibels (dB) participants could hear at frequencies of 500, 1000, and 2000 Hz were 26.37, 26.89, and 31.98, respectively. At 500 Hz, 58.5% of participants could hear the tone at 20 dB, while 9.4% were assigned 50 dB. At 1000 Hz, 56.6% of participants could hear the tone at 20 dB, while 11.3% were assigned 50 dB. At 2000 Hz, 52.8% of participants could hear the tone at 20 dB, while 32.1% were assigned 50 dB. Table 4 displays frequency data of the decibels at which participants were able to hear each level of Hz.

Table 4

Frequencies for responses to tone on auditory acuity measure

dB	500 Hz	1000 Hz	2000Hz
20-24	34	33	29
25-29	6	3	0
30-34	1	3	0
35-39	5	6	5
40-44	0	2	1
45-49	2	0	1
50	5	6	17
Total	53	53	53

General questionnaire. Frequencies for participation in mental activities, physical activities, reading books, and reading magazines are presented in Table 5 (page 31). The number of sick days, doctor visits, or hospital visits in the past six months is presented in Table 6 (page 31).

Table 5

Frequencies for mental and physical activities

Test	N	Daily	Weekly	Monthly	Hardly Ever
Mental activities	53	21	16	3	13
Physical activities	53	31	22	0	0
Read books	52	25	10	9	8
Read magazines	53	15	26	7	5

Table 6

Frequencies for health variables

Test	N	None	1-2	3-4	5+
Sick days	53	42	8	1	21
Doctor visits	53	6	26	14	7
Hospital visits	53	49	2	1	1

Correlations

A significance value of p=.05 was used for all comparative results. Although there was a fairly large participant sample, they were all identified as "healthy", and none showed extreme decline in vision, hearing, or cognitive functioning. This restricted the range in scores, making adopting a more conservative alpha value unlikely to reveal differences between participants.

Correlations were performed on all variables in the present study, to determine their relatedness. Table 7 gives the full correlation matrix, including all main variables. Age did not significantly correlate with the Landolt C or the FACT, but correlated significantly with the Rabin, $r(56) = -.29$, the Rabin Glare, $r(56) = -.32$ and with auditory acuity, $r(56) = -.51$. Age also correlated significantly with FRU, $r(54) = -.32$, but no other cognitive variables. The negative correlations demonstrate that older participants performed worse on the Rabin, Rabin Galre, auditiory acuity, and FRU. Auditory acuity did not correlate significantly with any of the vision tests. Hospital visits correlated with auditory acuity, $r(56) = -.28$, Landolt C, $r(56) = .31$, and the FACT, $r(56) = -.28$ (e.g., increased hospital visits were associated with reduced auditory acuity, Landolt C, and FACT performance), but no other sensory variables correlated with any of the health related variables. Although the vision tests correlated with each other, they showed different effects when interacting with other variables, as demonstrated in Table 7 (Page 33), and throughout the regressions described below.

Speed of processing. Speed of processing (SOP) correlated significantly with the FACT, FRR, and FRU. After controlling for age, SOP continued to correlate significantly with the FACT, $r(47) =.35$, FRU, $r(46) =.33$, and FRR, $r(47) =.34$. (e.g., increased SOP scores were related to increased FRU and FRR scores and increased FACT performance). After controlling for performance on the FACT, SOP continued to correlate significantly with performance on the FRU, $r(46) =.31$, and FRR, $r(47) =.33$, suggesting that the relationship between SOP and free recall performance was not confounded by FACT performance. The Speed Hypothesis states that speed explains the relationship between vision and memory in older adults. After controlling for performance on the SOP measure, FRR continued to correlate significantly with the Rabin, $r(47) =.29$, and the Rabin Glare, $r(47)$ -.29, suggesting that speed alone did not explain this relationship.

Table 7

Intercorrelations among variables

	Vision Tests					Auditory Acuity			Health			Free Recall		Digit Span		Cognitive Variables				
Measure	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1. Landolt C	-	-.45**	-.85**	-.77**	.17	.03	-.05	.14	.08	.34*	-.05	-.11	-.12	-.09	-.07	-.18	.16	.06	-.03	.16
2. FACT		-	.51**	.41**	-.15	-.21	-.14	-.01	-.15	-.29*	-.11	.16	.17	.15	.07	.36*	-.01	.09	.09	-.13
3. Rabin			-	.92**	-.20	-.20	-.09	.03	-.06	-.26	-.04	.26	.34*	.23	.24	.21	.07	.08	.01	-.32*
4. Rabin Glare				-	-.16	-.15	-.04	.09	-.16	-.22	-.02	.22	.32*	.28*	.18	.15	-.05	-.04	.00	-.33*
5. 500 Hz					-	.73**	.48**	-.02	.04	.07	.11	-.19	-.18	-.31*	-.38**	-.20	-.10	.08	.23	.34*
6. 1000 Hz						-	.72**	-.13	.21	.30*	.06	-.23	-.14	-.38**	-.45**	-.18	-.28*	-.04	.01	.38**
7. 2000 Hz							-	-.14	.23	.34*	.03	-.22	-.13	-.29*	-.37**	-.21	-.29*	-.15	-.01	.50**
8. Self Health								-	-.13	-.11	-.36**	.11	-.02	.12	.08	.14	.22	.17	.08	.07
9. Sick Days									-	.51**	.26	-.04	.16	-.21	-.21	.13	.10	.12	.01	-.04
10. Hospital Visits										-	.12	-.18	.01	-.06	-.16	.01	.01	.08	-.16	.10
11. MD Visits											-	-.05	-.03	-.11	-.29*	-.04	.10	.01	-.01	-.11
12. FRU												-	.71**	-.08	.31*	.35*	.41**	.36*	.07	.32*
13. FRR													-	.15	.35*	.36*	.47**	.39**	-.20	-.21
14. FDS														-	.57**	.08	.14	.03	-.26	-.15
15. BDS															-	.14	.33*	.20	-.18	-.19
16. SOP																-	.31*	.35*	-.17	-.13
17. Vocabulary																	-	.69**	-.31**	-.03
18. Education																		-	-.20	-.02
19. Ment. Act.																			-	.04
20. Age																				-

Health: health related variables

Regressions

Multiple regression analyses were performed on the dependent variables of FRU, FRR, FDS, BDS, and SOP mean scores. Predictor variables included Age, Education, SOP (for the digit span and recall tasks), self-rated health, engagement in mental and physical activities, vocabulary, self-rated hearing, auditory acuity at 500 Hz, 1000 Hz, and 2000 Hz, Rabin and Rabin Glare score, FACT score, and Landolt C score. This way, sensory and cognitive variables, as well as age, could be compared in their ability to predict performance on the dependent variable. For each dependent variable, a second regression analysis was conduced including only the sensory variables: Rabin and Rabin Glare, Landolt C, FACT, and auditory acuity at 500 Hz, 1000 Hz, and 2000 Hz. The second regression analysis was completed in order determine which vision test was the strongest predictor of each cognitive test or if auditory acuity would be the strongest sensory predictor.

The first prediction of the current paper was that vision performance would predict performance on all memory tests. The second prediction was that vision would be a stronger predictor of the unrelated than the related free recall lists. The third prediction was that vision would be a better predictor of all tests than hearing.

Free recall of unrelated lists. When all of the aforementioned variables were used to predict FRU mean scores, the linear analysis was not significant, $F(13, 34) = 1.28$, $p > .05$. When entered into a stepwise regression, vocabulary accounted for 17.1% of the variance, $F(1, 46) = 9.46$, $p < .01$. The relationship between vocabulary and FRU scores was inverse, $F(1,48) = 13.24$, $p < .01$, with some high vocabulary scores associated with low FRU scores, and some high FRU scores associated with low vocabulary scores.

