REDUCED LATERALITY AMONG OLDER ADULTS: BUILDING ON THE HAROLD MODEL

by

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ABSTRACT

Evidence of hemispheric asymmetry reduction among older adults (HAROLD) was investigated concerning four cognitive processes. Additionally, evidence was examined for two hypotheses which attempt to explain changes consistent with the HAROLD model; the dedifferentiation hypothesis suggests these changes are merely a byproduct of cognitive decline, and the compensation hypothesis suggests these changes are functional adaptations to cognitive decline. Results for the HAROLD model failed to reject the null hypothesis of no significant difference between younger and older adults concerning hemispheric lateralization across four cognitive processes. Correlational analyses were explored and found to provide mixed support for the compensation hypothesis and evidence against the dedifferentiation hypothesis. Specifically, the correlations between measures of asymmetry showed increased separation among older adults in comparison to younger adults. This stands in contrast to dedifferentiation which predicts a general increase in correlations among measures of asymmetry, via a broad increase in bilaterality. Statistical support for compensation was found for one cognitive process in the association of lateralization with performance only for younger adults. Further support for compensation was found in the association of cognitive status with lateralization among older adults, with normal cognition older adults showing greater asymmetry reduction compared to mildly impaired cognition older adults. There was also some support for an association of lateralization with performance, significant for one of the four cognitive processes, supporting compensation. Limitations of particular concern were sample size and a potential confounding variable of sex among older adults. Further research is needed to validate these results, particularly given the potential role of sex in obscuring changes consistent with the HAROLD

model among older adults. It is possible that the HAROLD model may not generalize to auditory linguistic, auditory emotional, spatial quantitative, or spatial attentive processing.

DEDICATION

This dissertation is dedicated to my wife, Anna Smitherman, for her loving support and for helping me to meet all my deadlines! I also dedicate this work to Elizabeth DiNapoli for being such a supportive friend, and to my family for their encouragement and support all these years.

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INTRODUCTION

Increased longevity and decreased fertility are driving an unprecedented shift in the relative proportion of global age groups. By 2050 older adults (60 years of age or older) will exceed youth (15 years of age or less) for the first time ever (Department of Economic and Social Affairs Population Division, 2002). This historic shift has already occurred in more developed regions. For example, in the year 2000 there were already 27 countries with more people 60 years and above than children 15 years and below, 26 in Europe and Japan. The population of young people and adults under 60 years in the US is expected to decrease between 2000 and 2050 from 22-19% and 62-55% of the population respectively, while the number of older adults is expected to increase from 16-27% of the population. This graying trend poses a twofold challenge. First, this shift will have a drastic effect on the ratio of US working age adults to potential dependents, from 62:38 in 2000 to 55:46 in 2050. Second, as dementia prevalence rises with age, 5% at 71-79 years, 37% at 90 years and above, the aging population will produce a substantial increase in the proportion of people with dementia, straining already limited care resources (Plassman et al., 2007). Ferri et al. (2005) predicted a 172% proportionate increase in the number of people with dementia in North America between 2001 and 2040. There is already urgent need for research regarding the trajectory and amelioration of cognitive decline in older adults, and the importance of this line of research will only increase over time.

The breadth of the population so affected also depends on the onset of cognitive decline which is a matter of ongoing controversy. The controversy is in part methodologically driven with cross-sectional literature suggesting age-related decline in early adulthood, whereas longitudinal analyses have supported decline starting somewhere between mid and late life. Salthouse has presented a body of work using cross-sectional analyses in which he has repeatedly argued for age-related decline as early as the 20s to 30s (Salthouse, 2004; Salthouse, 2009). Salthouse supports the continued use of cross-sectional analyses, arguing that longitudinal analyses fail to show early decline, largely due to test-retest effects.

Longitudinal analyses tend to support minimal age-related decline until late life (Aartsen, Smits, von Tilburg, Knipscheer, & Deeg, 2002). Results from the Seattle Longitudinal Study (SLS; Schaie, 1983) indicated no reliable decline prior to age 60, and even at 81, less than half had indications of reliable decrement. The discrepancy with cross-sectional analyses has been explained as a result of over-interpretation of cross-sectional analyses given limitations inherent to this type of data, such as cohort effects (Schaie, 2009). Some recent work has strengthened the claim for cognitive decline in middle age, while also providing further evidence for the limitations of cross-sectional analyses (Singh-Manoux et al., 2012). Singh-Manoux et al. (2012) used Whitehall II, a prospective cohort study from 1985 which began cognitive assessment in 1997, with a sample of 7,390 British civil servants, ranging between 49 and 70 years of age (Marmot & Brunner, 2005). Cognition was assessed three times over ten years with measurements of reasoning, vocabulary, and phonemic and semantic fluency. Singh-Manoux et al. (2012) compared analyses of age related decline using longitudinal and cross-sectional methods and found that cognitive decline in women was overestimated due to cohort differences in education. Their work also suggested age-related decline as early as age 49. Cognitive decline starting by age 49 suggests research on age-related cognitive decline applies to an even broader range of the population and supports the claim that such decline may be normative

(Hedden & Gabrieli, 2004). These results stress the need for research on the nature of cognitive decline and methods of amelioration, supporting the need for the current study.

Cognitive decline in the aging brain can be described both in terms of information processing and brain structure. Research on information processing has produced multiple theories of intelligence from which to analyze age related decline. Foremost of these theories are Spearman's (1927) theory of generalized intelligence and Horn and Cattell's (1966) theory of fluid and crystallized intelligence. Spearman's general intelligence factor g is thought of as a second order factor to Horn and Cattell's factors of intelligence. Fluid intelligence is generally thought to decline from early adulthood whereas crystallized intelligence is thought to increase up to late life.

Horn (1991) proposed the G_f-G_c theory as one of multiple intelligences encompassing nine factors which are differentially affected by age. Horn summarized research findings concluding: four abilities decrease steadily from the early 20s including fluid reasoning (G_f), short-term apprehension-retention (G_{sm}), processing speed (G_s), and correct decision speed (CDS); two abilities increase until between 30s and early 40s including visual processing (G_v) and auditory processing (G_a); and three abilities increase until around 60 years before declining including acculturation knowledge (G_c), fluency of retrieval from long-term storage (G_{lr}), and quantitative reasoning (G_q). In contrast, data from the SLS (Schaie, 1983) indicated no reliable decline before age 60 as noted above. The SLS supported decline in perceptual speed and numeric facility by 60; in inductive reasoning, spatial orientation, and verbal memory by 67; and in verbal ability by 81 (Schaie, 2005).

Concerning brain structure, aging brains display decreased neural and metabolic efficiency, lower blood flow, and overall cell loss. Furthermore, longitudinal analysis has evinced volumetric decline (Meltzer, 2003; Scheibel, 1996). For example, concerning tissue loss, Resnick et al. (2003) studied a sample of non-demented older adults aged 59-85 at baseline who showed significant tissue loss in both white and gray matter over four years. Resnick et al. also examined a subset of participants considered very healthy (no medical conditions and no cognitive impairment) and though the magnitude of tissue loss was reduced, it was still significant.

In contrast to declines in both information processing and brain structure, research suggests that even as neural efficiency decreases, neural activity increases with age, albeit with increased bilaterality (Cabeza et al., 1997; Grady, McIntosh, Rajah, Beig, & Craik, 1999; Reuter-Lorenz et al., 2000; Park & Reuter-Lorenz, 2009). Specifically, compared to younger adults, older adults tend to display increasingly bilateral patterns of prefrontal cortical (PFC) activity. For example, research has repeatedly found lateralized function in younger adults during perceptual tasks in contrast to bilateral function in older adults (Grady et al., 1994; Grady, McIntosh, Horwitz, & Rapoport, 2000). Positron emission tomography (PET) was used to examine PFC activity which was shown in the right hemisphere in younger adults during face matching tasks whereas in older adults activation was found in both hemispheres. Similar age-related differences in lateralization of function have been shown across multiple cognitive processes and operations including more complex operations such as episodic and working memory (Cabeza, 2002). Cabeza (2002) noted this overall pattern and conceptualized it under a model titled Hemispheric Asymmetry Reduction in Older Adults (HAROLD).

Function: Compensation and/or Dedifferentiation

Researchers have largely argued two hypotheses concerning whether age-related hemispheric asymmetry reduction is merely a byproduct of cognitive decline or potentially an adaptive functional response. The dedifferentiation hypothesis suggests changes consistent with the HAROLD model are byproducts of cognitive decline, perhaps decline in the ability to utilize specialized functions. The compensation hypothesis suggests changes consistent with the HAROLD model are a functional adaptation to cognitive decline. There is evidence for both of these competing hypotheses at present, with perhaps stronger support for the compensation hypothesis.

The dedifferentiation hypothesis explains age-related reductions in lateralized function as a result of age-related cognitive decline wherein the specificity and selectivity of neural processors break down (Li & Lindenberger, 1999). The hypothesis is initially supported by a general trend in age-related changes in correlations between cognitive abilities broadly (e.g. fluid and crystallized intelligence), where lateralized function or differentiation increases from adolescence to adulthood and then decreases in late life (Balinsky, 1941). Similarly, Baltes and Lindenberger (1997) found that correlations among five cognitive factors including perceptual speed, reasoning, memory, knowledge, and verbal fluency increased from a mean of 0.35 in an adult sample (M = 48 years) to a mean of 0.69 in an older adult sample (M = 85 years).

Dedifferentiation has been explained mechanistically as a function of neural noise (Li & Lindenberger, 1999; Li, Lindenberger, & Sikström, 2001), long hypothesized as a characteristic of aging brains (Welford, 1965). Neural noise is described as age-related loss in the ability to modulate neuronal signals which impairs the specificity of cortical representations (Li et al., 2001). Neurochemical correlates of neural noise offer support for dedifferentiation, with computer simulations linking age-related declines in catecholamine function to an increase in neural noise (Li & Lindenberger, 1999; Li et al., 2001).

Dopamine serves as one such neurochemical correlate of neural noise, suggesting support for the dedifferentiation hypothesis. Research suggests dopamine displays a consistent age-related decline in various brain regions during normal aging (Backman & Farde, 2004; Lindenberger & Oertzen, 2006). Additionally, dopamine's potential support for dedifferentiation is seen in the prevalence of age-related impairment in the PFC, the site of the majority of current support for the HAROLD theory (Cabeza, 2002). In the PFC, dopaminergic pathways are noted to initiate and maintain mental representations given a lack of actual stimuli cues, as well as direct attention (Miller & Cohen, 2001). That both cognitive faculties of the PFC and dopamine levels in the PFC have age-related declines suggests dopamine may play a role in HAROLD model changes. In a recent review, researchers found further support for the role of dopamine in age-related cognitive decline (Bäckman, Lindenberger, Li, & Nyberg, 2010). The authors noted a growing body of evidence for age-related losses in dopamine which lowered the signal-to-noise ratio in relevant areas, thereby decreasing the recruitment of task-relevant brain regions and increasing recruitment of other brain regions in late life.

The compensation hypothesis suggests that changes consistent with the HAROLD model serve as functional adaptations to cognitive decline (Cabeza et al., 1997). This hypothesis suggests that, as age-related decline brings decreased neural efficiency the brain compensates for the decline in efficiency through greater bilateral activation. Cabeza, Anderson, Locantore, and McIntosh (2002) suggest that compensation is achieved through bilateral activation because it involves the recruitment of an alternate network as opposed to greater activation of the original brain region. The compensation hypothesis is supported in part by a body of research which suggests that bilateral activation facilitates recovery from brain damage. Evidence supporting the link between increased bilateral activation and recovery of function is found in post-stroke recovery of motor control (Aizawa, Inase, Mushiake, Shima & Tanji, 1991; Cao, Vikingstad, Huttenlocher, Towle, & Levin, 1994; Cramer et al., 1997; Sabatini et al., 1994), in recovery from Wernicke's aphasia (Weiller et al., 1995), and in post-stroke recovery from aphasia (Cao, Vikingstad, George, Johnson, & Welch, 1999). This evidence of bilateral activation facilitating recovery from brain injury suggests the plausibility of it also acting in a compensatory fashion in older adults.

Support for the compensation hypothesis is also provided by a body of evidence indicating increased performance related to decreased asymmetry in older adults. In one imaging study, older adults with greater bilateral activation in the PFC were faster in verbal working memory than those without bilateral activation (Reuter-Lorenz, 2000). A study investigating visual laterality with behavioral methods also supported the compensation hypothesis, as it found older adults performing better bilaterally than unilaterally (Reuter-Lorenz, Stanczak, & Miller, 1999). Abassi and Joanette (2011) found further support again using behavioral methods in their research on the meaning of emotional words investigated using visual half-field priming. They found that using both hemispheres, older adults attained equivalent accuracy to younger adults using one hemisphere, albeit, with a time delay for older adults likely related to increased sensory thresholds. Bangen et al. (2011) used imaging to examine whether there are changes consistent with the HAROLD model which support successful associative coding. They found older adults demonstrated increased bilateral activation and that greater activation was associated with better memory performance. This collective body of work suggests significant support in the literature for the compensation hypothesis.

However, patterns of lateralization associated with performance in younger adults and bilaterality associated with performance in older adults are not without counter-evidence. Boles, Barth, and Merrill (2008) examined 13 behavioral lateralization measures for significant correlations of lateralization with performance among a sample of young adults. They reported that a majority of tasks displayed a significant association of lateralization with performance. However, findings included both negative and positive correlations suggesting the effect of asymmetry, whether benefit or hindrance, was process dependent.

A finding among older adults, while consistent with the HAROLD model, provides evidence inconsistent with the compensation hypothesis (Colcombe, Kramer, Erickson, & Scalf, 2005). The researchers used fMRI imaging data to compare the performance of 20 younger and 40 older adults using an adaptation of the Eriksen flanker task. Consistent with the HAROLD model, they found older adults exhibited greater bilateral activation of the PFC during the task than younger adults. However, they found that among older adults there was a negative association of performance with bilaterality in contrast to the general theme of a compensatory nature of reduced asymmetry.