When both age and vocabulary were combined, they accounted for 26.3% of the variance, $F(2, 45) = 8.04$, $p<.001$. The relationship between age and FRU scores was also inverse, $F(1,48) = 5.57$, $p<.05$, with a general trend towards younger participants performing better, but some older adults scoring very high, and some younger adults scoring very low.

When only the sensory variables were included in the regression analysis: Rabin, Rabin Glare, Landolt C, FACT, Auditory Acuity at 500hz, 1000hz, and 2000 Hz, $F(7,42) = .97$, $p>.05$, no variables reached significance. The results of the FRU regressions do not support any of the predictions (vision was not the strongest predictor of a visually presented test, vision was not a greater predictor for FRU than for FRR, vision was not a better predictor than hearing).

Free recall of related lists. When all variables were used to predict FRR mean scores, the equation reached significance, $F(13, 34) = 2.67$, $p<.05$. When entered into a stepwise regression, significant variables were vocabulary, $F(1, 46) = 13.10$, $p<.01$, and the Rabin Glare, $F(2, 45) = 11.42$, $p<.001$. The relationship between vocabulary and FRR scores was linear, $F(1,49) = 4.57$, $p<.001$, high vocabulary scores being associated with high FRR scores. The variance accounted for by vocabulary alone was 22.2% and increased to 33.6% when the Rabin Glare was added to the equation. The relationship between FRR and Rabin Glare scores was exponential, $F(1,49) = 5.53$, $p<.05$: those with the highest FRR scores had high Rabin Glare scores, but many with high Rabin Glare scores had average or low FRR scores.

When only the sensory variables were included in the regression analysis: Rabin, Rabin Glare, Landolt C, FACT, Auditory Acuity at 500hz, 1000hz, and 2000 Hz, $F(7,43)$

=2.05, $p<.05$, significant variables were the Rabin and Landolt C.. The Rabin accounted for 11.4% of the variance, $F(1, 49) = 6.29$, $p<.05$. The relationship between FRR and Rabin scores was exponential, $F(1,49) = 6.75$, $p<.05$, with a similar pattern as between FRR and Rabin Glare scores. When Landolt C was also added to the equation, 21.3% of the variance was accounted for, $F(2, 48) = 6.51$, $p<.01$. The Landolt C, however, did not demonstrate a significant curve fit. The results of the FRR regressions support the first and third predictions (visual performance was related to memory performance, vision was a better predictor than hearing), but not the second prediction (vision was not a greater predictor for FRU than FRR).

Forward digit span. When all of the aforementioned variables were regressed on FDS, the equation did not reach significance, $F(13, 34) = .88$, $p>.05$. In a stepwise regression, Auditory Acuity at 1000 Hz reached significance, $F(1, 46) = 7.65$, $p<.01$, accounting for 14.3% of the variance. Next, only the sensory variables were included in the regression analysis: Rabin, Rabin Glare, Landolt C, FACT, Auditory Acuity at 500 Hz, 1000 Hz, and 2000 Hz, $F(7,43) = 1.81$, $p>.05$. In a stepwise regression, only Auditory Acuity at 1000 Hz reached significance, accounting for 14.3% of the variance, $F(1,47) = 7.82$, $p<.01$. When age was controlled for, FDS still neared significance with Auditory Acuity at 1000 Hz, $r(47) = -.28$, $p=.05$. The results of the FDS regressions are contrary to the first and third predictions (vision was not related to memory performance, hearing was a better predictor than vision).

Backward digit span. When all of the aforementioned variables were used to predict BDS, the equation did not reach significance, $F(13, 34) = 1.39$, $p>.05$. When entered into a stepwise regression, the strongest predictor was Auditory Acuity at

1000Hz, $F(1, 46) = 11.42$, $p < .001$, accounting for 19.9% of the variance. Next, only the sensory variables were included in the regression analysis: Rabin, Rabin Glare, Landolt C, FACT, Auditory Acuity at 500hz, 1000hz, and 2000 Hz, $F(7,42) = 2.34$, $p < .05$. In a stepwise regression, only Auditory Acuity at 1000Hz reached significance, 19.9% of the variance, $F(1,47) = 11.67$, $p < .001$. After controlling for age, BDS continued to correlate with Auditory Acuity at 500 Hz, $r(47) = -.29$, $p < .05$, 1000Hz, $r(47) = -.38$, $p < .01$, and neared significance at 2000 Hz, $r(47) = -.28$, $p = .05$. The results of the BDS regressions are contrary to the first and third predictions (vision was not related to memory performance, hearing was a better predictor than vision).

Speed of processing. In psychological research on aging, speed of processing (SOP) is alternatively presented as a cause and as an outcome of cognitive performance (e.g., Luszcz & Bryan, 1999, Anstey & Smith, 1999). In the present study, SOP was used as an independent variable when examining other cognitive tests (i.e., digit span and free recall), but also used as a dependent variable. When all other aforementioned variables were used to predict SOP scores, the equation did not reach significance, $F(12, 35) = 1.47$, $p > .05$. In a stepwise regression, the FACT reached significance, $F(1, 46) = 6.81$, $p < .05$, accounting for 12.9% of the variance. The relationship between the FACT and SOP scores was linear, $F(1,48) = 7.10$, $p < .05$, with higher FACT performance associated with higher SOP scores. When vocabulary was entered into the equation, both variables accounted for 23% of the variance, $F(2, 45)$, $= 6.72$, $p < .01$. Next, only the sensory variables were included in the regression analysis: Rabin, Rabin Glare, Landolt C, FACT, Auditory Acuity at 500hz, 1000hz, and 2000 Hz, $F(7,42) = 1.21$, $p > .05$. When entered into a stepwise regression, the FACT was significant, $F(1, 48) = 7.10$, $p < .05$, accounting for 12.9% of the variance. These results support the first and third predictions (vision was related to performance on a visually presented test, vision was a better predictor than hearing).

ANOVAs

One and two-way ANOVAs were performed to assess the impact of various independent variables (i.e., vision, self-rated hearing with and without a hearing aid, vocabulary, education, frequency of engagement in mental activities) on vocabulary, speed of processing, forward and backward digit span, and free recall for the unrelated and related lists. ANOVAs were performed rather than regression analyses because the independent variables could be classified as categorical rather than continuous. In exploring the characteristics of the participant sample, a number of analyses not directly relevant to the hypotheses of the current study, but of interest to the general study of age-related cognitive and sensory degradation, and understanding the current sample of participants, were also performed.

Self-rated hearing. One-way ANOVAs examined self-rated hearing scores as a predictor for FRU, FRR, FDS, BDS, and SOP. The ANOVAs were performed multiple times; removing individuals who wore hearing aids, including them but using their ratings with their hearing aids on, and including them but using their ratings without their hearing aids on. Self-rated-hearing was not predictive of cognitive performance. The results of all self-rated hearing analyses can be found in Appendix C.

The Common Cause Hypothesis predicts that hearing loss should correlate with reduced memory performance regardless of whether the individual can hear through a corrective device (i.e., a hearing aid). To examine the predictions made by the Common

Cause Hypothesis, a self-rating of natural, uncorrected hearing ability was required. Therefore, in all regressions and subsequent analysis, self-rated hearing refers to ratings without wearing hearing aids, for all participants.

Hearing aids. A one-way ANOVA examined performance as a function of how often individuals wore a hearing aid: always, sometimes, not often, or not at all. Owning a hearing aid was related to performance on FDS and BDS, but no other cognitive measures. Likewise, frequency of using a hearing aid was related to performance on FDS and BDS, but no other cognitive measures. The results of all hearing aid analyses can be found in Appendix C.

Education. One-way ANOVAs were used to determine whether the highest level of education achieved was related to performance on vocabulary, FRU, FRR, BDS, FDS, and SOP scores. All means and standard deviations are presented in Table C1 (Appendix C). Education was predictive of vocabulary score, but not performance on the cognitive measures. The results and discussion of education analyses can be found in Appendix C.

Vocabulary. Although vocabulary scores ranged from zero to ten, it was of interest to examine whether vocabulary "groups" would show differences as well. Specifically, the question was asked "How does someone with a vocabulary score of 1/10 differ from someone with a vocabulary score of 10/10?" Vocabulary scores were divided into three groups, "Low" scores from 1-3.5 (n=10), "Medium" scores from 4-6.5 (n=20), and "High" scores from 7-10 (n=22). All means and standard deviations are presented in Table C2 (Appendix C). Vocabulary groups differed according to performance on FRU, FRR, BDS, as well highest level of education completed. The results of the analyses performed on vocabulary groups can be found in Appendix C.

Mental activity. One-way ANOVAs were run to determine if frequency of engaging in mental activities was related to cognitive performance. All means and standard deviations are presented in Table C1 (Appendix C). Engagement in mental activities was not related to cognitive performance. Discussion of mental activity analyses are presented in Appendix C.

Eye surgery. Some types of age-related vision problems (e.g., cataracts) are largely correctable through surgery. While the Common Cause Hypothesis would claim vision correction to be irrelevant in the relationship between vision loss and memory performance, the Information Degradation and Speed hypotheses would expect vision correction to increase individual performance on memory tests. One-way ANOVAs were run to determine if eye surgery was related to cognitive or visual performance. The sixteen participants who had undergone eye surgery performed significantly worse than participants who had not undergone eye surgery on FRU, $F(1, 46) = 4.78$, $p < .05$, FRR, $F(1, 47) = 7.57$, $p < .05$, BDS, $F(1, 47) = 5.12$, $p < .05$, and the Rabin, $F(1, 48) = 6.42$, $p < .05$.

The participants who had undergone eye surgery were significantly older than those who had not undergone eye surgery, $F(1, 48) = 6.04$, $p < .05$. When age was controlled for, eye surgery still related to performance on FRR, $F(1, 47) = 2.21$, $p < .05$. The relationship between eye surgery and FRR supports the Common Cause Hypothesis, but is inconclusive due to the confounds of contrast sensitivity and age, and due to the need for within participant (before surgery and after surgery) testing.

Gender. Females performed better than males on FRU, $F(1, 48) = 4.45$, $p < .05$, but not FRR, $F(1, 49) = .01$, $p > .05$. Females also rated their hearing as significantly better than males, $F(1, 49) = 10.43$, $p < .05$, although there were no significant differences on the auditory acuity measure at 500 Hz, $F(1, 50) = 1.48, p > .05$, 1000 Hz $F(1, 50) = .08, p > .05$, or 2000 Hz, $F(1, 50) = 2.34, p > .05$. Females also reported participating in mental activities for longer periods of time, $F(1, 44) = 6.89, p < .05$, and participating in physical activities more frequently, $F(1, 50) = 5.17, p < .05$.

High and Low Vision Groups

The regression analyses revealed a non-linear relationship between visual and cognitive performance. Dividing participants into visual groups by a median split allowed the extreme ends of performance to be compared. One-way ANOVAs were run to determine if high and low vision groups differed on cognitive performance.

Rabin. The Low Rabin group performed significantly worse than the High Rabin group on both FRU $F(1, 48) = 4.90, p < .05$ (Figure 1), and FRR, $F(1, 49) = 6.41, p < .05$ (Figure 2). The Low Rabin group performed slightly, but not significantly worse on FDS than the High Rabin group $F(1, 50) = 3.76, p > .05$. The Low Rabin group was also significantly older than the High Rabin group, $F(1, 50) = 7.30, p < .01$. Rabin performance continued to correlate with FRR after age had been controlled, $F(1, 48) = 4.38, p < .05$. The results of the Rabin ANOVA support the first prediction: that vision would relate to memory performance.

Rabin Glare. The Low Rabin Glare group performed slightly, but not significantly, worse on the FRU, $F(1, 48) = 3.64, p = .06$ (Figure 2) than the High Rabin Glare group and significantly worse on FRR $F(1, 49) = 6.41, p < .05$ (Figure 1) than the High Rabin Glare group. Low and High Rabin Glare groups did not differ on any of the other tests. Again, the High Rabin Glare group was significantly older, $F(1, 50) = 6.75, p < .05$, than the Low Rabin Glare group. Rabin Glare performance was still significantly related to FRR after age had been controlled, $F(1, 48) = 4.43$, $p < .05$. The results of the Rabin Glare ANOVA support the first prediction, that vision would relate to memory performance.

Landolt C. Landolt C groups did not significantly differ on any of the tests. Figure 2 compares Low and High Landolt C groups by average performance on FRU tests. Figure 1 compares Low and High Landolt C groups be average performance on FRR tests. The results of the Landolt C ANOVA do not support the first prediction, as visual acuity did not relate to memory performance.

FACT. FACT groups did not significantly differ on any of the cognitive tests, although the Low FACT group performed slightly worse on FRU than the High FACT group, $F(1, 48) = 3.27$, $p = .08$ (Figure 1). Figure 2 demonstrates how Low and High FACT groups performed on the FRU lists. The results of the FACT ANOVA do not support the first prediction, as low-contrast visual acuity did not relate to memory performance.

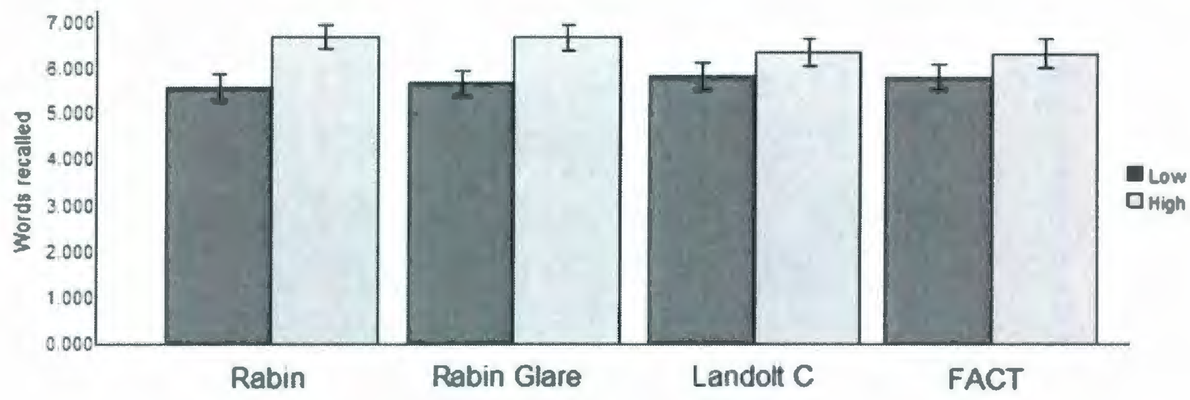

Figure 1. FRR average scores according to designation in Low or High vision groups by performance on the Rabin test of contrast sensitivity, the Rabin Glare test of contrast sensitivity, the Landolt C test of Visual Acuity, and the Functional Acuity Contrast Test of Low-Contrast Visual Acuity.