Colcombe et al. (2005) explained the contrasting findings by arguing for an adjustment to the interpretation of the compensation hypothesis. They note that young adults on the flanker task showed activation in the right middle frontal gyrus. They also point out that research has indicated that posterior regions of the PFC are often left lateralized for verbal and right lateralized for non-verbal materials. They noted that the increased activation was not compensatory, and argue this was because the additional activity was primarily verbal processing, providing no help given the nonverbal nature of the flanker task. Colcombe et al. (2005) therefore propose the complementary hypothesis, which suggests that increased activity in a homologous opposite region may only serve a compensatory role if it provides processing which is complementary to the original function.

The work of Boles et al. (2008) and Colcombe et al. (2005) initially seems to be evidence against the compensation hypothesis, but this is not necessarily so. Boles et al. (2008) worked with young adults and as a result their findings may not apply to older adults. Colcombe et al. (2005) found evidence of a negative association of performance with bilaterality among older adults, suggesting stronger potential counter evidence; however, as the authors argue, this may be adequately explained as a case of bilateral activity where the additional counter-hemispheric activation could not play a complementary role. Additionally, Colcombe et al.'s (2005) possible evidence against compensation may not necessarily imply support for dedifferentiation. The negative association of performance and bilaterality may be because it is not functionally significant, not because it is due to dedifferentiation.

Thus, the literature offers strong support for the compensatory role of reduced asymmetry among older adults (Reuter-Lorenz & Cappell, 2008). Support marshaled for the dedifferentiation hypothesis is less prominent, and exists alongside evidence against it (Cabeza et al., 2002). This suggests that hemispheric asymmetry reductions in older adults likely play a compensatory role, assuming complementary function, in the brain's adaptation to decreases in efficiency in old age. However, given the limitation suggested by the complementary hypothesis, not all reductions in asymmetry will necessarily be compensatory or functionally significant.

Generalizability

Cabeza (2002) stated that the HAROLD model was proposed for the PFC; however, he suggested the model may generalize to other brain regions. Cabeza found support for the HAROLD model in research on cognitive processes including episodic memory, working memory, semantic memory, perception, and inhibitory control. Research has generally supported the HAROLD model, with a majority of the research specific to processes of the PFC (Rajah & D'Esposito, 2005). However, research has also supported the HAROLD model beyond the PFC.

Beyond the PFC, evidence has so far supported changes consistent with the HAROLD model in temporal, parietal, and motor regions. In terms of specific cognitive processes, HAROLD-specific changes are supported in facial encoding and recognition, motor coordination, and manual tracing ability. Yet, much of the work on motor processing is nascent, suggesting the need for further confirmatory work. This and other gaps in the literature as discussed below, point to the need for research into the generalization of the HAROLD model.

Researchers have extended the HAROLD model to include motor behaviors such as coordination (Przybyla, Haaland, Bagesteiro, & Sainburg, 2011; Raw, Wilkie, Culmer, & Mon-Williams, 2012). Przybyla et al. (2011) studied the coordination of multidirectional reaching by age. Subjects moved their hand in a single, uncorrected, rapid movement from a start position to one of three targets. They were assessed in terms of accuracy and trajectory curvature. Younger adults had a straighter trajectory and more accurate final position relative to the target for their dominant versus nondominant arm. Conversely, older adult trajectories and accuracies were symmetric, and relative to young adults the difference arose from a decrease in nondominant arm curvature instead of an increase in dominant arm curvature. Raw et al. (2012) examined the ability to trace lines by age and found younger adults demonstrated hand asymmetries whereas older adults did not. Research on lateralization of motor function in older adults is less established than that on the PFC, but this preliminary evidence is supportive of the overall generalizability of the HAROLD model beyond the PFC.

Generalization of the HAROLD model into perception has preliminary support in face-matching and letter matching. Grady, Bernstein, Beig, and Siegenthaler (2002) looked at age-related differences in brain activity during the encoding and recognition of faces using imaging and found positive correlations between performance and temporoparietal activity in the left hemisphere for younger adults but in both hemispheres for older adults. Reuter-Lorenz, Stanczak, and Miller (1999) used behavioral methods to investigate letter matching projected onto one visual field compared to simultaneous projection in both visual fields across three levels of matching complexity. They reported that younger adults showed little difference in accuracy comparing within and between hemisphere activity at all task complexity levels. Conversely, older adults showed a consistent advantage to accuracy of between hemisphere activity, which was significant at both intermediate and high complexity levels. For response time, results indicated young adults had within hemisphere advantage for low complexity, equivalence for medium complexity, and bi-hemispheric superiority for high complexity. For older adults, low complexity was associated with single hemisphere superiority, while both medium and high complexity showed bi-hemispheric superiority. This suggests an age-related gradient of utilization where older adults used bilateral activation earlier than younger adults, at lower levels of task complexity.

Work on emotional judgment in older adults is sparse, with limited evidence in visual emotional processing. Research has addressed visual emotional processing using emotional judgments of chimeric faces where results indicated support for the association of aging with more bilateral processing in line with the HAROLD model (Coolican, Eskes, McMullen, & Lecky, 2008; Gunning-Dixon et al., 2003). However, there remains an absence of research on auditory emotional processing in the literature. The auditory linguistic process has similarly received little direct attention among older adults. Grady, Yu, and Alain (2008) found support for HAROLD consistent changes in working memory for auditory information. Yet, analysis of the lateralization of basic linguistic processing among older adults is lacking. Such research would help by supplementing prior findings in the temporal region as well as giving more location specificity with new information on the aging superior temporal gyrus.

Research on spatial processing in older adults has addressed spatial working memory (Rypma and D'esposito, 2000) as well as work specific to spatial auditory information, where older adults displayed HAROLD-consistent changes (Grady, Yu, & Alain, 2008). However, work on spatial quantitative processing appears to be lacking for older adults, suggesting an area for new research. And while there is some support for the HAROLD model concerning spatial attentive processing (Schmitz & Peigneux, 2011), evidence is limited, suggesting potential utility for confirmatory research. Overall, research examining the HAROLD model in perceptual processing is sparse. Aside from some work applying the HAROLD model to visual emotional processing, research on perceptual processing represents a significant gap in the literature. This strongly encourages research into the general applicability of the HAROLD model in perceptual processing.

Potential Clinical Application

Researching the generalizability of the HAROLD model serves as a goal with clinical importance as it may help in the eventual development and application of ameliorative techniques for cognitive dysfunction. If changes consistent with the HAROLD model are indicative of a compensatory adaptation of the aging brain, and if this compensatory process is generalizable to much of the rest of the brain, then this suggests the possibility of improving or maintaining late life cognition through the application of techniques designed to promote decreased asymmetry/increased bilaterality. However, evidence is very limited for training-related changes in laterality. It is research supporting late life brain plasticity and promising evidence for the efficacy of cognitive training which suggests trained modification of laterality as a future possibility.

Research in general cognitive training is hopeful and suggests its potential for lasting significant effects. Results from the Advanced Cognitive Training for Independent and Vital Elderly (ACTIVE) randomized controlled trial supported the ability of cognitive training interventions to improve targeted cognitive abilities (memory, reasoning, and speed of processing) and maintain gains over a two year follow-up (Ball et al., 2002). Willis et al. (2006) looked at a five year follow-up of the ACTIVE sample and found continued support for cognitive training. Further evidence is provided by Brehmer, Westerber, and Backman (2012) who studied working memory training implemented using commercial software. Individuals were trained in tasks involving holding multiple stimuli in their minds at the same time with short delays during which the stimuli were held in working memory. The control group worked with tasks of unvarying difficulty whereas the experimental group trained on an adaptive version where the tasks increased in difficulty with a growing number of items to be held in working memory. Results demonstrated training gains in both groups, but greater in the adaptive group, which were maintained at a 3-month follow-up.

Contrasting evidence was introduced in a recent meta-analysis which cast doubt on the efficacy of cognitive training (Zehnder, Martin, Altgassen, & Clare, 2009). Zender et al. (2009) used 24 studies of healthy and mildly impaired older adults to examine the effects of memory training. Results for cognitive training groups versus active control groups were significant for face-name immediate recall among healthy but not impaired older adults, one of seven outcome measures. Zender et al. (2009) suggest that this indicates training effects were largely not specific, potentially indicating cognitive training may be no more effective than the nonspecific stimulation of an attention-only comparison group.

However, several limitations of the above work as well as new supportive analyses suggest cognitive training may be efficacious. Zender et al.'s (2009) analyses were at times limited by sample size and number of included studies, for example in impaired older adults the active control comparison used two studies totaling 73 participants across one outcome measure. A systematic review suggested prior non-significant findings were likely influenced by unclear intervention definitions (Gates, Sachdev, Singh, & Valenzuela, 2011). Furthermore, Gates et al. (2011) noted that multiple prior reviews included structurally different techniques and that failing to distinguish between types of cognitive training may have obscured clinically-relevant effects. Given concern for unclear intervention definitions the authors operationalized cognitive training to necessitate repetition of work on problem activities utilizing standardized tasks which target specific cognitive processes. Based on this definition their review found moderate to large effect sizes for cognitive training on memory outcomes. Hindin and Zelinski (2011) provided further support for cognitive training using meta-analytic techniques which revealed that extended cognitive practice training for older adults improved performance on previously untrained cognitive tasks.

Research specific to changes in hemispheric asymmetry accompanying cognitive training is less developed. Erickson et al. (2007) compared 34 older adults randomly assigned to either a training group or a control on a dual-task trial. The training group received five hour-long sessions of training with adaptive performance feedback over a two to three week period, while the control group took a two to three week break. They tested for brain plasticity retention in old age by examining whether improved performance on the dual-task trial was associated with changes in the fMRI pattern of activation. They also looked at whether improved performance would result in a concordant reduction in asymmetry as the compensation hypothesis predicts. Their results indicated support for plasticity in late life, with cognitive training improving performance and altering patterns of cortical activation. However, results showed a training-related increase in lateralization, inconsistent with the compensation hypothesis. Given the limited evidence, there is a need for further research into the effects of cognitive training on hemispheric activity. Such research will aim to find ways to train decreased asymmetry in brain regions or cognitive processes which already display performance related benefits to increased bilateral activation in older adults.

Aims and Hypotheses

The current project had 3 aims: (1) to provide further confirmation of the HAROLD model using established behavioral methods in a new sample of older adults in comparison to younger adults in the Tuscaloosa county area; (2) to explore the generalizability of the HAROLD model using behavioral methods including tasks and cognitive abilities less well established in the literature; (3) and as possible, to analyze these tasks for potential support of the dedifferentiation and compensation hypotheses.

First, it was hypothesized that older adults would display reduced asymmetry compared to younger adults for each of four asymmetry measures, supporting generalization of the HAROLD model to new tasks and cognitive processes. Second, it was hypothesized that the analyses would be consistent with dedifferentiation as indicated by greater correlations among the asymmetry measures in older versus younger adults. Third, it was hypothesized that for the correlation of laterality and performance, there would be a correlation among younger adults but not among older adults. Fourth, it was hypothesized that given an adequate sample for comparison, there would be a significant difference for each asymmetry measure among the older adults, with the cognitively intact displaying greater bilaterality than the mildly impaired, supporting the compensation hypothesis.

METHODS

Subjects

Participants were drawn from two populations, younger adults and older adults. Participants were excluded from final analyses based on inclusion criteria cutoff points enumerated below. As a result, an initial sample of 102 participants (71 younger adults and 31 older adults), was cut to a final sample of 88 participants (60 younger adults and 28 older adults).

The young adult group included undergraduate students at the University of Alabama currently enrolled in an introductory psychology course. Students in the class were recruited through the online subject pool and were incentivized with credit towards their research participant requirement in psychology 101. Inclusion criteria for younger adults included mildly impaired or better cognitive status (assessed using the Saint Louis University Mental Status Examination; SLUMS), age between 19 and 29 inclusive, normal or corrected vision of 20/40 or better, hearing loss $\leq$ 40 dB, right-handedness, and normal mood as assessed using a five-item subtest of the original CES-D (Radloff, 1977). These criteria allowed for a sample that is generalizable to the majority of the student population.

The older adult group included residents of Tuscaloosa County. Recruitment sites included the following locations: FOCUS on Senior Citizens center, Capstone Village, and Osher Lifelong Learning Institute, and general community residents recruited through flyers and other media. Inclusion criteria for the older adult group included mildly impaired or better cognitive status (assessed using the SLUMS), age 60 or higher, normal or corrected vision of 20/40 or better, hearing loss $\leq$ 40 dB, right-handedness, and normal mood as assessed using a five-item subtest of the original CES-D. The sample generalized to community residents age 60 and up who are not experiencing significant cognitive impairment.

Recruitment methods for the study were IRB-approved at the University of Alabama. Subjects recruited from the community and through the University of Alabama subjects pool gave consent in person and were run through study procedures if eligible.

All participants were advised of what their results on the cognitive, mood, hearing, and vision screeners indicated. However, they were told that their results are suggestive, not diagnostic. They were given recommendations as applicable (see Appendices G, F, and E). They were also given referral sources as applicable including (a) The Psychology Clinic at The University of Alabama [(205) 348-5000], (b) The Geriatrics Clinic in The University Medical Center [(205) 348-2880], (c) The Geropsychology Clinic at the University of Alabama [(205) 348-5000], and (d) The Speech and Hearing Center at The University of Alabama [(205) 348-7131].

The inclusion of visual and auditory screening criteria was necessary given the possibility of decreased perceptual abilities, more common in the older adult sample, serving as a confounding factor. In addition, including visual and auditory screeners produced a strong incentive for potential participants who frequently expressed their interest in the free hearing and vision screening assessment.

The current study attempted to test whether older adults display reduced asymmetry. Research has generally been supportive of the compensation hypothesis which suggests that decreased asymmetry is a functional compensation for slowed and less efficient processing (Cabeza et al., 2002). This research has found low performing older adults tend to display a lateralized pattern for many tasks, similar to younger adults, whereas high performing older adults tend to display a bilateral pattern. Given the aim of testing for the presence of reduced asymmetry in older adults, participants were excluded based on a significant cognitive impairment.

The assessment of premorbid (crystallized) intelligence was performed to allow for better comparisons of young to old. It was hoped that premorbid intelligence would serve as a covariate in analyses. A secondary interest was also to assess the relation between crystallized intelligence and lateralization among the younger adult sample. Furthermore, it was hoped that the ability to accept more impaired participants, and then covary out crystallized intelligence, would add power to the analyses.

Recruiting severely impaired older adults would also have made it more difficult to attain permission to begin the study due to the concern for the ability of an impaired person to give informed consent. One option would have been to then seek out proxy consent, however, this would have introduced further difficulty in recruiting participants and overall added more weight to the exclusion of cognitively impaired participants. Alternatively, excluding participants with any form of impairment would have made finding sufficient numbers of participants more difficult. As a compromise it was proposed that the current project assess cognition, excluding participants who were indicated as demented, and continuing with participants who scored as either normal or mildly impaired. It was hoped this would still allow for informed consent as those with rated mild impairment were likely to be relatively high functioning, given the high cut-off point of recent cognitive screeners. Finally, to control for cognitive impairment as a limitation the two cognitive groups of older adults were assessed for significant lateralization differences before being compared as a whole to younger adults.

Last, the addition of a depressive screener was suggested by research which indicates that patients with major depressive disorders may show impaired right-hemisphere functioning (Miller, Fujioka, Chapman, & Chapman, 1995). It can be argued that the inclusion of a mood screener could create difficulty attaining permission to begin the study. However, the mood screener used in this study does not ask about suicidality, and it was believed this would help minimize crises. Further, it was proposed that the assessment administrator would have the number of a licensed supervisor as back-up. Additionally, a depression screening was also considered as an incentive for some people to participate in the research. Given these points, it was perceived as worthwhile to attempt to control for the potential confounding factor of depressed mood.

Methodology Selection

The use of behavioral methodology for assessing laterality was selected primarily due to practical limitations related to imaging including access, invasiveness, and expense. Additionally, research supports strong overall agreement between the assessment of lateralization using behavioral and imaging techniques. Hund-Georgiadis, Lex, Friederici, and Cramon (2002) compared language lateralization assessed using fMRI and a dichotic listening task on a sample of thirty-four healthy subjects aged 20 to 67. They reported global agreement between the two techniques of 97.1%. They also used discriminant analysis to assess agreement between the techniques and found a 94.1% reclassification rate for hemisphere language dominance with the dichotic listening task employed as a group discriminator and the fMRI as a discriminating parameter.

Task Selection

Task selection for analyses examining age-based group differences in laterality was based on several criteria. First, four laterality measures were desired. One measure was to provide replication of prior laterality findings in older adults in the current sample. The remaining three measures were to explore the generalizability of the HAROLD model. These tasks were selected based on a significant gap in the literature on the lateralization of perception. The gap indicated the need for research in this area suggesting an initial winnowing of tasks to those addressing the identified areas of perceptual processing. Second, tasks were selected in part based on research showing an asymmetry for each task believed to trace to a single cognitive process, allowing for potentially clearer interpretation of results. Finally, additional criteria included (a) duration: the total procedure was not to extend much beyond 60 minutes including the laterality measures; (b) reliability: laterality measures had to demonstrate *minimum* Spearman-Brown corrected split-half reliability of 0.30 (Boles, 1998a; Boles, 1998b); and (c) feasibility: laterality measures with established literature on age differences had to suggest a moderate to large effect size. A total of four tasks, each providing an asymmetry measure, were selected based upon these criteria.

Apparatus

Two of the four tasks (dichotic syllables and dichotic emotions) used tape-recorded presentations of stimuli, with differing simultaneous inputs for both ears. Stereo headphones and a stereo cassette player were used to present the stimuli. The other two tasks (bargraphs and landmark) were presented using Superlab Pro (Cedrus Corp, 2000) on a 14-inch CRT monitor and external keyboard, run on an Apple iMac. Additionally, a chin rest positioned 60 cm from the monitor was used to standardize the viewing distance. Assessment of hearing impairment required the use of a portable MAICO MA41 audiometer (MAICO Diagnostics). The remaining measures largely utilized pen and paper.

Measures

The Saint Louis University Mental Status examination. (SLUMS; Tariq, Tumosa, Chibnall, Perry, & Morley, 2006). The SLUMS is a brief, 30-item, screening questionnaire. The SLUMS tests orientation, memory, attention, and executive functions. Normal cognitive performance is indicated by a score of 27-30 for people with a high school education and 25-30 for those with less than a high school education. Mild neurocognitive impairment is indicated by a score of 21-26 and 20-24 respectively. Research suggests the SLUMS and the Mini-Mental State Examination (MMSE; Folstein, Folstein, & McHugh, 1975) have comparable sensitivity, specificity, and area under the receiver operating characteristic (ROC) curve (the discriminatory accuracy of the measure) in detecting dementia; however, the ROC for the SLUMS was better than for the MMSE for the diagnosis of mild neurocognitive disorder (Tariq et al., 2006). However, research has suggested regional variability in appropriate cutoff scores for a similar cognitive screener. The suggested cutoff score for the Montreal Cognitive Assessment (MoCA; Nasreddine et al., 2005) (26) produced a low specificity (35%) for a sample from the Southeastern United States (Luis et al., 2009). Luis et al. found adjusting the cutoff to 23 produced improved sensitivity (96%) and specificity (95%), supporting the need for awareness of domain-specific cutoff scores (Montero-Odasso & Muir, 2010; Stewart, O'Riley, Edelstein, & Gould, 2012). Given a lack of evidence for the SLUMS caution is suggested in its application. This provides support for the conditional acceptance of participants rating as mildly impaired.

Near visual acuity chart. (Sloan & Brown, 1963). Visual acuity criteria were assessed using a near visual acuity chart containing Sloan letters presented in LogMAR sizes designed for testing at 16 inches. Letters included C, D, H, K, N, O, R, S, V, and Z as suggested by Louise Sloan (1959). Line and letter spacing was based on the Logarithm of the Minimum Angle of

Resolution (LogMAR; Bailey & Lovie, 1976). The LogMAR presentation style results in advantages for testing visual acuity including presentation of an equal number of letters per line, using regular spacing between lines and letters, using a uniform progression in letter size, presenting a final score based precisely on the total of all letters read, and using a finer grading scale which allows for improved accuracy and test/retest reliability (Bailey & Lovie, 1976). Participants were asked to read letters beginning with the lowest line they could clearly see. Visual acuity scores were calculated using the near vision chart. Acuity was measured separately for the right and left eyes (with corrective devices, if applicable). Resulting scores of 20/40 or better indicated normal vision, scores worse than 20/40 but better than 20/200 indicated visual impairment, and scores worse than 20/200 indicated legal blindness (Rubin et al., 1997).

Audiometric screening. Participants were screened for hearing deficits using a portable audiometer conducted in accordance with established guidelines (American Speech-Language-Hearing Association, 2005). Pure-tone air-conduction thresholds was obtained for each ear at 250 to 4000 Hz (250, 500, 1000, 2000, 4000). Assessment started at 1000 Hz at 30 dB and was adjusted to determine the decibel threshold for each pitch level based on participant responses. A metric commonly used to define hearing loss in terms of pure-tone thresholds is the traditional pure-tone average (PTA) of thresholds at 500, 1000, and 2000 Hz (Goldstein, 1984). Descriptive labels for hearing loss were based on the American Speech-Language Hearing Association guidelines (Clark, 1981) including normal (0-25 dB), mild loss (26-40 dB), moderate loss (41-55 dB), moderate-severe loss (56-70 dB), severe loss (71-90 dB), and profound loss (>90 dB). Results were plotted on an audiogram (see Appendix H). The task was estimated to take approximately 10 minutes (M. Hay-McCutcheon, personal communication, August 28th, 2013). As per the recommendation of Dr. Hay-McCutchon, participants with hearing loss up to 40 dB were included in the study. Given the nature of the study's tasks for the main hypotheses, testing for laterality versus hearing loss, it was expected that people with up to a mild loss would be able to participate fully. This was backed by data suggesting that general conversation tends to be near 60 dB (57 dB in a suburban home at 1 meter, 55 dB in a patient's room in a hospital, 75 dB on a train at .4 meters, and 51 dB in an anechoic chamber simulating a quiet environment at 1 meter; Olsen, 1998). Therefore, it was recommended that exclusion criteria be set in part as PTA loss greater than 40 dB, indicative of moderate or greater loss, in either ear. Additionally, as speech-frequency tends to range between 500 and 4000 Hz (Agrawal, Platz, & Niparko, 2008), and hearing loss of 3000 Hz and higher is earliest in life and most severe (Dobie, 2001), it was recommended that loss greater than 40 dB at 4000 Hz also be an exclusion criteria. Hearing loss in the elderly tends to be symmetrical (M. Hay-McCutcheon, personal communication, August 28th, 2013) with supportive evidence for women (Houston et al., 1999) and for both sexes (Divenyi & Haupt, 1997). One study reported 95% bilateral hearing loss in a sample of 3,753 (Cruickshanks et al., 1998). Yet, regardless of the generally symmetrical loss in older adults and conversation averaging 60 dB, given the audiological nature of two of the four asymmetry measures used to test this study's main hypotheses, hearing loss in each ear and asymmetry of loss were all considered for use as covariates.

Dichotic syllables. (Boles, Barth, & Merrill, 2008). Thirty pseudorandomly selected pairs of syllables including "ba", "da", "ga", "ka", "pa", and "ta" were presented dichotically. Participants listened to each syllable pair and noted their answers on a prepared answer sheet. After the initial 30 trials the headphones were reversed and the tape was replayed. Asymmetry was calculated for each participant's data separately using a laterality coefficient (LC) formula, where %C represents percent correct and %E represents percent errors. For accuracy in excess of 50%, LC = (R%C - L%C) / (R%E + L%E), and for accuracy less than 50%, LC = (R%C - L%C) / (R%C + L%C). Positive values suggested a right ear, left hemisphere advantage. Use of the laterality coefficient allowed for analyses independent of accuracy level. The task was estimated to take approximately 10 minutes (Boles & Pasquarette, 1996). Literature specific to the auditory linguistic process lacks lateralization findings for older adults, but findings indicate a right ear advantage for younger adults (Boles & Pasquarette, 1996). Spearman-Brown corrected split-half reliability on a sample of younger adults has been reported as acceptable (r = .78) for this measure (Boles, 1998b).

Dichotic emotions. (Boles et al., 2008). Stimuli consisted of short sentences with neutral verbal content (e.g., "This is for you.") crossed orthogonally with happy, bored, distressed, or angry tones of voice. A prepared tape contained 24 dichotic pairs, with different emotions presented in each ear, and the participant was to circle the emotions heard on a prepared answer sheet with four possibilities for each dichotic pair, two correct and two distracters. After the 24 pairs the headphones were reversed and the tape replayed. A correct answer was one that matched the emotion presented. For example if distressed and happy emotions were presented and the response options were "distressed" and "angry", the choice of distressed was correct. Asymmetry was calculated using the LC as described above. Again, positive values suggested a right ear, left hemisphere advantage. The task was estimated to take approximately 10 minutes (Boles & Pasquarette, 1996). While the literature lacks findings specific to lateralization among older adults, among younger adults the literature indicates a left ear advantage (Boles & Pasquarette, 1996). Spearman-Brown corrected split-half reliability using a sample of younger adults has been reported as acceptable (r = .30) for this measure (Boles, 1998b).

Bargraphs. (Boles, 1991). Participants were presented with bar graphs representing the numbers one through eight. Bar graphs were presented as vertical rectangles against a horizontal reference line. Bargraphs were shown on bilateral displays with an arrowhead to indicate where to attend. Trials involved a 750ms fixation point, followed by a 100ms blank, and then a 100ms bar graph stimulus. Participants were to decide if the bar graph represents an even or odd number and report this on a keyboard, after which reaction time feedback was given. Twenty-four practice trials were followed by 144 experimental trials made up of three blocks of 48. This task produced a reaction time asymmetry for each subject calculated as the median right visual field reaction time subtracted from the median left visual field reaction time, using only correct response trials. Negative values suggested a left visual field, right hemisphere advantage. The task was estimated to take approximately 10 minutes. While there appears to be a lack of research on lateralization using the bargraphs task among older adults, research indicates a left visual field advantage for younger adults (Boles, 1991). Spearman-Brown corrected split-half reliability on a sample of younger adults has been reported as acceptable (r = .35-.39) for this measure (Boles, 2002; Boles, 1998b).

Landmark. (Milner, Brechmann, Roberts, & Forster, 1993; Pohl, 1973). The landmark task (adapted from Schmitz & Peigneux, 2011) presented the participants with 200 trials involving a horizontal line (200 x 1.5mm) divided vertically (10 x 0.2 mm). On 100 of the trials the vertical divider evenly divided the horizontal line and on 100 of the trials the vertical divider was 5 mm to the left or right of center. Lines were presented in the center of the computer screen for 1000 ms in random order, with a visual mask presented before and after each trial to disrupt visual retention. Two questions, "which end is shorter?", and "which end is longer", were used in alternating trials. Participants were falsely informed that none of the lines were evenly balanced. Participants were forced to make a choice even if they have to guess. Participants responded with a key press (left/right) using two buttons on a keyboard using their right hand. Participants had as much time as they desired to make a response. Upon responding, the next trial began. Asymmetry for perceptual bias was calculated as percentage of left longer/ right shorter responses on the evenly divided lines. Values greater than 50 indicated selection of ‘left longer/right shorter’ above chance, thus a leftward attentional/right hemispheric bias. Based on the report of Schmitz and Peigneaux (2011) the task was expected to last 15 minutes. The literature supports a leftward advantage in younger adults and a shift to a bilateral or rightward advantage in older adults (Schmitz & Peigneux, 2011). There appear to be no published reliability data for the landmark task. However, researchers have noted the instrument's stability when used with a sample of older adults in a control group (Harvey, Hood, North, & Robertson, 2003; M. Harvey, personal communication, September 4th, 2013). Additionally, a similar asymmetry task, visual lines, was reported to have acceptable (r = .63) Spearman-Brown corrected split-half reliability on a sample of younger adults (Boles, 1998).