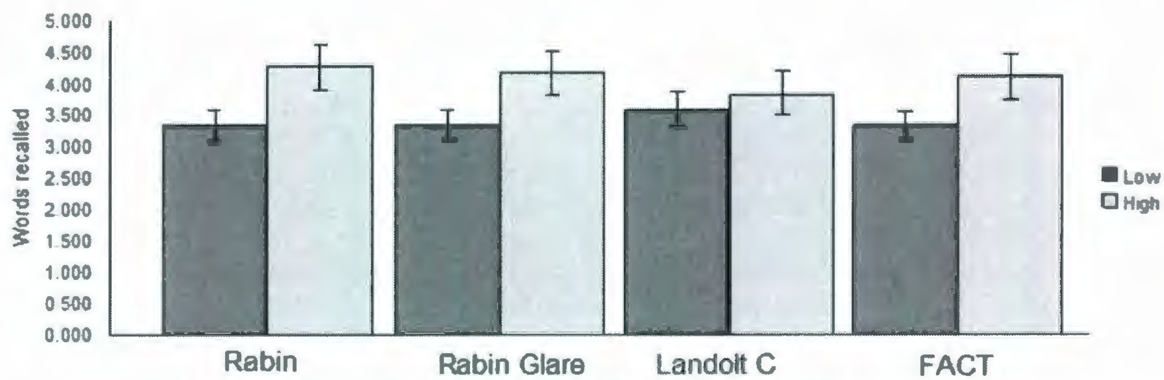

Figure 2. FRU average scores according to designation in Low or High vision groups by performance on the Rabin test of contrast sensitivity, the Rabin Glare test of contrast sensitivity, the Landolt C test of Visual Acuity, and the Functional Acuity Contrast Test of Low-Contrast Visual Acuity.

Discussion

The current study tested aspects of three theories regarding the relationship between age-related memory loss and sensory decline. The Common Cause Hypothesis states that cognitive decline and sensory decline are both symptoms of an underlying common cause. The Speed Hypothesis states that sensory decline causes longer encoding times, leaving less time for rehearsal. A lack of rehearsal results in worse memory performance than when rehearsal is permitted. Finally, the Information Degradation Hypothesis states that reduced sensory functioning directly causes reduced memory performance by impairing the quality of the encoded and to-be-retrieved information.

Past research examining the cognitive-sensory relationship has often involved loading multiple tests onto single cognitive factors. Previous research has shown that older adults show different patterns of performance on tests such as forward or backward digit span, and contextual or conceptual stimuli (Salthouse, 1999, Spencer & Raz, 1995). While some tests may seem interchangeable, loading them onto a single factor can hide different patterns of results. The aim of the present study was to examine the effects of sensory degradation on specific stimuli, so tests were examined individually rather than loaded onto single factors. Unfortunately, this strategy leads to a complicated pattern of results that does not lend itself to simple analyses or to a single, easy answer to the hypotheses tested. Nonetheless, this strategy should lead to more concrete, replicable data than the variance partitioning methods. The interactions among various sensory and cognitive variables are likely to be complicated, thus, this complexity in the data reflects the complexity in the processes that are being examined.

The current study looked at performance on five cognitive tests individually: Free recall of lists in which the items were 1. related or 2. unrelated, digit span in a 3. forward or 4. backward manner, and performance on a 5. speed of processing measure. Likewise, vision loss is not a single concept, but can affect acuity, contrast, and a combination of the two. In the current study, participants had their vision measured with three different vision tests, each assessing a different type of common vision loss. Finally, while the study was mainly concerned with vision loss, a brief screening test for auditory acuity was also performed. Each hearing threshold was looked at individually.

It is common in research on aging for a group of older adults to be compared to a group of younger adults. The present study only tested older adults for the reasons explained on pages fourteen-to-fifteen of the current paper. An effect of age was not predicted, due to the lack of a younger adult comparison group. As mentioned in the descriptive statistics, many participants were in their early 60s, so there was not a great amount of variance on age.

The present study involved three working hypotheses, although many additional analyses were also performed. The first prediction was that vision loss would correlate with memory loss, a finding that would be in support of the Common Cause, the Speed Hypothesis, and Information Degradation Hypotheses. The second prediction was that vision loss would be a greater predictor for the unrelated than the related lists. The second prediction stemmed from studies showing large age differences for contextual and detail specific stimuli (e.g., Spencer & Raz, 1995) and small age differences for categorical lists (e.g., Smith, 1977). All participants should be able to utilize the gist-based processing memory strategy on the related lists (e.g., focus first on remembering the category, then memory strategy on the related lists (e.g., focus first on remembering the category, then on the specific words). It was expected that participants with worse vision would have to focus harder to view the lists than participants with better vision, affecting their encoding of specific stimuli, as required in the unrelated lists, but not for categorized stimuli, as required in the related lists. The Common Cause and Speed of Processing hypotheses do not predict differences between stimuli so a different relationship between vision loss and different types of stimuli would only support the Information Degradation Hypothesis. The third prediction was that in regression analyses, vision would be the best sensory predictor of all tests because the stimuli were all visually presented. The relationship between vision, but not hearing, and cognitive performance would support the Information Degradation and Speed Hypotheses, but go against the predictions of the Common Cause Hypothesis.

Prediction 1: Vision loss should correlate with memory loss

The first prediction was that participants with worse vision should also show worse performance on the recall, digit span, and speed of processing tests than participants with better vision. There is a large body of research showing correlations between vision, hearing, and cognitive performance (e.g., Anstey et al., 2006; Baltes & Lindenberger, 1997; Salthouse et al., 1998; Zekveld et al., 2007). In the current study, performance on the measures of low contrast visual acuity and visual acuity did not correlate significantly with any of the free recall or digit span tests. Performance on the low contrast visual acuity measure did correlate positively with the speed of processing test, although no other visual measures did.

Performance on the contrast sensitivity measure correlated positively with on FRU. Performance on the contrast sensitivity measure with the glare correlated positively with performance on FRR as well as performance on FDS. Additionally, the High Rabin group performed better than the Low Rabin group on both the FRR and FRU, while the High Rabin Glare group performed better than the Low Rabin Glare group on the FRR and slightly, but not significantly, better on the FRU. The combined findings from the ANOVAs and regression analyses suggest that individuals with worse vision performed worse on certain cognitive tests than participants with better vision. The different relationships between type of vision and type of cognitive tests suggests a specific, rather than general relationship between vision and cognition.

That the low-contrast visual acuity and visual acuity measures did not significantly correlate with the digit span or free recall tests is an important finding. While the free recall tests were created for the present study, the digit span tests are a common standardized measure. As Anstey et al., (2006) found, aging affects different types of vision loss in different ways. If the present study had loaded vision tests onto a single variable, the lack of a significant relationship between performance on tests of low-contrast visual acuity and visual acuity and performance on cognitive tests would not have been noticed.

Just as the visual measures did not correlate significantly with FRU, FDS, or BDS, the visual measures were also not significant predictors of FRU, FDS, or BDS in the regressions. The contrast sensitivity measure remained the strongest predictor of FRR, even when non-sensory variables were included as predictors in the regression. The visual acuity measure also reached significance in predicting FRR scores when entered into a stepwise equation. This suggests that while the contrast sensitivity measure was the strongest predictor of FRR scores, the visual acuity measure also could be used as a predictor, though not as successfully.

The findings of the present study partially support each hypothesis. All three predicted a relationship between vision and cognitive performance. While there was a relationship between vision and cognitive performance, it was not inclusive of all visual or cognitive measures. Studies supporting the Common Cause Hypothesis often use visual acuity as their visual measure (e.g., Anstey & Smith, 1999; Lindenberger & Baltes, 1994), but visual acuity was not found to be a strong predictor in the present study. Only contrast sensitivity with the glare was found to correlate with FDS, while BDS showed no relationship with any visual measure. The inconsistencies in the present findings demonstrate the importance of examining both visual and cognitive measures individually rather than factor loading.

Prediction 2: Vision loss should be a greater predictor for unrelated than related lists

The second prediction was that the relationship between vision loss and memory performance should be greater on the unrelated than the related lists. The second prediction was not supported by the present study. In fact, vision correlated only with performance on the related lists, and not with performance on the unrelated lists. The High Rabin group did perform significantly better than the Low Rabin group on both the unrelated and related lists. However, the relationship between Rabin scores and free recall performance was greater for the related than the unrelated lists on both the regression analysis and ANOVA. Because it was clear that those with worse vision did not perform significantly worse than those with better vision on the unrelated than the related lists, additional analyses examining the size of the difference were not performed.