Edinburgh handedness inventory. (Oldfield, 1971). Dragovic (2004) recommends a modified version of the Edinburgh Handedness Inventory containing seven items which index hand preference. Dragovic reported that seven of the original ten items provided a valid and internally consistent measure of handedness. Items concerning drawing, use of a broom, and opening a box-lid were all removed due to both collinearity between writing and drawing and large measurement error related to broom and box-lid. The seven remaining items included writing, throwing, scissors, toothbrush, knife, spoon, and matches. Participants rate their hand preference for each item within two columns (left and right) on a range including *strong* (++), *less strong* (+), and *indifferent* (+/+). A laterality quotient (LQ: range -100 to +100) was calculated as summing all values for each hand, subtracting the left from the right, dividing by the sum of both, and multiplying by 100 (Oldfield, 1971).

5-Item subtest of Center for Epidemiological Studies Depression scale. (5-item CES-D; Shrout & Yager, 1989). The five-item, 0 to 15 point, subtest of the original CES-D (Radloff, 1977) is supported as a reliable and valid screening measure of depression ($\alpha = .76$) which has a high correlation ($r = .91$) with the full 20-item measure (Bohannon, Maljanian, & Goethe, 2003). Bohannon et al. report a cut-point of 5.5 was highly sensitive (.923), and specific (.828), and had high validity given area under the ROC curve (.947) in a sample ranging in age from 18-78.

Demographics. Collection of participant demographics included age, sex, and race. Research on sex suggests it may account for at most 0.9% of the variance in asymmetry, with the importance of the variable varying by lateralization task (Boles, 2005). Similarly, race is not expected to account for significant variance (Borowy & Goebel, 1976).

Additional demographic collection included education (in years completed) and the primary caregivers' main occupation(s) during the participant's childhood (0-18). The occupation was matched as closely as possible to one of the 505 occupations listed in the Census 2002 occupational classification scheme. Prestige scores were assigned based on an updated (Frederick, 2010) version of the work of Nakao and Treas (1994) where prestige scores had a possible range from 0 (lowest) to 100 (highest). Averaged for each occupation across all raters (n = 1166), prestige scores ranged from 16.8 for "miscellaneous food preparation (e.g., dishwashers)" to 86.1 for physicians. In the case of multiple working primary caregivers, an averaged prestige score will be used, weighted for the number of years present as a caregiver with that job. Education and occupational prestige were used to control for socioeconomic status (SES). Research suggests SES may predict hemispheric specialization in children (Raizada, Richards, Meltzoff, and Kuhl, 2008), and generally suggests reduced lateralization in lower SES groups (Boles, 2011).

Weschler Adult Intelligence Scale - Fourth Edition - Information Subtest. (Weschler, 2008). For the WAIS-IV Information subtest the participant answered questions regarding a broad range of general knowledge topics designed to assess long-term memory for factual information. The Information subtest has been shown to perform reliably across age groups with reliability coefficients at or above .89 for each age group (age 16 to age 90 and 11 months). When compared directly reliability coefficients were similar for older adults age 65-90 (0.91) and younger adults age 16-64 (0.94). Test-retest reliability for the same age groups was also similar, 0.88 for younger adults and 0.93 for older adults.

Procedure

Potential participants were greeted at the recruitment location and given a brief explanation of the purpose of the study. Given continued interest, participants were asked to complete the demographic questionnaire. If age and handedness exclusion criteria were not met, participants were asked to read an informed consent document after which the researcher assessed the participant's capacity to give informed consent based on their comprehension of the University of Alabama IRB consent document (see Appendix J). The researcher then assessed for the remaining exclusion criteria starting with the SLUMS (Tariq, Tumosa, Chibnall, Perry, & Morley, 2006) to confirm cognitive eligibility. To be eligible participants had to score at least 21 out of 30, or in the case of less than high school education, 20 out of 30, given standardization findings (Tariq et al., 2006). Participants were also screened for hearing impairment using the portable audiometer. To be eligible participants had to demonstrate hearing loss ≤40 dB for both PTA and at 4,000 Hz, in both ears, indicating either normal hearing or mild hearing loss.

Participants were then screened for visual impairment using the near visual acuity chart. Eligible participants had to demonstrate visual acuity of 20/40 or better. Next, participants were screened for depressive symptoms using the 5-item CES-D. Eligible participants had to score 4 or less.

Participants who meet exclusion criteria for cognitive impairment, depressed mood, visual impairment, or hearing impairment were advised that their responses indicated a possible significant issue (i.e. hearing loss, depressed mood, etc). However, they were informed that the screening was not clinically diagnostic and did not suggest a diagnosis. Participants were then given basic recommendations for cognitive health (see Appendix F), mood (see Appendix G), as well as visual and auditory health (see Appendix E), as applicable, and given referral sources for follow-up assessment and/or treatment. Participants were then thanked for their help and excused from the study.

Participants meeting all eligibility requirements were administered the four laterality measures which were expected to take approximately 45 minutes. Administration order of laterality measures was arranged using Latin squares to control for order effects. Last, participants were asked to complete a 7-item version of the Edinburgh Handedness Inventory (Oldfield, 1971) to confirm their right-handedness.

Data Analysis

Data analysis began with four analyses of covariance (ANCOVAs) to compare younger and older adults on the laterality coefficients, reaction time asymmetry, and perceptual bias asymmetry scores of the four laterality measures while controlling for significant covariates.

Pearson correlations were used to assess support for the compensation and dedifferentiation hypotheses. First, correlations were used to assess the association between the four asymmetry measures, separately for each age group. The dedifferentiation hypothesis predicted a statistically significant correlation among measures of asymmetry for older adults and a non-significant association among younger adults. Next, the correlation between laterality and performance was assessed for dichotic syllables, dichotic emotions, and bargraphs tasks. Analyses were run separately for older adults and younger adults. The compensation hypothesis predicted a correlation in younger adults but not in older adults.

Spearman-Brown corrected split-half reliability were calculated for each laterality measure to determine internal consistency using the total sample. Split-half reliability was reassessed separately for each age group to assess the comparative suitability of the laterality measures among older adults.

RESULTS

Participants

Participants were excluded from final analyses based on the inclusion criteria cutoff points; an initial sample of 102 participants (71 younger adults and 31 older adults) was cut to a final sample of 88 participants (60 younger adults and 28 older adults). Participants were excluded disproportionately from the young adult sample, primarily related to positive depression screening scores (10 younger adults, 2 older adults). For analyses based on the bargraphs asymmetry task, participants were required to score at least above a chance level of 60% accuracy to be included in analyses. This resulted in a lower sample size for analyses using the bargraphs task, 62 total participants, 47 younger adults and 15 older adults. For the overall sample of 88, participants for both the younger adult and older adult groups were a majority female, White, and of college education or higher. Participant age groups did not differ on gender, cognitive status (SLUMS), mood status (CESD), or handedness. Older adults were significantly more likely to be of White race (93% vs. 72%), higher education (18 years vs. 13 years), from parents with lower occupational prestige (54 vs. 66), have greater overall hearing deficits (21 dB vs. 8 dB), greater overall visual deficits (20/33/ vs. 20/23), and to have higher scores on the WAIS-IV information subtest (13 vs. 11).

Further analyses were run based on the 88 participants split into three groups including: 60 younger adults, 13 older adults with normal cognition (older adults - high), and 15 older adults with mild cognitive impairment (older adults - MCI). The two older adult groups did not differ on age, gender, race, education, occupational prestige, overall hearing deficit, overall visual deficit, handedness, or WAIS-IV information subtest scaled score. Older adults - high had significantly higher cognitive status scores (28 vs. 25) and significantly higher depression screener scores (3 vs. 2), albeit all depression scores were still within the normal range.

Reliability

The reliability of the four measures of asymmetry with the current study sample was addressed by computing Spearman-Brown corrected split-half reliability coefficients, using an odd-even split. After correcting for the split sample size using the Spearman-Brown correction, all four measures were at or above the recommended minimum of .30 (Boles, 1998a; Boles, 1998b) including: dichotic syllables ($r = .83$); dichotic emotions ($r = .55$); bargraphs ($r = .30$); and the Landmark measure ($r = .96$). When the sample was split by age group (younger adults and older adults) results were similar for all measures across age groups, with all corrected reliability coefficients above .30. When the older adult sample was split by cognitive status (older adults - high and older adults - MCI) results for reliability analyses were also above the minimum coefficient of .30 for all measures across both groups, with one exception in the case of older adults with mild cognitive impairment on the bargraphs task. A summary of the results for reliability analyses is presented in Table 1.

Table 1. Spearman-Brown corrected reliability coefficients

	Full Sample	YA	OA	OA-High	OA-MCI
DS	.83	.81	.86	.91	.81
DE	.55	.55	.55	.37	.59
BG	.30	.32	.38	.40	-.42
LM	.96	.96	.96	.97	.95

Note. DS = dichotic syllables laterality coefficient, DE = dichotic emotions laterality coefficient, BG = bargraphs reaction time asymmetry, LM = landmark leftward perceptual bias.

Note. YA = younger adults, OA = older adults, OA-High = older adults - high, OA-MCI = older adults - MCI.

Older adults with mild cognitive impairment on the bargraphs task produced a negative uncorrected split-half reliability (r = -.42). As a result the reliability coefficient was left uncorrected in this one case. In general, reliability is based on an estimate of the relationship between the measurement and true score (Spearman, 1904; Spearman 1910). In this case, the negative coefficient indicates that the measure of lateralization among older adults with mild cognitive impairment had less than zero relation with the actual asymmetry among this population, an atheoretical result. As a result, the reliability for bargraphs with this group was left uncorrected as it was thought to be essentially meaningless, and its corrected form (r = -1.46) similarly meaningless. Nichols (1999) notes that even when assumptions for reliability estimates are met, if there is excess measurement error, sample values may be negative, even when true population covariances among items are positive. Nichols (1999) suggests that this is particularly likely when reliability is based on small sample size, as it was in the case of bargraphs and the eight older adults with mild cognitive impairment. Given this sample size, it is likely that sampling error produced a negative average covariance; despite the fact that the actual asymmetry for this population is likely acceptable. This seems particularly plausible given the acceptable reliability of both older adults with normal cognitive status ($r = .40$) and older adults collectively ($r = .38$). Further, the standard error of the mean (40.6) was larger than the SD (32.1). This also suggests the spread of scores was likely due to measurement error rather than to true lack of reliability in measuring lateralization (Hays, 1981). Therefore, subsequent analyses of this subgroup should be interpreted with caution; however, not completely disregarded as this is likely an artifact of small sample size rather than lack of true reliability.

Assessment of Basic Asymmetry

The full sample was assessed for asymmetry in performance on the four measures of hemispheric asymmetry (dichotic syllables, dichotic emotions, bargraphs, and the Landmark task) as a manipulation check for basic agreement with the literature on lateralization of function. For dichotic syllables, one-sample t-tests against chance value (0) revealed that the sample attended to syllables in their right ear above chance ($M = .14$, $SD = .20$, N = 77; $t(76) = 6.32$, $p < .001$, *Cohen's d* = .70). These results are consistent with literature supporting a right ear advantage among younger adults (Boles & Pasquarette, 1996). For dichotic emotions, one-sample t-tests against chance value (0) revealed that the sample correctly attended to emotions in their left ear above chance ($M = -.12$, $SD = .19$, N = 87; $t(86) = -5.83$, $p < .001$, *Cohen's d* = -.63). These results are consistent with literature supporting a left ear advantage among younger adults (Boles & Pasquarette, 1996). For bargraphs, one-sample t-tests against chance value (0) revealed that the sample made accurate quantitative assessments faster in their left visual field (compared to their right) above chance ($M = -73.6$, $SD = 87.7$, N = 62; $t(61) = -6.61$, $p < .001$, *Cohen's d* = -.84). These results are consistent with literature supporting a left visual field advantage among younger adults (Boles, 1991). For the Landmark task, one-sample t-tests against chance value (.50) revealed that the sample showed a rightward attentive bias, assessing evenly balanced lines as "right longer/left shorter" above chance (M = .55, SD = .23, N = 85; t(84) = -2.06, p = .042, *Cohen's d* = 2.39). These results are inconsistent with literature supporting a leftward attentive bias among younger adults, but could still be consistent with literature supporting a shift towards a bilateral or rightward attentive bias among older adults (Schmitz et al., 2011). Overall, results suggest basic lateralization consistent with the literature among the measures for the full sample; however the age (younger adults vs older adults) and cognitive status (older adults - high vs older adults - MCI) subgroups were expected to vary, necessitating the below planned group comparisons.

ANCOVAS

Younger adults vs. older adults. Primary analyses of younger and older adults were conducted to investigate the HAROLD model (i.e., older adults should show significantly reduced asymmetry in comparison to younger adults). Potential variables were accepted as covariates only when (a) they were significantly different between younger adults and older adults and (b) they made conceptual sense. For the primary analyses comparing younger and older adults, statistically significant differences were found for race, education, occupational prestige, hearing, vision, and information scaled scores. Other potential covariates including gender, scores on the SLUMS, scores on the CESD, and scores on the Edinburgh handedness inventory were noted as showing no statistically significant difference between younger and older adults. A summary of descriptive statistics and tests for significant differences for these two groups is presented in Table 2.

Table 2. Descriptive Statistics of the Study Variables and Test for Significant Difference Between Younger Adults and Older Adults

	YA N = 60	OA N = 28	t [a]	sig
Age	19.28	69.36	-36.47	<.000
Gender (% Male)	40	35.7	-.381	.705
Race (% White)	71.7	92.9	2.83	.006
Education	12.58	17.46	-8.80	.000
Occupational Prestige	65.86	54.24	2.61	.013
SLUMS	26.35	26.04	.603	.548
Hearing PTA R	7.39	21.90	-7.88	.000
Hearing PTA L	8.84	20.77	-6.70	.000
Hearing PTA Overall	8.11	21.34	-7.53	.000
Visual Acuity R	30.10	56.21	-5.22	.000
Visual Acuity L	29.05	50.57	-4.27	.000
Visual Acuity Overall	23.20	32.93	-5.08	.000
CESD	2.27	2.39	-.37	.716
Handedness	80.50	85.16	-.752	.454
Information Scaled Score	10.73	12.75	-3.17	.002

Note: YA = Younger Adults, OA = Older Adults.

Note. [a] chi-square for % variables

All statistically significant covariates were retained with the exception of hearing in the case of visual tasks (bargraphs and the Landmark task) and vision in the case of auditory tasks (dichotic emotions and dichotic syllables). Attempts to statistically control for visual deficits and hearing deficits were pursued to maximize meaningful differences in cognitive processing rather than variance associated with physical impairment. Controlling for race, education, and occupational prestige was supported by research supporting the interplay of socioeconomic status and lateralization of function. Specifically, Boles (2011) reported socioeconomic status was associated with reduced functional specialization, based on a review of research on younger adults. This finding supports the role of socioeconomic status in creating a potential developmental delay or overall reduction in functional specialization, supporting the need for controlling socioeconomic status. Lacking data on income, occupational prestige of participant's parents during childhood (0 - 18 years) was used, along with years of education. Race was also controlled for due to the association of race with socioeconomic status. Information scaled scores were included as a covariate to statistically control a proxy for crystallized intelligence.

Additionally, for analysis of the bargraphs task, accuracy on this measure was added as a covariate to control for any relationship between accuracy and asymmetry. Accuracy was not used as a covariate for either dichotic listening task as both used a laterality coefficient which itself statistically controls for the relationship between accuracy and asymmetry. Accuracy was not used as a covariate for the Landmark task as it was used to create the dependent variable; analysis of patterns of incorrect answers of "left is longer/shorter" or "right is longer/shorter" to evenly balanced lines.

One-way between-groups analysis of covariance was conducted to compare groups on the lateralization of auditory linguistic processing. The independent variable was age group (younger and older adults) and the dependent variable was the laterality coefficient score on the dichotic syllables task. Participants' race, education, total weighted prestige scores, overall hearing deficit, and information scaled scores were used as covariates in this analysis. Levene's test of homogeneity of variance did not support a significant difference between the variance of the two groups, $F(1, 75) = .32$, $p = .573$. After adjusting for the covariates, there was no significant difference between the groups on the dichotic syllables laterality coefficient, $F(1, 70) = 1.08$, $p = .301$. Based on estimated marginal means, results revealed no significant difference between the right ear/left hemisphere advantage of younger ($M = .18$, $SEM = .04$, N = 49) and older adults ($M = .08$, $SEM = .07$, N = 28) concerning auditory linguistic processing. A summary of relevant group means laterality coefficients is presented in Table 3.

Table 3. Younger Adults vs Older Adults on Dichotic Syllables, Group Means Before and After Adjusting for Covariates

	Younger Adults	Older Adults
Unadjusted	.16 (*SD* = .19)	.12 (*SD* = .21)
Adjusted	.18	.08

Note: Covariates included race, education, occupational prestige, hearing deficit, and information scaled scores.

A second one-way between-groups analysis of covariance was conducted to compare groups on the lateralization of auditory emotional processing. The independent variable was the group (younger and older adults) and the dependent variable was the laterality coefficient score on the dichotic emotions task. Participants' race, education, total weighted prestige scores, overall hearing deficit, and information scaled scores were used as covariates in this analysis. Levene's test failed to support a significant difference between the variance of the two groups, $F(1, 85) = 3.38$, $p = .069$. After adjusting for the covariates, there was no significant difference between the groups on the dichotic emotions laterality coefficient, $F(1, 80) = .28$, $p = .601$. Based on estimated marginal means, results revealed no significant difference between the left ear/right hemisphere of younger adults ($M = -.10$, $SEM = .04$, N = 60) and older adults ($M = -.15$, $SEM = .07$, N = 27) concerning auditory emotional processing. A summary of relevant group mean laterality coefficients is presented in Table 4.

Table 4. Younger Adults vs Older Adults on Dichotic Emotions, Group Means Before and After Adjusting for Covariates

Adjustment for Covariates	Younger Adults	Older Adults
Unadjusted	-.11 ($SD = .17$)	-.15 ($SD = .22$)
Adjusted	-.10	-.15

Note: Covariates included race, education, occupational prestige, hearing deficit, and information scaled scores.

A third one-way between-groups analysis of covariance was conducted to compare groups on the lateralization of spatial quantitative processing. The independent variable was the group (younger and older adults) and the dependent variable was the reaction time asymmetry score on the bargraphs task. Participants' race, education, total weighted prestige scores, overall visual deficit, accuracy scores on the bargraphs task, and information scaled scores were used as covariates in this analysis. Levene's test did not indicate a violation of equality of variances,

$F(1, 60) = .12$, $p = .728$. After adjusting for the covariates, there was no significant difference between the groups on the bargraphs reaction asymmetry scores; however, results trended towards significance, $F(1, 54) = 3.78$, $p = .057$. Based on estimated marginal means, results revealed older adults (*M* = -164.3 ms, *SEM* = 47.9, N = 15) displayed a trend towards a significantly greater left visual field/right hemisphere advantage than younger adults (*M* = -44.7 ms, *SEM* = 18.5, N = 47), concerning spatial quantitative processing. A summary of relevant group means is presented in Table 5.

Table 5. Younger Adults vs Older Adults on Bargraphs, Group Means Before and After Adjusting for Covariates

Adjustment for Covariates	Younger Adults	Older Adults
Unadjusted	-65.2 (*SD* = 83.5)	-100.0 (*SD* = 98.2)
Adjusted	-44.7	-164.3

Note: Covariates included race, education, occupational prestige, visual deficit, bargraph task accuracy, and information scaled scores.

A fourth one-way between-groups analysis of covariance was conducted to compare groups on a second measure of the lateralization of spatial attentive processing. The independent variable was the group (younger and older adults) and the dependent variable was leftward perceptual bias score on the Landmark task. Participants' race, education, total weighted prestige scores, overall visual deficit, and information scaled scores were used as covariates in this analysis. Levene's test supported a potential violation of the assumption of equality of variances, $F(1, 83) = 9.45$, $p = .003$. This suggested the variance in the Landmark task was not homogeneous among the age groups. Aiming to utilize data transformation, one method for addressing issues with violations of homoscedasticity, histograms of the dependent variable for each age group were examined, presented in Figures 1 and 2.

Figure 1: Histogram of the Landmark task for younger adults

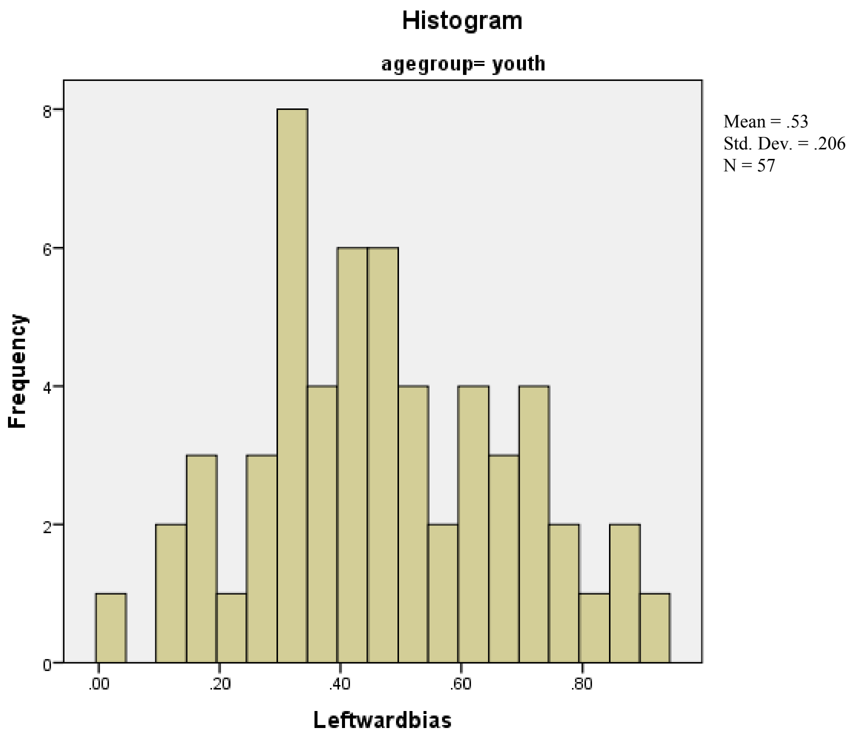
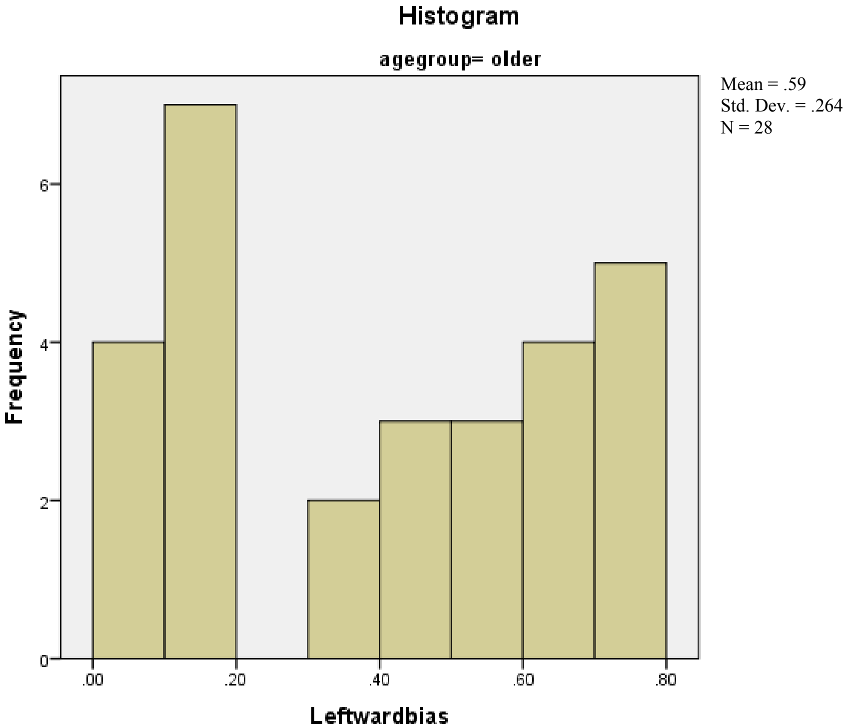


Figure 2: Histogram of the Landmark task for older adults



Results revealed a bimodal distribution among older adults resulting in greater variance among older adults (SD = .27) compared to younger adults (SD = .21). A series of power transformations identified a square transformation (X^2) as appropriate, achieving homogeneity of variance between age groups. The variance in the square transformation (X^2) of the Landmark task data was homogenous between age groups. Levene's test of was run again and the result did not suggest a violation, $F(1, 83) = 1.57$, $p = .214$. After adjusting for the covariates, results revealed no significant difference between the groups on the transformed landmark leftward perceptual bias scores, $F(1, 78) = .66$, $p = .418$. Based on estimated marginal means, transformed back to the original scale using the square root function, results revealed no significant difference between the leftward attentional/right hemisphere advantage of younger adults ($M = .47$, $SEM = .04$, N = 57) and the rightward attentional/left hemisphere advantage of older adults ($M = .55$, $SEM = .07$, N = 28), concerning spatial attentive processing (it will be recalled that asymmetry was assessed as the percentage of left longer/right shorter responses on the evenly divided lines). For comparative purposes the untransformed dependent variable was also run and found to produce similar results, $F(1, 78) = 1.22$, $p = .274$. A summary of relevant group perceptual bias asymmetry means is presented in Table 6.

Table 6. Younger Adults vs Older Adults on the Landmark Task, Group Means Before and After Adjusting for Covariates

Adjustment for Covariates	Younger Adults	Older Adults
Unadjusted	.53 (*SD* = .21)	.59 (*SD* = .26)
Adjusted	.52	.62
Transformed & Adjusted	.47	.55

Note: Covariates included race, education, occupational prestige, visual deficit, and information scaled scores.

Older adults - high vs. older adults - MCI. Secondary analyses comparing older adults by cognitive status were run to maximize power, as compared to the final three group analyses, while examining possible support for dedifferentiation (i.e., if changes in asymmetry are the result of broad age-related dedifferentiation, then there should be no significant difference between older adult groups by cognitive status). Similar to the primary analyses described above, potential variables were accepted as covariates only when (a) they were significantly different between younger adults and older adults, and (b) they made conceptual sense. Statistically significant differences were found for scores on the SLUMS and scores on the CESD. Other potential covariates including gender, race, education, occupational prestige, vision, hearing, scores on the Edinburgh handedness inventory, and Information scaled scores were all noted as showing no statistically significant difference between older adults - high and older adults - MCI. A summary of descriptive statistics and tests for significant differences for older adults - high compared to older adults - MCI is presented in Table 7.

Table 7. Descriptive Statistics of the Study Variables and Test for Significant Difference Between Older Adults - High and Older Adults - MCI

	OA-High N = 13	OA-MCI N = 15	t [a]	Sig
Age	67.15	71.27	-1.53	.137
Gender (% Male)	38.5	33.3	-.273	.787
Race (% White)	92.3	93.3	.10	.920
Education	17.54	17.40	.12	.902
Occupational Prestige	51.54	56.59	-.606	.550
SLUMS	27.77	24.53	8.22	.000
Hearing PTA R	18.33	25.00	-1.98	.059
Hearing PTA L	18.33	22.89	-1.37	.182
Hearing PTA Overall	18.33	23.94	-1.72	.098
Visual Acuity R	52.46	59.47	-.735	.469
Visual Acuity L	46.69	53.93	-.751	.459
Visual Acuity Overall	31.62	34.07	-.697	.492
CESD	3.15	1.73	2.42	.023
Handedness	91.75	79.45	1.00	.325
Information Scaled Score	13.31	12.27	1.14	.266

Note: OA-High = Older adults with normal cognitive function, OA-MCI = Older adults with mild cognitive impairment.