A possible reason the second prediction was not successful could be the overall low performance on the FRU. All participants benefited greatly from categorized lists, with much higher performance on the FRR than the FRU. On the FRU, participants scored a mean of 3.77 (1.51), while on the FRR they scored a mean of 6.17 (1.42). Increased performance on the related lists reaffirmed findings by Spencer and Raz (1995) that older adults show increased performance with conceptual (i.e., meaningful) rather than contextual (i.e., detail specific) stimuli. Low performance on FRU may have restricted variance, and therefore the ability to demonstrate significant findings. The current study used ten items per recall list, a similar method as used by Smith (1977). It is possible that the large number of items may have overwhelmed some participants, even after the practice trials. Future research might amend the stimuli used in the present study by reducing the number of items in each list to seven rather than ten. Although there might be a ceiling effect for a few participants, perhaps there would not be such a floor effect overall.

According to the Information Degradation Hypothesis, distance vision should not have affected results using the current test format. While the computerized free recall tests still required contrast sensitivity, acuity should not have been an issue since participants sat directly in front of the material. The Common Cause Hypothesis, however, would predict that there should be no interaction between sensory loss and type or presentation of stimuli. Additionally, many participants wore corrective lenses which correct acuity, but not contrast sensitivity. Corrected vision should not have been an issue, however, if there was a common cause accounting for results, making quality of encoded information irrelevant. Even so, contrast sensitivity was related to performance on the word lists while visual acuity was not related to cognitive performance at all. Anstey et al. (2006) found older adults demonstrated longer latencies when contrast of stimuli was low rather than when it was high. Future research should continue to examine experimentally whether test conditions (e.g., distance from screen, level of contrast) can influence the relationship between vision and cognitive performance.

Prediction 3: Vision should be the best sensory predictor for all cognitive tests

The third prediction tested the Information Degradation and Speed hypotheses, which both predict that vision loss should specifically impact performance on visual stimuli, and not impact performance on auditory stimuli. If vision was the best sensory predictor for all tests, predictions of the Information Degradation and Speed hypotheses would be supported. The Common Cause Hypothesis, however, predicts a general relationship between all types of sensory and cognitive degradation, as all are presumed to be symptoms of the common cause. If auditory acuity was the best sensory predictor for any of the tests, which were all visually presented, support would be provided against the Information and Speed hypotheses, but not necessarily against the Common Cause Hypothesis.

The current results did not support the third prediction for the FRU, FDS, or BDS. For the FRU, vocabulary and age were the strongest predictors, without any sensory variables predicting a significant amount of the variance. The finding that vocabulary performance is a predictor of free recall performance provides some evidence against all three hypotheses, suggesting that what individuals do to preserve their own cognition may be more important than sensory decline. The relationship between vocabulary and free recall performance is discussed in Appendix C. Age was also a significant predictor of FRU scores, supporting findings by Spencer and Raz (1995) and Smith (1977), that older participants show reduced performance compared to younger participants, even in a sample of older adults, when stimuli are detail specific.

For both digit span tests, auditory acuity, specifically at the 1000 Hz threshold, was the strongest predictor of performance. All levels of the auditory measure (500 Hz, 1000 Hz, and 2000 Hz) correlated significantly with both BDS and FDS. After age was controlled for in a partial correlation, FDS still neared significance with auditory acuity at 1000 Hz and BDS continued to significantly correlate at 500 Hz, 1000 Hz, and neared significance at 2000 Hz. The relationship between auditory acuity and digit span provides evidence against the Information Degradation and Speed hypotheses as the tests were visually presented and vision was not at all related to performance. The Common Cause Hypothesis predicts that both hearing and vision should relate to cognitive performance. Since only hearing was related to digit span performance and not vision, this does not support the Common Cause Hypothesis.

On both digit span tasks, participants clicked the numbers one-to-nine, which were presented on the screen in the order they had seen them. Order was the important factor, not item recall. It is possible that with the format of the digit span tests, factors related to working with information in memory would be more important predictors than vision, despite the task being visual. It would be interesting to further examine why hearing is related to digit span performance, even after controlling for age. Salthouse (1991) found that older adults use different strategies for forward and backward digit span. In the current study, BDS correlated with all levels of the hearing test after controlling for age, while FDS only neared significance with one level. The results suggest that auditory acuity may be a better predictor of BDS than of FDS. Further research should continue to use both formats of digit span testing, and not solely one or the other.

The third prediction was supported by the results of the FRR and SOP tests. Of both the sensory and non-sensory variables, the Rabin was the strongest predictor of performance on FRR. The Rabin continued to correlate significantly with FRR after controlling for age. Visual acuity was also a predictor of FRR, but no longer significantly correlated with FRR after controlling for age. Auditory acuity was not related to FRR, supporting the Information Degradation Hypothesis because the FRR tests were visual, so hearing should not be a relevant factor. The findings of the present study do not reject the Common Cause Hypothesis because the two theories are not necessarily exclusive. As Craik and Salthouse (2000) suggested, the hypothesized common cause might independently produce vision, hearing, and memory loss, but each loss further impacts the other because our senses determine the quality of information encoded into memory.

Speed of processing correlated significantly with the FACT, FRR and FRU, supporting the Speed Hypothesis, which predicts that speed of processing should be related to both vision and memory. After controlling for age, performance on SOP continued to correlate with performance on the FRR and FRU. That the relationship between speed and memory performance was not entirely explained by age supported the Speed Hypothesis, which predicts that the relationship between speed of processing, memory, and vision should increase with age but also share variance not accounted for by age. After controlling for performance on the FACT, SOP continued to correlate significantly with FRU and FRR. The Speed Hypothesis predicts that reduced visual functioning should cause reduced speed of processing, resulting in less rehearsal and lower recall of items, compared to normal visual functioning. The continued significant correlation between SOP and free recall after controlling for FACT performance suggests that vision could not alone explain the relationship. Rather, the continued correlation between SOP and free recall after controlling for the FACT supports the Common Cause Hypothesis, suggesting that both speed of processing and free recall are symptoms of an alternative cause. It could also be explained by the Information Degradation Hypothesis, with different types of vision loss impacting different formats of cognitive testing.

After controlling for SOP, vision and memory correlations were tested again. Originally, FRR had correlated significantly with the Rabin and the Rabin Glare, and continued to after controlling for performance on SOP. This finding contradicts the Speed Hypothesis because speed did not explain the relationship between contrast sensitivity and free recall performance. Speed was also not a significant predictor of performance on any of the digit span or recall tests, while sensory measures (i.e., vision or auditory acuity) were. In summary, SOP performance was related to performance on both free recall tests and the FACT, not the Rabin. Performance on free recall was related to performance on the Rabin and the Rabin Glare, not to performance on the FACT. Speed could not explain the relationship between vision and free recall, and vision could not explain the relationship between speed and free recall. The evidence does not support the Speed hypothesis.

General Discussion

The current design allowed for individual sensory and cognitive variables to be examined in relation to each other. Rather than loading correlating variables on a single factor, the unique contribution of each variable was determined. Two different types of variables were successful in predicting scores: those related to sensory abilities (i.e., hearing and vision), and those related to cognitive engagement (i.e., vocabulary). While hearing and vision correlated with age, vocabulary scores showed no relationship with age, but were related to education. Even so, only the extreme ends of the educational spectrum significantly differed in memory performance. It may be not the way in which a person has been formally educated that is important for preserving memory, but rather the way they self educate (i.e., continue to learn outside of formal education, such as reading books). Vocabulary scores also correlated with self reported frequency of reading books or magazines.