Note. [a] chi-square for % variables

Based on conceptual reasoning, the CESD was the only statistically significant covariate utilized. Scores on the SLUMS were not used as a covariate for these analyses as they were used to create the grouping variable. Controlling for scores on the CESD was justified given research supporting the interplay of depression and brain activity. Miller, Fujioka, Chapman, and Chapman (1995) found an association of major depressive disorders and right-hemisphere functional impairment, which supported statistical control. Additionally, for analysis of the bargraphs task, accuracy on this measure was added as a covariate to control for the potential relationship between accuracy and asymmetry.

One-way between-groups analysis of covariance was conducted to compare groups on the lateralization of auditory linguistic processing. The independent variable was the group (older adults - high and older adults - MCI) and the dependent variable was the laterality coefficient score on the dichotic syllables task. Participants' scores on the CESD were used as covariates in this analysis. Levene's test did not support a significant difference between the variance of the two groups, $F(1, 26) = .64$, $p = .432$. After adjusting for the covariates, there was no significant difference between the groups on the dichotic syllables laterality coefficient, $F(1, 25) = 1.11$, $p = .303$. Based on estimated marginal means, results revealed no significant difference between the right ear/left hemisphere advantage of older adults - high ($M = .07$, $SEM = .06$, N = 13) and older adults - MCI ($M = .16$, $SEM = .06$, N = 15) concerning auditory linguistic processing. A summary of relevant group means is presented in Table 8.

Table 8. Older Adults - High vs Older Adults - MCI on Dichotic Syllables, Group Means Before and After Adjusting for Covariates

Adjustment for Covariates	Older Adults - High	Older Adults - MCI
Unadjusted	.11 (*SD* = .24)	.12 (*SD* = .19)
Adjusted	.07	.16

Note: Covariates included scores on the CESD.

A second one-way between-groups analysis of covariance was conducted to compare groups on the lateralization of auditory emotional processing. The independent variable was the group (older adults - high and older adults - MCI) and the dependent variable was the laterality coefficient score on the dichotic emotions task. Participants' scores on the CESD were used as covariates in this analysis. Levene's test was nonsignificant, $F(1, 25) = .327$, $p = .573$. After adjusting for the covariates, there was a significant difference between the groups on the dichotic emotions laterality coefficient, $F(1, 24) = 4.73$, $p = .04$. Based on estimated marginal means, results revealed older adults - MCI ($M = -.23$, $SEM = .06$, N = 15) displayed a statistically greater left ear/right hemisphere advantage than older adults - high ($M = -.04$, $SEM = .06$, N = 12), concerning auditory emotional processing. A summary of relevant group means is presented in Table 9.

Table 9. Older Adults - High vs Older Adults - MCI on Dichotic Emotions, Group Means Before and After Adjusting for Covariates

Adjustment for Covariates	Older Adults - High	Older Adults - MCI
Unadjusted	-.07 (*SD* = .20)	-.21 (*SD* = .22)
Adjusted	-.04	-.23

Note: Covariates included scores on the CESD.

A third one-way between-groups analysis of covariance was conducted to compare groups on the lateralization of spatial quantitative processing. The independent variable was the group (older adults - high and older adults - MCI) and the dependent variable was the reaction time asymmetry score on the bargraphs task. Participants' scores on the CESD and accuracy scores on the bargraphs task were used as covariates in this analysis. Levene's test did not indicate a significant difference between the variance of the two groups, $F(1, 13) = 1.17$, $p = .298$. After adjusting for the covariates, there was no significant difference between the groups on the bargraphs reaction asymmetry scores, $F(1, 11) = 2.12$, $p = .17$. Based on estimated marginal means, results revealed no significant difference between the left visual field/right hemisphere advantage of older adults - high (M = -59.6 ms, SEM = 37.6, N = 8) and older adults - MCI (M = -146.2 ms, SEM = 40.6, N = 7), concerning spatial quantitative processing. A summary of relevant group means is presented in Table 10.

Table 10. Older Adults - High vs Older Adults - MCI on Bargraphs, Group Means Before and After Adjusting for Covariates

Adjustment for Covariates	Older Adults - High	Older Adults - MCI
Unadjusted	-75.4 (*SD* = 130.1)	-128.0 (*SD* = 32.1)
Adjusted	-59.6	-146.2

Note: Covariates included scores on the CESD and bargraphs task accuracy.

A fourth one-way between-groups analysis of covariance was conducted to compare groups on the lateralization of spatial attentive processing. The independent variable was the group (older adults - high and older adults - MCI) and the dependent variable was the leftward perceptual bias score on the Landmark task. Participants' scores on the CESD were used as covariates in this analysis. Levene's test was not indicative of a violation of the assumption of equality of variances, $F(1, 26) = .07$, $p = .796$. After adjusting for the covariates, there was no significant difference between the groups on the Landmark leftward perceptual bias, $F(1, 25) = .16$, $p = .69$. Based on estimated marginal means, results revealed no significant difference between the rightward attentional/left hemisphere advantage of older adults - high ($M = .57$, $SEM = .08$, N = 13) and older adults - MCI ($M = .61$, $SEM = .07$, N = 15), concerning spatial attentive processing. A summary of relevant group means is presented in Table 11.

Table 11. Older Adults - High vs Older Adults - MCI on the Landmark Task, Group Means Before and After Adjusting for Covariates

Adjustment for Covariates	Older Adults - High	Older Adults - MCI
Unadjusted	.58 (*SD* = .26)	.60 (*SD* = .27)
Adjusted	.57	.61

Note: Covariates included scores on the CESD.

Younger adults vs. older adults - high vs. older adults - MCI. Tertiary analyses comparing young adults, older adults with normal cognitive status, and older adults displaying mild cognitive impairment were run to allow full examination of the compensation hypothesis (i.e., if reduced asymmetry is the product of successful compensation, younger adults should look like mildly impaired older adults, both displaying greater asymmetry in comparison to normal cognitive status older adults). Covariates were handled in a similar fashion to prior analyses, resulting in the use of education, occupational prestige, hearing and vision as appropriate, scores on the CESD, Information scaled scores, and bargraphs task accuracy as appropriate. The three group analyses were performed as planned. However, as results were not statistically significant for any of the four measures, they are not reproduced below. In summary, results indicated that there were no statistically significant differences among the groups concerning auditory linguistic processing, auditory emotional processing, spatial quantitative, and spatial attentive processing.

Correlations Among Asymmetry Measures

Correlational analyses investigating the associations between measures of asymmetry were run to explore support for the dedifferentiation hypothesis (i.e., dedifferentiation suggests increasingly bilateral hemispheric activation, which would be supported by stronger correlations among measures of asymmetry for older adults in comparison to younger adults). The relationships among the four measures of asymmetry (dichotic emotions laterality coefficient, dichotic syllables laterality coefficient, bargraphs reaction time asymmetry, and landmark leftward perceptual bias) were investigated separately for each group (younger adults, older adults - high, older adults - MCI) using Pearson product-moment correlation coefficients. Correlations were also run for a combined group of all older adults. Overall, there were two significant correlations, one between the dichotic emotions and landmark tasks for the combined group of older adults, and a second between the dichotic emotions and dichotic syllables tasks for younger adults. A summary of results for analyses of the correlations among asymmetry measures is presented in Tables 12a and 12b.

Table 12a. Correlations Among Measures of Asymmetry, Older Adults - High and Older Adults - MCI

	DS	DE	BG	LM
DS	---	-.13	-.02	.10
DE	.43	---	-.41	-.49
BG	-.46	.12	---	.39
LM	.33	-.40	-.37	---

Table 12b. Correlations Among Measures of Asymmetry, Younger Adults and Older Adults

	DS	DE	BG	LM
DS	---	.29*	-.06	.15
DE	.13	---	.14	.17
BG	-.38	.05	---	.04
LM	.22	-.46*	.15	---

Note. DS = dichotic syllables laterality coefficient, DE = dichotic emotions laterality coefficient, BG = bargraphs reaction time asymmetry, LM = landmark leftward perceptual bias.

[a] Older adults - MCI are above the diagonal on the first table ($\overline{\chi}$ = -.09; | $\overline{\chi}$ | = .25).

[b] Older adults - high are below the diagonal on the first table ($\overline{\chi}$ = -.05; | $\overline{\chi}$ | = .35).

[c] Younger adults are above the diagonal on the second table ($\overline{\chi}$ = .12; | $\overline{\chi}$ | = .14).

[d] Older adults are below the diagonal on the second table ($\overline{\chi}$ = -.05; | $\overline{\chi}$ | = .23).

Note. * $p < .05$

Further analyses compared the correlations among the asymmetry measures (dichotic emotions laterality coefficient, dichotic syllables laterality coefficient, bargraphs reaction time asymmetry, and landmark leftward perceptual bias) across groups (younger adults, older adults, older adults - high, and older adults – MCI) using Fisher's r-to-z transformation. Analyses produced z-scores that were used to assess the significance of the difference between two correlation coefficients found in two independent samples and test the null hypothesis that the difference across groups was 0. Overall, there were two significant differences. The first was on the correlation of dichotic emotions with the Landmark task, between younger adults ($r = .17$) and older adults ($r = -.46$), $Z = -2.73$. The second was on the correlation of dichotic emotions with the Landmark task, between younger adults ($r = .17$) and older adults - MCI ($r = -.49$), $Z = -2.23$. A summary of results for tests of statistically significant differences across age groups on correlations among asymmetry measures is presented in Table 13.

Table 13. Correlations Among Asymmetry Measures Across Age Groups

	Youth vs OA	Youth vs OA – MCI	Youth vs OA - High	OA - MCI vs OA - High
DS r DE	0.66	1.29	-0.47	1.34
DS r BG	1.01	-0.09	-0.9	-0.71
DS r LM	-0.29	0.15	-0.55	0.57
DE r BG	0.26	1.09	0.03	0.78
DE r LM	2.73**	2.23*	1.67	0.25
BG r LM	-0.57	0.71	-0.9	-1.19

Note: Values indicate Z-score. Z-scores were computed using Fisher's Z-transformation to transform correlations among asymmetry measures and then test the null hypothesis that the difference across groups was 0.

Z-scores with a positive value indicate the first group had a greater correlation than the second.

Z-scores with a negative value indicate the first group had a smaller correlation than the second.

DS = dichotic syllables laterality coefficient, DE = dichotic emotions laterality coefficient, BG = bargraphs reaction time asymmetry, LM = landmark leftward perceptual bias.

Values greater than |1.96| are considered significant.

Note. * $p < .05$, ** $p < .01$

Correlation of Asymmetry with Performance

Correlational analyses investigating the associations between asymmetry and performance were run to explore support for the compensation hypothesis (i.e., compensation suggests reductions in asymmetry are compensatory adjustments in brain activation, meant to adjust for losses in efficiency in previously asymmetrical functional specialization; as a result, positive associations of asymmetry with performance among younger adults, and reduced or negative associations of asymmetry with performance among older adults would support compensation). The association of hemispheric asymmetry with performance was analyzed using Pearson product-moment correlation coefficients, run separately for the dichotic syllables, dichotic emotions, and bargraphs tasks. Analyses were run with a simple age-group split (younger adults, older adults) and rerun with three groups so as to separate older adults with any cognitive impairment from those with none (younger adults, older adults - high, older adults - MCI). Overall, there was a single significant correlation for younger adults on the dichotic emotions task. A summary of correlations of performance with asymmetry is presented in Table 14.

Table 14. Correlations of Performance and Asymmetry

Group	Measures	Correlation w/ perf	N	Correl w/ perf Boles 2008 (N)
Young adults	Dichotic syllables	-.03	49	.42*** (118)
Older adults	Dichotic syllables	-.29	28	
Older adults high	Dichotic syllables	-.42	13	
Older adults MCI	Dichotic syllables	-.24	15	
Younger adults	Dichotic emotions	-.35**	60	.13 (162)
Older adults	Dichotic emotions	-.17	27	
Older adults-high	Dichotic emotions	-.42	12	
Older adults-MCI	Dichotic emotions	-.05	15	
Younger adults	Bargraphs	-.22	47	-.37*** (527)
Older adults	Bargraphs	.03	15	
Older adults-high	Bargraphs	-.16	8	
Older adults-MCI	Bargraphs	.64	7	

Note. * $p < .05$, ** $p < .01$, *** $p < .001$

Exploratory Analyses

Covariate selection methodology. The approach taken in the current study for covariate selection did not focus on maximizing power. The covariate selection method may have reduced power by selecting covariates which had low correlation with the dependent variables, high correlation with other covariates, and/or high correlation with the independent variable. Accordingly, the ANCOVA was rerun with the focus on maximizing statistical power.

First, race, education, occupational prestige, hearing deficit, and visual deficit were all found to be significantly associated with at least one other covariate suggesting reduced power in the above ANCOVAs. Of the covariates, sex and scores on the CESD were the only variables significantly associated with a dependent variable, sex in the case of dichotic emotions, and scores on the CESD in the case of dichotic syllables.

Second, age group (younger and older adults) comparisons were rerun using only the covariates associated with dependent variables. A one-way between-groups ANCOVA was run for dichotic syllables, with scores on the CESD as a covariate, and results were nonsignificant, $F(1, 74) = .91$, $p = .344$. Similarly, ANCOVA for dichotic emotions, with sex as a covariate, produced nonsignificant results, $F(1, 84) = .81$, $p = .370$. No covariates were used in the age group analyses for bargraphs or the Landmark task, given that none were significant for these dependent measures. A one-way between-groups analysis of variance was run for bargraphs and results were nonsignificant, $F(1, 60) = 1.81$, $p = .184$. Similarly, ANOVA for the Landmark task was run and results were nonsignificant, $F(1, 83) = 1.35$, $p = .249$.

Cognitive status comparisons among older adults (OA-High and OA-MCI) were also rerun using the same covariates. A one-way between-groups ANCOVA was run for dichotic syllables, with scores on the CESD as a covariate, and results were nonsignificant, $F(1, 25) = 1.11$, $p = .303$. Similarly, ANCOVA for dichotic emotions, with sex as a covariate, produced nonsignificant results, $F(1, 24) = 2.31$, $p = .142$. No covariates were used in the cognitive status analyses for bargraphs or the Landmark task. A one-way between-groups ANOVA was run for bargraphs and results were nonsignificant, $F(1, 13) = 1.08$, $p = .319$. Similarly, ANOVA for the Landmark task was run and results were nonsignificant, $F(1, 26) = .02$, $p = .890$.

Correlation of education with laterality. This study's older adult sample averaged 18 years of education (*SD* = 2.9 years). This demographic factor was concerning given a consistent finding in the literature that high educational attainment is associated with decreased risk of dementia (Fratiglioni & Wang, 2007). The cognitive reserve hypothesis in dementia suggests, in part, that certain preexisting factors such as intelligence and life experiences such as educational attainment, may supply a neural reserve through redundancies within the neuronal system (Scarmeas & Stern, 2003). The concern for this study was that investigating the generalization of the HAROLD model might be impaired by a highly educated older adult sample who may not have experienced shifts in hemispheric activation, due to their ability to rely on preexisting redundancies to buffer against age-related losses in neural efficiency. Support for this possibility was investigated by examining the correlation of education and laterality among the older adult sample. The association of hemispheric asymmetry with education was investigated using Pearson product-moment correlation coefficients, run separately for the four laterality tasks. Results indicated that among older adults, education was not significantly associated with dichotic syllables ($p = .324$), dichotic emotions ($p = .873$), bargraphs ($p = .278$), or the Landmark task ($p = .746$).

Correlation of intelligence with laterality. Based on a relative dearth in the literature concerning the association of lateralization with intelligence, exploratory analyses were conducted. The association of hemispheric asymmetry with crystallized intelligence was investigated using Pearson product-moment correlation coefficients, run separately for the dichotic syllables, dichotic emotions, bargraphs, and Landmark tasks. Crystallized intelligence was approximated using the WAIS-IV Information subtest scaled scores. Results indicated no significant correlations among the measures of asymmetry and crystallized intelligence. Given the intent of comparing age groups, results were rerun using the WAIS-IV Information subtest raw scores. Results again indicated no significant correlations.

Post-Hoc MANOVA. After running the planned ANCOVAs, results indicated a consistent pattern suggestive of an age-related shift towards right hemisphere activation across tasks, when comparing younger adults to older adults. Results included a similar pattern when older adults were split, in which generally both older adults - high and older adults - MCI showed movement towards the right hemisphere across the four measures of laterality when compared to younger adults, with one exception in the case of dichotic emotions. These observations were pursued for statistical confirmation using MANOVA, with the hypothesis of an age-related shift across all four measures of asymmetry. However, results were non-significant. Overall, younger adults were not significantly different from older adults, older adults - high, or older adults - MCI on their mean asymmetry across the four measures.

DISCUSSION

The HAROLD Model

The first study hypothesis predicted age-related reductions in hemispheric asymmetry on four measures of lateralization. This would have confirmed prior support for the HAROLD model in the case of spatial attentive processing (Schmitz & Peigneux, 2011), and extended the model to new cognitive processes including auditory linguistic, auditory emotional, and spatial quantitative processing, all in concert with literature supporting the HAROLD model (Cabeza et al., 1997; Grady, McIntosh, Rajah, Beig, & Craik, 1999; Reuter-Lorenz et al., 2000; Park & Reuter-Lorenz, 2009).

The study results failed to support the HAROLD model for all of the cognitive processes in question. In particular, for the comparison of older and younger adults, the analyses failed to statistically support the HAROLD model for the dichotic syllables, dichotic emotions, bargraphs, and Landmark tasks. The nonsignificant findings stand in contrast to prior research supporting the HAROLD model (Schmitz & Peigneux, 2011) for spatial attentive processing, and is novel evidence against the generalization of the HAROLD model to auditory linguistic, auditory emotional, and spatial quantitative processing.

However, although the results did not support a significant difference between older adults and younger concerning lateralization across the four cognitive processes, the pattern of data for dichotic syllables suggests at least potential support for the HAROLD model related to auditory linguistic processing. In particular, results for dichotic syllables suggested a right ear advantage among younger adults in agreement with the literature (Boles, 1998b), and trended towards bilaterality among older adults. Thus, descriptively, older adults displayed reduced lateralization of auditory linguistic processing. In contrast, dichotic emotions, bargraphs, and the Landmark were descriptively in opposition to the HAROLD model, suggesting increased hemispheric asymmetry among older adults concerning auditory emotional, spatial quantitative, and spatial attentive processing. In the case of bargraphs this is more concerning as the results trended towards significance.

However, given the lack of prior research among older adults on auditory linguistic, auditory emotional, and spatial quantitative processing, all that can be adequately supported is failure to reject the null hypothesis. This suggests the HAROLD model may not generalize to these three processes. The results also failed to support HAROLD-consistent changes concerning the Landmark task. This suggests that spatial attentive processing may not show age-related reductions in hemispheric asymmetry. However, this finding was in contrast to the literature (Schmitz & Peigneux, 2011).

Methodological differences with prior research supportive of the HAROLD model may provide some explanation of the null results. Schmitz and Peigneux (2011) found support for the HAROLD model using the Landmark task. Their participants were selected based on unimpaired or corrected vision, but there was no indication that they assessed or controlled for education and it is unclear whether they considered controlling for any potential covariates. Cabeza et al. (1997) found support for the HAROLD model using a memory task involving visual encoding of a list of words, followed by later recognition and recall. Their sample of older adults ranging in age from 67 to 75 years were matched on education to a younger adult sample. However, there was no indication that they assessed or controlled for visual deficits.. Cabeza et al. (2002) similarly examined memory for words and found support for the HAROLD model. There is no indication that they assessed or controlled for any covariates in this study either. As a result, differences in sample characteristics or in use of covariates may have played a role in this study's null findings.

The Dedifferentiation Hypothesis

It was also hypothesized that there would be greater correlations among asymmetry measures for older adults in comparison to younger adults, supportive of dedifferentiation. This would have supported prior evidence of broad and nonspecific decreases in lateralization of function in late life (Balinsky, 1941). Specifically, age-related increases in correlations among various cognitive processes, as seen in prior research (Baltes & Lindenberger, 1997), would support dedifferentiation.

An initial examination of average correlations among measures suggested evidence against the dedifferentiation hypothesis across the four cognitive processes. Specifically, the correlations between measures of asymmetry were summed and the mean of these correlations was produced for each group (younger adults, older adults, older adults - high, older adults - MCI). Results suggested evidence against dedifferentiation. While absolute correlations indicated greater correlations among measures of asymmetry for older adults ($|\bar{\chi}| = .23$) than younger adults ($|\bar{\chi}| = .14$), directional means indicated the opposite. There were greater correlations among younger adults ($\bar{\chi} = .12$) than among older adults ($\bar{\chi} = -.05$). The negative mean correlation was also evidence against dedifferentiation as it suggested increasing separation between the measures for older adults, with some showing increased left hemisphere asymmetry and some increased right. This suggested that overall, correlations among measures of asymmetry, when compared between groups, provided evidence against the dedifferentiation hypothesis, in contrast to literature supporting dedifferentiation (Baltes & Lindenberger, 1997).

To gain greater clarity regarding this evidence against the dedifferentiation hypothesis, the individual associations among asymmetry measures were statistically compared between groups. Results provided further evidence against dedifferentiation. Results concerning the correlations involving dichotic syllables and bargraphs were nonsignificant and failed to support the study hypothesis for all group comparisons. Results addressing the correlation of dichotic emotions with the Landmark task were significant for two group comparisons. In the first, older adults collectively ($r = -.46$) showed a significantly stronger negative correlation between dichotic emotions and the Landmark task than younger adults ($r = .17$). In the second, the subgroup of older adults with mild cognitive impairment ($r = -.49$) showed a significantly stronger negative correlation between dichotic emotions and the Landmark task than younger adults ($r = .17$). Both cases provide evidence against the dedifferentiation hypothesis, with the negative correlations among measures of asymmetry for older adults indicating separation between the measures of asymmetry. Further, the statistical difference compared to younger adults suggests increased separation in comparison to younger adults. Altogether, these results suggested evidence against dedifferentiation as they contrasted with the general increase in correlations among asymmetry measures predicted by the dedifferentiation hypothesis, via a broad and nonspecific increase in laterality.

The Compensation Hypothesis: Lateralization and Performance

It was also hypothesized that there would be a correlation between laterality and performance among younger adults but not among older adults. This would have provided evidence partially supporting the compensation hypothesis which explains reduced hemispheric asymmetry as a functional adaptation to cognitive decline (Cabeza et al., 1997). Specifically, while previous research has yielded significant associations between lateralization and performance among younger adults (Boles, Barth, & Merrill, 2008), the compensation hypothesis essentially predicts the opposite. That is, as the compensation hypothesis predicts reductions in lateralization in association with maintained cognitive function, this would likely result in reductions in the association of lateralization with performance among older adults.

Results provided mixed support for the study hypothesis. For dichotic syllables, bargraphs, and the Landmark task, results indicated neither young adults nor older adults (collectively or split by cognitive status) showed statistically significant associations of lateralization with performance. These findings fail to support the compensation hypothesis related to auditory linguistic and spatial quantitative processing. However, results for dichotic emotions indicated a statistically significant association of laterality with performance for younger adults, contrasting with nonsignificant associations of lateralization with performance among older adults, older adults with mild impairment, and older adults with normal cognitive function. This suggests support for the compensation hypothesis related to auditory emotional processing.

Study results for younger adults stand in contrast to the literature concerning younger adults. Specifically, this study's sole statistically significant association of performance and lateralization on dichotic emotions (r = -.35), contrasts with Boles et al. (2008) who reported a nonsignificant correlation of performance and lateralization on dichotic emotions (r = .13). Additionally, in contrast to this study's results, Boles et al. (2008) found significant associations of laterality with performance on both dichotic syllables (r = .42) and bargraphs (r = -.37).

This study's finding for dichotic emotions could be explained as a spurious result, particularly given the uniform lack of associations on all other combinations of group and task. However, the difference in sample sizes may play a role with Boles et al. (2008) analyzing samples of 118 young adults on dichotic syllables, 162 young adults on dichotic emotions, and 527 young adults on bargraphs, in comparison to this study's single largest group of 60 young adults for dichotic emotion ranging down to 7 older adults with mild cognitive impairment for analyses based on bargraphs.

The Compensation Hypothesis: Association of Cognitive Status with Lateralization

It was hypothesized that there would be a significant difference for each asymmetry measure among the older adults. Specifically, those with normal cognitive status would display reductions in lateralization because they were compensating for losses in neural efficiency; in contrast, those with mild cognitive impairment would display significantly smaller reductions in lateralization, as they were either not compensating or were doing so to a lesser degree. This provided a second examination of support for the compensation hypothesis. Results indicating greater reductions in lateralization for older adults with normal cognitive status in contrast to those with mildly impaired cognitive status would support the role of reduced lateralization in maintaining cognitive function.

Results provided varying levels of support for the compensation hypothesis. The analyses comparing normal cognitive status older adults and those displaying mild cognitive impairment produced three non-significant comparisons (dichotic syllables, bargraphs, and the Landmark task) and one statistically significant difference (dichotic emotions). Consistent for all four comparisons, older adults with normal cognitive status displayed reduced hemispheric asymmetry relative to older adults with mild cognitive impairment, albeit non-significantly so for auditory linguistic, spatial quantitative, and spatial attentive processing. This general direction of results suggested broad support for the compensation hypothesis, with differential movement towards bilaterality by cognitive status. However, results failed to reject the null hypothesis concerning lateralization for three of the four measures between older adult groups by cognitive status. Furthermore, the pattern of data among these nonsignificant results could also be interpreted as evidence against the compensation hypothesis, and instead supportive of the dedifferentiation hypothesis which would better explain the nonsignificant findings. However, the one significant comparison stands in contrast.

Results suggested older adults with normal cognitive status had significantly reduced lateralization on the dichotic emotions task compared to older adults with mild cognitive impairment. The significant difference can be interpreted as evidence against dedifferentiation. Specifically, if age-related changes in lateralization of function were the result of age-related cognitive decline resulting from losses in the sensitivity and specificity of neural processors (Li & Lindenberger, 1999), whatever the change in lateralization, it should have been similar between the groups of older adults. This difference in auditory emotional processing by cognitive status in older adults could potentially be explained by the compensation hypothesis, in which the difference would be the result of compensatory bilateral activation, which would support greater asymmetry among the older adults with mild cognitive impairment as seen in the current results for dichotic emotions.

Results concerning auditory emotional processing supported the compensation hypothesis in both the analysis comparing lateralization by cognitive status group and in the prior analysis of the association of lateralization with performance. These results support the compensation hypothesis in two fashions. First, in a weaker sense, the significant association of asymmetry and performance among younger adults but not among older adults supports compensation. Second, stronger evidence for compensation is drawn from the significant association of lateralization with cognitive status, in which older adults who maintained cognitive function were noted to have a statistically significant reduction in lateralization of auditory emotional processing in comparison to older adults with mild cognitive impairment. However, further examination of this possibility would benefit from a comparison with the younger adult sample. Specifically, the relative asymmetry of the younger adults would determine whether the older adults with normal cognitive status displayed a shift towards bilaterality, supporting compensatory movement, or potentially the opposite.

In the tertiary analyses comparing all three groups (younger adults, older adults - high, older adults - MCI), results were non-significant for all four measures. However, the marginal means for the three group analysis of dichotic emotions indicated not only failure to support a statistically significant difference among the three groups, but no numerical movement between younger adults (-.09) and older adults with normal cognitive status (-.09), in contrast to older adults with mild cognitive impairment (-.24). This suggests caution in interpreting the prior comparison of older adults on the lateralization of auditory emotional processing as supportive of the compensation hypothesis. Compensation explains reductions in lateralization as functional adaptations, but the three group analysis numbers indicate no change in lateralization for older adults with maintained cognitive status. Instead, the numbers suggest a large albeit nonsignificant increase in lateralization among older adults with mild cognitive impairment.