The Common Cause Hypothesis states that many aspects of the body deteriorate alongside memory other than vision and hearing, but this was not reflected in the current results. Doctor visits, hospital visits, number of sick days, physical activity, and self-rated health were not related to memory performance. Self-rated health, mental, and physical activity were also not related to age, replicating findings by Anstey and Smith (1999).

It is possible that there was insufficient variance in the scores to show a relationship between health-related variables and memory. For example, it was previously mentioned that all participants rated their health from average to excellent. The relatively high health self-ratings may explain why neither vision nor hearing loss were related to self-rated health, as the Common Cause Hypothesis would predict. It would be interesting to explore what factors participants consider when rating their own health in relation to same age peers. One potential participant, for example, described herself as in good health, but also mentioned that she was experiencing significant hearing loss and had recently undergone heart surgery. Perhaps health ratings reflect the participants' optimism rather than the true state of their health. Of the variables assessed in the current study, self-rated health only correlated significantly with the number of doctor visits.

Conclusions and Implications for Future Research

The present results gave partial support for Common Cause and Information Degradation hypotheses. Participants showed much better performance on the FRR than the FRU lists, of which performance on the Rabin was a predictor. Additionally, the High Rabin group performed significantly better on both the FRR and FRU than the Low Rabin Group, and the High Rabin Glare group performed significantly better on the FRR than the Low Rabin Glare group. Performance on the FACT related to performance on SOP, while the Landolt C did not correlate with any of the cognitive variables. The different relationships between contrast sensitivity and visual acuity measures and tests of cognitive performance replicate findings by Anstey et al. (2006). Vision should then not be examined as a single variable, encompassing tests of both contrast sensitivity and visual acuity. Rather, each specific type of vision should be tested for its unique contribution or relation to performance. To increase test reliability, it would be acceptable to load similar vision tests onto a factor (e.g., multiple measurements of visual acuity).

The current results demonstrated little support for the Speed Hypothesis. None of the vision groups differed according to performance on the speeding of processing measure. Scores on the speed of processing measure did correlate with performance on the FACT, FRU, and FRR. Speed of processing scores, however, were not significant independent predictors of FRU, FRR, FDS, or BDS results in the multiple regression analyses. It is possible that reduced SOP in those with poor vision is a symptom rather than a cause. The Information Degradation Hypothesis would explain this relationship as poor vision longer encoding times and also a worse encoded trace of the to-be-processed stimuli, resulting in low memory scores. The Common Cause Hypothesis would argue that declines in SOP, free recall, and vision are all symptoms of the common cause.

Unexpectedly, hearing was the best predictor for both digit span tests. The Speed and Information Degradation hypotheses both predict a direct relationship between sensory decline and the sense required by a particular measurement. Because all cognitive tests in the current study required vision, and none required hearing, the Speed and Information Degradation hypotheses would not have predicted any correlation between hearing and cognitive performance. The relationship between hearing and digit span was therefore only in support of the Common Cause Hypothesis. Without an additional relationship between vision and digit span, however, this is not sufficient evidence towards the Common Cause Hypothesis.

While variance partitioning techniques tend to yield simpler results than the present study, it is important to acknowledge that there is nothing simple about human cognition, nor its interactions with the body's sensory systems. Future research should continue to examine relationships between specific types of vision, hearing, and cognition. The current study used four lists for each type of recall. This number could be increased to increase reliability.

Future research should examine the relationship between hearing and order recall, a finding in the current study. Vocabulary was related to performance on word lists, but not number lists. Future research should continue to examine the relationship between vocabulary, education, and memory, to determine whether increasing vocabulary is beneficial to memory itself, or only memory for words.

Many studies on age-related memory loss compare groups of older adults to groups of younger adults. Differences in cognitive and sensory performance between older and younger adults are often attributed to age differences, and thus to aging itself. In the present study, hearing and vision performance, but not age, were predictors of performance on FRR, FDS, BDS, and SOP. Age, however, correlated with all levels of auditory acuity and both forms of contrast sensitivity, with older participants demonstrating worse performance than younger participants. While it is possible that age is an underlying variable, not directly related to cognition but mediating the relationship between cognitive and sensory tests, the continued relationship between auditory acuity and digit span after age was controlled for would suggest otherwise.

Craik and Salthouse (2000) examined 288 studies testing cognition in older adults. They found that only 18% of studies using auditory materials tested for auditory acuity and only 21% of studies using visual materials tested for visual acuity. Finally, only one of the 288 studies used sensory information as a covariate rather than a tool for participant selection (p. 178). Whether the Common Cause Hypothesis or the Information Degradation Hypothesis is correct in explaining the cognitive-sensory relationship, both would likely suggest visual and auditory screening be mandatory for all studies involving comparisons between older and younger adults. If, by chance, a sample of half the participants in the current study with the worst hearing scores was taken, and compared to a sample of younger adults on a digit span test without a mandatory auditory screening, age would emerge as the significant predictor in performance. The results of the current study demonstrate the need to provide a mandatory auditory and visual screening for age-related cognitive research.

Research examining the relationship between sensory functioning and cognitive ability is important to pursue. Many areas of the world are currently facing rapidly aging populations alongside changing life expectancies. A primary concern of older adults is maintaining their cognitive health. It is clear from the present research that cognitive performance is a complex issue, with different aspects impacted by a diverse array of factors. Although the relationship between sensory and cognitive functioning may appear to be explainable by extraneous variables (e.g., age, health, speed), research has found the sensory-cognitive relationship to remain after controlling for all relevant confounding factors (e.g., Anstey, 1999a, Lindenberger & Baltes, 1997). The current study found no relationship between self-rated health or speed and cognitive or sensory functioning. It did, however, find a relationship between cognitive and sensory functioning, which was often dependent on the demands of the task.

Results from the current study partially supported both the Common Cause and the Information Degradation hypotheses. If the predictions stemming from either the Common Cause or the Information Degradation hypotheses are supported, the treatment of cognitive degradation in older adults could be significantly improved. The Common Cause Hypothesis predicts that cognition and physiological functioning decline alongside each other as symptoms of a general deterioration. If this theory were accepted clinically, optometrists and audiologists could recommend that patients showing a steady decline in sensory functioning consider having their cognitive functioning examined as well. To say that cognition and sensory functioning are symptoms which decline concurrently is not to say they cannot be reversed.

The Information Degradation Hypothesis predicts that it is the strain caused by sensory degradation that reduced the quality of a stimulus and memory for that information. Predictions stemming from the Information Degradation Hypothesis could be especially useful in clinical settings and policy. Many health care plans offer only partial coverage for corrective lenses and hearing aids. If the link between vision and hearing loss and cognitive decline were shown to be distinct and causal, many would demand full coverage. Additionally, while individuals may accept and adjust to vision or hearing loss, memory loss bears greater social and personal repercussions. If the public were aware that correcting vision or hearing loss could prevent cognitive decline, even partially, many would be more inclined to acquire the necessary aids. Finally, if the combination of the two theories, as suggested by Salthouse (2000), is the best in explaining the relationship, both preventative and corrective measures may be implemented.

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Appendix A: General Questionnaire

General Questionnaire Subject #: ______

Please complete the following questionnaire regarding your general health and activity level.
If you have any questions about the wording or anything else, feel free to ask the experimenter for clarification.
If you feel uncomfortable or for any reason do not wish to answer some questions, you may leave them blank.

1. Please indicate the day, month, and year of your birth:

   ____

2. Please check your gender:
   - Male
   - Female

3. Please check your handedness:
   - Left Handed
   - Right Handed

4. Is English your first language?
   - Yes
   - No

5. Please check your living situation:
   - Independent
   - With a spouse or partner
   - With family
   - In a community setting (e.g., retirement home)
   - Other (please elaborate) ________________

6. Do you use a hearing aid? (Please check)
   No, I don't have or use one.
   I have one, but hardly ever use it.
   I have one that I use sometimes.
   Yes, I wear a hearing aid.

7. *If you use a hearing aid,* please rate your hearing *when you are using it*, with 1 meaning extremely poor, 4 meaning average, and 7 meaning excellent

   1 2 3 4 5 6 7

8. Please rate your hearing *without a hearing aid* (whether you have one or not) with 1 meaning extremely poor, 4 meaning average, and 7 meaning excellent

   1 2 3 4 5 6 7

9. Please check your highest level of formal education
   Some grade school (grade 8 education or less)
   Some high school (less than grade 12 education)
   High school diploma (grade 12 education or equivalent)
   Community college or trade school
   Some University (attended but did not attain a degree)
   University Bachelors Degree
   Masters University Degree or higher.

10. In the past six months, about how many days did you spend sick in bed?
   none
   1- 2
   3-4
   5 or more

11. In the past six months, about how many days did you spend in a hospital?

    None
    1-2
    3-4
    5 or more

12. In the past six months, how many times have you visited a medical physician (*not* an eye doctor, dentist, etc.)

    None
    1-2
    3-4
    5 or more

13. Please indicate your general health, in relation to your same age peers, with 1 meaning extremely poor, 4 meaning average, and 7 meaning excellent

    1 2 3 4 5 6 7

14. How often do you read a newspaper?

    Daily
    Weekly
    Monthly
    Hardly Ever

15. How often do you listen to or watch the news?

    Daily
    Weekly
    Monthly
    Hardly Ever

16. How often do you participate in mentally stimulating activities (e.g., chess, checkers, cards)?
    - Daily
    - Weekly
    - Monthly
    - Hardly Ever

17. When you do participate in mentally stimulating activities, as indicated above, how long do these sessions last for, on average?
    Under 15 minutes
    Under 30 minutes
    Under an hour
    An hour or more
    Other/Depends (please explain): ______________

18. How often do you participate in physical activities (e.g., tennis, line dance, go for walks, swim)?
    Daily
    Weekly
    Monthly
    Hardly Ever

19. When you do participate in physical activities, as indicated above, how long do these sessions last for, on average?
    Under 15 minutes
    Under 30 minutes
    Under an hour
    An hour or more
    Other/Depends (please explain): ______________

20. How often do you read *magazines*?
    - Daily
    - Weekly
    - Monthly
    - Hardly Ever

21. If you read magazines, check *all* that you read:
    - General Interest (e.g., TV guide, Readers Digest)
    - Specific Interest (e.g., Hunting, Home Décor, Cooking)
    - News / Politics (e.g., Newsweek, Macleans)
    - Other (please indicate) _______________
    - I don't read magazines.

22. How often do you read *books*?
    - Daily
    - Weekly
    - Monthly
    - Hardly Ever

23. If you read books, are they generally
    - Fiction
    - non-fiction
    - or a mix of both?
    - I don't read books

24. If you wear corrective lenses, are you near sighted or far sighted (does your prescription say "+" or "–"):
    - + (near sighted)
    - – (far sighted)
    - Not sure.

25. Have you ever had eye surgery?
    Yes
    No

26. If you answered yes to the previous question, please describe
    a) what it was for (e.g., cataracts): ____________________
    b) how long ago it was (an estimate):____________________
    c) how many eye surgeries you had:____________________

27. Do you currently have any medical vision/hearing issues we should know about (e.g., cataracts)? If so, please list them:

    ____

28. Finally, please list any prescription medications you are taking that might affect your performance here today, and your general cognitive performance.

    ____

    ____

Thank you!

Appendix B: Free Recall Word Lists

Free Recall Unrelated

Practice List 1:	Test List 1:
Cornell	Flute
Dallas	Polo
Window	Moth
Gold	Triangle
Piccolo	Leaflet
Folk	Bracelet
Taxi	Dime
Sociology	Nutmeg
Limbo	Carrot
Boot	Waist
Practice List 2:	**Test List 2:**
Purple	Ginger
Adverb	Fork
Major	Canoe
Opera	Deputy
Valley	Pork
Blizzard	Mansion
Nitrogen	Trolley
Cobra	Brandy
England	Squirrel
Harry	Nickel

Free Recall Related

Practice List 1:	**Test List 1:**
Mary	Robin
Sue	Eagle
Anne	Canary
Jane	Hawk
Carole	Pigeon
Barbara	Swallow
Linda	Lark
Nancy	Warbler
Judy	Quail
Practice List 2:	**Test List 2:**
General	Trout
Sergeant	Bass
Private	Minnow
Captain	Haddock
Colonel	Perch
Major	Shrimp
Corporal	Whale
Admiral	Oyster
Commander	Clam
Ensign	Lobster

Appendix C: Additional analyses

Education. One way ANOVAs were performed with Education level as the independent variable and FRU, FRR, BDS, FDS, SOP, and vocabulary as the dependent variables. The ANOVAs were significant for vocabulary, $F(5, 46) = 11.47, p < .001$, and neared significance for FRU, $F(5, 45) = 2.42, p = .05$, but were not significant for FRR, $F(5, 46) = 1.97, p > .05$, BDS, $F(5, 46) = .58, p > .05$, FDS, $F(5, 46) = .49, p > .05$, or SOP, $F(5, 44) = 1.65, p > .05$. Tukey post hoc comparisons revealed that the eight participants with some high school performed significantly worse on the FRU than the six participants with a university degree. All means and standard deviations are presented in Table C1.

Table C1

Performance according to highest level of education achieved

	Some High School			H.S. Diploma			CC/Trade School			Some University			University BD			MA or Higher		
	N	Mean	SD	N	Mean	SD	N	Mean	SD	N	Mean	SD	N	Mean	SD	N	Mean	SD
FRU	8	2.69	1.00	4	4.50	.91	12	5.92	1.12	15	3.37	1.55	5	5.20	1.79	21	3.74	1.62
FRR	8	5.00	.53	4	6.00	1.29	12	3.46	.94	15	6.53	1.63	6	6.42	1.59	21	6.36	1.58
FDS	8	5.75	.89	3	5.78	.86	12	5.32	1.07	16	5.82	.99	6	5.51	.74	20	6.04	.59
BDS	8	4.48	1.04	3	4.93	.89	12	4.51	.57	16	4.91	1.21	6	5.00	1.25	21	5.18	.77
Speed	8	37.44	8.79	3	43.67	2.02	12	40.71	6.97	15	41.43	4.88	6	44.50	4.46	19	43.47	7.60
Voc.	8	2.75	1.25	4	6.63	1.49	12	5.29	1.76	15	6.63	2.57	6	7.33	1.57	21	7.05	.63
Age	8	69.88	4.64	4	68.00	9.70	12	68.33	6.13	16	68.75	6.22	6	66.00	7.62	21	67.33	5.81

Note: H.S. Diploma = High School Diploma, CC/Trade School =Community College or Trade School, University BD = University Bachelors Degree, MA or Higher = Masters University Degree or Higher, Voc. = Vocabulary

Vocabulary group analyses. Vocabulary scores were divided into three groups, "Low" scores from 1-3.5 (n=10), "Medium" scores from 4-6.5 (n=20), and "High" scores from 7-10 (n=22). One-way ANOVAs used vocabulary groups as the independent variable and FRU, FRR, FDS, BDS, SOP, education, auditory acuity, and vision as the dependent variables. Groups differed significantly on FRU, $F(2, 48) = 5.58$, $p < .01$, FRR, $F(2, 49) = 7.19$, $p < .01$, BDS, $F(2, 48) = 4.08$, $p < .05$, and education $F(2, 49) = 20.63$, $p < .001$. Tukey post hoc tests revealed that the High vocabulary group scored significantly higher than the Low group on FRR and FRU. The High group also scored significantly higher than the Medium group on FRR. The Medium group scored significantly higher than those in the Low group on BDS. Table C2 displays means on each test according to vocabulary group.

Table C2.
Means on tests according to vocabulary group

	Low			Medium			High		
Test	N	Mean	SD	N	Mean	SD	N	Mean	SD
FRU	10	2.55	.93	19	3.74	1.06	22	4.36	1.82
FRR	10	5.15	.71	20	5.85	1.06	22	6.91	1.65
FDS	10	5.75	.78	19	5.34	1.11	22	5.91	.78
BDS	10	4.39	.95	19	4.45	.83	22	5.18	1.00
Speed	10	39.60	8.20	19	40.66	5.80	21	43.43	5.42
Age	10	70.30	5.50	20	68.20	5.44	22	68.50	7.68
500 Hz	10	27.75	11.45	20	27.00	9.13	22	24.89	10.48
1000 Hz	10	31.00	12.65	20	28.63	11.16	22	23.75	7.51
2000 Hz	10	37.00	14.94	20	35.00	14.60	22	27.50	11.65
Landolt C	10	.23	.23	19	.24	.16	22	.27	.15
Rabin Chart	10	1.24	.46	19	1.19	.31	22	1.30	.31
Rabin Glare	10	.96	.52	19	.86	.38	22	.93	.42
FACT	10	58.50	34.04	19	63.16	17.99	22	56.97	22.81

Mental activity. ANOVAs were run to determine if there were any differences in cognitive performance between participants who reported engaging in mental activities daily, weekly, monthly, or hardly ever. The dependent variables were FRU, $F(3, 47) = .27, p > .05$, FRR, $F(3, 48) = 1.01, p > .05$, FDS, $F(3, 48) = 2.12, p > .05$, BDS, $F(3, 48) = 2.01, p > .05$, and SOP, $F(3, 46) = .80, p > .05$. Only vocabulary approached significance, $F(3, 49) = 2.45, p = .07$, with those reporting more frequent engagement in mental activity demonstrating slightly higher vocabulary scores than those reporting less frequent engagement in mental activity. All means and standard deviations according to frequency of participation in mental activities are presented in Table C3.

Table C3
Performance according to frequency of participation in mental activities

	Daily			Weekly			Monthly			Hardly Ever		
Test	N	Mean	SD	N	Mean	SD	N	Mean	SD	N	Mean	SD
FRU	21	3.74	1.62	15	3.57	1.43	3	4.33	1.04	12	3.96	1.78
FRR	21	6.36	1.58	16	6.28	1.28	3	6.67	.29	12	5.54	1.56
FDS	20	6.04	.59	16	5.39	1.28	3	5.78	.43	13	5.37	.79
BDS	21	5.18	.77	16	4.39	1.01	2	4.71	.18	13	4.68	1.31
Speed	19	43.47	7.60	16	40.56	5.85	3	40.00	7.81	12	40.63	3.76
Voc.	21	7.05	2.63	16	6.13	2.68	3	5.83	2.84	12	4.92	2.24
Age	21	67.33	5.81	16	71.06	6.63	3	66.67	8.96	13	68.46	6.25

Voc. = Vocabulary

The mental activities ANOVA did not show any relationship between frequency of engagement in mental activities and cognitive performance. Vocabulary groups, however, differed significantly on the free recall word lists. It is possible that vocabulary scores provide a more objective assessment of participation in certain types of mental activities than does self report. Alternatively, different definitions of what constitutes a mental activity (e.g., chess, cards, reading, etc.) could result in different performance patterns. While reading daily might increase working memory for lists of words, playing Sodoku daily might increase working memory for lists of digits. The current study inquired as to how often and how long individuals participate in mentally engaging activities, but future research might additionally ask what types of activities they are engaging in.

Self-Rated Hearing with and without Aids. Alongside the objective auditory acuity test, there was a subjective scale of hearing ability. Individuals who wore hearing aids indicated how often these were worn and rated their hearing ability with and without their aids in. In order to use self rating of hearing, differences among participants with and without hearing aids were considered. One-way ANOVAs using self-rated hearing scores as an independent variable and cognitive tests as the dependent variables, without including the individuals who wore hearing aids, did not reach significance for FRU, $F(5, 36) = .67, p > .05$, FRR, $F(5, 36) = .15, p > .05$, FDS, $F(5, 39) = 1.17, p > .05$, BDS, $F(5, 36) = .58, p > .05$, or SOP, $F(5, 34) = 1.96, p > .05$. One-way ANOVAs including those who wore hearing aids, using their rating with their hearing aids on, did not reach significance for FRU, $F(6, 43) = .87, p > .05$, FRR, $F(6, 44) = .57, p > .05$, FDS, $F(6, 44) = 1.25, p > .05$, BDS, $F(6, 44) = 1.56, p > .05$, or SOP, $F(6, 42) = 1.34, p > .05$. One-way ANOVAs including those who wore hearing aids in the analysis, using their ratings without their hearing aids on reached significance for FDS, $F(6, 44) = 2.72, p < .05$, with high hearing ratings associated with high FDS scores, but not FRU, $F(6, 43) = 1.17, p > .05$, FRR, $F(6,$

44) =1.17, $p>.05$, BDS, $F(6, 44) = 1.89$, $p>.05$, or SOP, $F(6, 42) = .97$, $p>.05$. Although auditory acuity was related to some of the cognitive measures, self ratings of hearing ability were not predictive of cognitive performance.

A one-way ANOVA examined performance as a function of how often individuals wore a hearing aid: always, sometimes, not often, or not at all. There were no significant differences on SOP, $F(3, 50) = .28$, $p>.05$, FRU, $F(3, 49) = 1.08$, $p>.05$ or FRR, $F(3, 51) = 1.44$, $p>.05$, but groups differed on FDS, $F(3, 50) = 7.76$, $p<.001$, and BDS, $F(3, 49) = 4.96$, $p<.01$. Post hoc comparisons using the Tukey HSD test revealed that for FDS and BDS, the 44 participants who did not own a hearing aid ($M = 5.87$, $SD = .71$, $M = 5.00$, $SD = .99$, respectively) performed significantly better than the six who always wore one ($M = 4.65$, $SD = 1.16$, $M = 3.88$, $SD = .48$, respectively).

Participants who did not own a hearing aid were slightly younger ($M = 67.73$, $SD = 5.95$) than those who always wore one ($M = 71.50$, $SD = 4.59$), but this age difference was not significant. After controlling for age, owning a hearing aid continued to correlate, with FDS, $r(45) = .52$, $p<.001$ and BDS, $r(45) = .39$, $p<.01$, but not FRU, $r(45) = .04$, $p>.05$, or FRR, $r(45) = .002$, $p>.05$, again demonstrating the relationship between hearing and digit span performance in the current sample, and the lack of relationship between hearing and free recall performance. It should be noted that the group who did not own a hearing aid was much larger, and the discussed results are more exploratory than statistically meaningful.

Footnotes

[1] Variance partitioning techniques are often used to determine the relationship between sensory and cognitive functioning. In variance partitioning, multiple tests are correlated to form latent and mediator variables. Latent and mediator variables (e.g., vision, sensory functioning, cognition) encompass results from multiple related constructs. Regression analyses are then performed to assess the percentage of variance in a dependent variable accounted for by each factor (e.g., Baltes & Lindenberger, 1997) Variables that share variance with both age and cognition (e.g., changes in auditory acuity) are proposed to be underlying factors in the cognitive decline that is associated with aging.

In the research reviewed in the present paper, the term, "cognition", generally refers to a composite variable created by loading correlated tests of cognitive ability, such as short-term memory and speed of processing tests. Because different researchers load different measures onto the variable named "cognition", the specific tests used in each study need to be specified in any literature review. Problems with the loading approach are discussed in the Introduction of the present paper. To avoid such problems, the present study examined each cognitive test individually (e.g., free recall memory) rather than using loading techniques.