The three group analyses were nonsignificant on all four measures. This is evidence against the HAROLD model and both the compensation and dedifferentiation hypotheses. Specifically, this indicates the HAROLD model may not generalize to auditory linguistic, auditory emotional, spatial quantitative, and spatial attentive processing. This also suggests the compensation hypothesis may not be supported for these four cognitive processes. Furthermore, the dedifferentiation hypothesis would have required some difference between older adults collectively and younger adults, while the compensation hypothesis would have been supported by reduced asymmetry among the older adults with normal cognitive status in contrast to older adults with mild cognitive impairment and younger adults. If not for power concerns related to sample size, discussed at a later point, these would be concerning results.

Measure Reliability

One additional point of discussion focuses on this study's analysis of the reliability of the measures. When looking at the full sample, all four measures of asymmetry had Spearman-Brown corrected split-half reliability coefficients at or above the established minimum of .30 (Boles, 1998a; Boles, 1998b), suggesting adequate reliability. When the sample was split by age groups, and again when the older adult sample was split by cognitive status, all four measures showed reliability at or above the minimum of .30. Of potential concern, the reliability coefficient for bargraphs on the full sample just reached the stated minimum ($r = .30$). One likely factor is the earlier noted unusual result for the reliability of bargraphs with the older adult with mild cognitive impairment. As noted in the results, given the small sample size in this case ($N = 8$), and as indicated by a greater standard error of the mean (40.6) than SD (32.1), the reliability for this sample was likely the result of measurement error and not to true lateralization (Hays, 1981; Lord & Novick, 1968; Nichols, 1999). Yet, when added in to the full sample calculation of reliability, this may have played some part in limiting reliability. However, the general indication of adequate reliability for the measure is in agreement with literature supporting the use of this measure and its reliability (Boles, 1998b). Literature supports reliable findings of asymmetry using bargraphs with acceptable split-half reliability in similar samples of younger adults; $r = .35$ (Boles, 1998b) and $r = .39$ (Boles, 2002).

Exploratory Analyses

Two exploratory analyses were pursued and found non-significant. First, analyses were run to explore possible associations of crystallized intelligence with laterality. Results were non-significant for all group types (young adults, older adults, older adults – high, older adults – MCI); all $p > .05$. Second, given consistent patterns suggestive of an age-related shift towards right hemisphere activation across tasks, when comparing younger to older adults, MANOVA was used to assess for an age-related shift across all four tasks. However, again, results were non-significant.

Potential Threats to Validity

Loss of statistical power due to covariate selection methodology. One potential threat to the validity of this study's results concerns the method of selecting covariates for the ANCOVAs. As covariates were not selected so as to maximize power, their use may have reduced power. However, when the ANCOVAs by age group (older and younger adults) and by cognitive status (OA-High and OA-MCI) were rerun using only significant covariates, all resulted in nonsignificant results. The original ANCOVA examining the effect of cognitive status on dichotic emotions was significant. However, despite the effort to maximize power, the revised version was nonsignificant. This suggests that the primary methodology for selecting covariates may not have meaningfully impaired power.

The cognitive reserve hypothesis. A second potential threat to the validity of this study's results concerns the high level of educational attainment among this study's older adult sample. The cognitive reserve hypothesis suggests high educational attainment may result in a cognitive buffer which can delay the onset of age-related cognitive decline. Specifically, high education, along with other preexisting factors and life experiences, are thought to supply a neural reserve through redundancies within the neuronal system (Scarmeas & Stern, 2003).

However, the results of correlation analyses comparing the association of education and laterality among older adults were nonsignificant for all four laterality tasks, which argues against this possible threat to validity.

Sample size. A third potential threat to the validity of this study's results is limited sample size. Some analyses, particularly those which split the older adult group by cognitive status, were based on small sample sizes which may have increased the likelihood of type II error. In the case of the comparisons between older adults with normal cognitive status and those with mild cognitive impairment, samples sizes ranged from a total of 28 (OA-MCI: 15, OA-high: 13) to a total sample size of 15 for bargraphs (OA-MCI: 7, OA-high: 8). These issues then carried over into the three group comparisons, which supports ongoing concern for underpowered analyses.

For the primary analyses comparing younger adults to older adults, sample size concerns were judged adequate based on a number of factors. A priori sample size was calculated for the current project in part based on prior literature. Schmitz and Peigneux (2011) used the Landmark task and found a main effect of age with a large estimated effect size using a sample of 32 young adults and 19 older adults. Beyond the Landmark task, research based on the line bisection task has supported an age-related shift towards a rightward attentive advantage. Many of these studies have used similar sample sizes: 107 total with 30 older adults (Failla et al., 2003), 108 total with 36 older adults (Fujii et al., 1995), and 24 total participants (Fukatsu et al., 1990). Furthermore, a review of studies examining the HAROLD model's generalizability indicated an average total sample size of 53 for behavioral studies. As a result the current study's sample of 60 younger adults and 28 older adults seems justified by prior literature. Additionally, a priori power analysis indicated a sample of 60 younger adults and 30 older adults would result in power of .56 to detect a medium effect size, and .94 to detect a large one. Altogether, this suggests the sample was adequate for the analyses comparing younger adults to older adults.

Sample representativeness. A fourth potential threat to the validity of this study's results can be drawn from concerns related to sample representativeness. Specifically, it is possible that the sample consisted of a relatively unique group, potentially explaining results differing from the literature. For example, in this study's analysis of the association of lateralization with performance, results were at odds with the literature concerning younger adults. Whereas this study found a significant association of performance and lateralization for dichotic emotions and nonsignificant associations of performance and lateralization for dichotic syllables and bargraphs, Boles, Barth, and Merrill (2008) found an opposite pattern of results (e.g., nonsignificant associations of performance and lateralization for dichotic emotions, and statistical significance for associations of performance and lateralization for dichotic syllables and bargraphs). As noted previously, differing sample sizes between studies likely play a role; for dichotic syllables Boles et al. (2008) based results on 118, while the current study used 49; for dichotic emotions 162 in contrast to 60; and for bargraphs 527 in contrast to 47. Yet, while differing from the literature, the sample sizes for this analysis are adequately powered for correlational analyses, begging the question of whether the opposing pattern of findings is the result of a relatively unique sample.

However, this study's methodology followed prior research in aiming to examine the HAROLD model. Specifically, the sample was drawn from undergraduate university students, consistent with prior methodology (Boles, 1991; Scarisbrick, Tweedy, & Kuslansky, 1987), as well as community older adults. Furthermore, as noted in the assessment of basic asymmetry at the beginning of the results section, basic lateralization among the measures for the full sample was consistent with prior literature on younger adults for dichotic syllables, dichotic emotions, and bargraphs, the tasks of particular question in relation to analyses of lateralization and performance. This suggests the sample should have been representative based on sampling methodology, and was representative based on basic agreement with the literature on asymmetry.

A third variable. A fifth potential threat to the validity of this study's results can be drawn from concerns for confounding variables. In particular, while the literature suggests sex accounts for an average of 0.09% of the variance in functional lateralization among younger adults (Boles, 2005), the literature is less clear on the potential for sex differences in functional lateralization among older adults. Some research supports a stronger role of sex in old age. In one study looking at a line bisection task, the age-related reduction in leftward bias was sex-specific (Chen et al., 2011). Chen et al. found that younger men and women displayed the expected leftward bias, and men displayed the expected age-related reduction in lateralization, however, women maintained the leftward bias into old age. Supporting this finding, other research has previously noted the role of sex in functional lateralization among older adults. Varnava and Hilligan (2007) used a line bisection task and found women aged 14 - 80 displayed a leftward advantage, while men aged 14 - 80 displayed a reduced hemispheric asymmetry or reversed it into a rightward advantage with age. Similarly, Barrett and Craver-Lemley (2008) used a line bisection task and found the age-related reduction in asymmetry was more pronounced in men than in women. Across the three studies, men displayed an age-related reduction in lateralization on the line bisection task, whereas women did not.

Beste, Hamm, and Hausmann (2006) provide a contrasting finding of potential concern. Using left-handed line bisection, they found a stable leftward advantage in men throughout the lifespan and a contrasting reduction in hemispheric asymmetry for women from 50 to 69 years of age. However, as others have noted (Chen et al., 2011), Beste et al. (2006) may have looked at an unusual sample as they failed to replicate the well-established right-handed leftward advantage in men. So, one possible explanation for study results concerning spatial reasoning is that an age effect of reduced asymmetry in older adult men was suppressed by a lack of change among older adult women. However, pursuing these analyses would further divide an already small sample size, yielding less than meaningful results. Therefore, this is an area for exploration in future studies.

Study Limitations

These study results are limited by a number of factors, but most prominently by sample size. The sample size for comparisons of younger adults to older adults was judged sufficient for analyses. However, when the older adult sample was bifurcated, comparisons of older adults by cognitive status brought sample sizes down to 15 for older adults – MCI and 13 for older adults – high for most analyses, and down to 7 and 8 for bargraphs, respectively. The small sample size likely led to the unusual reliability finding for bargraphs among older adults with mild cognitive impairment. Subsequently, analyses based on bargraphs for that group needed caution in interpretation; however, they were generally nonsignificant. Thus, results related to this measure and subgroup in particular call for replication given these limitations. Beyond this one instance, small sample sizes suggested the need for caution in interpreting results more generally, particularly for those comparing any subgroup of the older adult sample.

Another significant weakness was in sample demographics; older adults had on average five more years of education than younger adults. While analyses attempted to control for education when relevant, such statistical control would be better replaced with a more equitable sample in any future research. Similar demographic comments apply to significant differences by age in race, occupational prestige, overall hearing deficit, overall visual deficit, and information scaled scores. Study results are also restricted in generalizability, as results for young adults may generalize only to undergraduate college students and for the whole sample may be regionally restricted by a southeastern population.

Clinical Implications

Failure to support the HAROLD model for the four cognitive processes suggests limitations to the applicability of the HAROLD model. Given the long-term clinical goal of identifying areas for cognitive rehabilitation/protection through some behavioral, medical, or other form of treatment meant to induce shifts in lateralization, the results are disappointing. However, this helps inform any future development of cognitive rehabilitation specific to induced reduction in laterlization. Assuming future work accords with this study's findings for the HAROLD model, research developing methods to induce reductions in lateralization should focus on other cognitive processes with proven support for the HAROLD model and for the compensation hypothesis.

Conclusions

This study failed to support generalizing the HAROLD model to auditory linguistic, auditory emotional, spatial quantitative, and spatial attentive processing. This suggests the HAROLD model may not generalize to these areas of functional specialization. The evidence was against the dedifferentiation hypothesis, as the results suggested contrasting and incompatible patterns of data. The results suggested support for the compensation model, assuming changes consistent with the HAROLD model are supported in future research concerning the cognitive processes addressed in this study. Results suggest the need for further research in this area, particularly given the limitations related to sample size. As a result, replication of current findings and expanded exploration of potential areas of generalization for the HAROLD model serve as the next step. Future work could also more closely examine potential sex differences among a larger sample of older adults.

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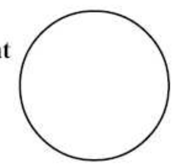
Appendix A

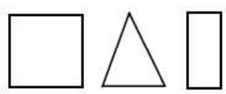
VAMC
SLUMS Examination

Questions about this assessment tool? E-mail aging@slu.edu.

Name________________________ Age ________________________
Is patient alert?________________________ Level of education ________________________

__/1	1	1. **What day of the week is it?**
__/1	1	2. **What is the year?**
__/1	1	3. **What state are we in?**
		4. **Please remember these five objects. I will ask you what they are later.** Apple Pen Tie House Car
		5. **You have $100 and you go to the store and buy a dozen apples for $3 and a tricycle for $20.**
	1	**How much did you spend?**
__/3	2	**How much do you have left?**
		6. **Please name as many animals as you can in one minute.**
__/3		0 0-4 animals 1 5-9 animals 2 10-14 animals 3 15+ animals
__/5		7. **What were the five objects I asked you to remember?** 1 point for each one correct.
		8. **I am going to give you a series of numbers and I would like you to give them to me backwards. For example, if I say 42, you would say 24.**
__/2		0 87 1 649 1 8537
		9. **This is a clock face. Please put in the hour markers and the time at ten minutes to eleven o'clock.**
	2	Hour markers okay
__/4	2	Time correct
__/2	1	10. **Please place an X in the triangle.**
	1	**Which of the above figures is largest?**
		11. **I am going to tell you a story. Please listen carefully because afterwards, I'm going to ask you some questions about it.** Jill was a very successful stockbroker. She made a lot of money on the stock market. She then met Jack, a devastatingly handsome man. She married him and had three children. They lived in Chicago. She then stopped work and stayed at home to bring up her children. When they were teenagers, she went back to work. She and Jack lived happily ever after.
	2	**What was the female's name?**
	2	**What work did she do?**
__/8	2	**When did she go back to work?**
	2	**What state did she live in?**





_______ **TOTAL SCORE**

Department of Veterans Affairs

SAINT LOUIS UNIVERSITY

Scoring

High School Education		Less than High School Education
27-30	Normal	25-30
21-26	MNCD*	20-24
1-20	Dementia	1-19

* Mild Neurocognitive Disorder

SH Tariq, N Tumosa, JT Chibnall, HM Perry III, and JE Morley. The Saint Louis University Mental Status (SLUMS) Examination for Detecting Mild Cognitive Impairment and Dementia is more sensitive than the Mini-Mental Status Examination (MMSE) - A pilot study. J am Geriatri Psych (in press).

Appendix B
Edinburgh Handedness Inventory

Surname______________________________ Given Names______________________________

Date of Birth___________________________

Please indicate your preference in the use of hands in the following activities *by putting + in the appropriate column*. Where the preference is so strong that you would never try to use the other hand unless absolutely forced to, *put* ++. If in any case you are really indifferent *put + in both columns*.

Some activities require both hands. In these cases the part of the task, or object, for which hand preference is wanted is indicated in brackets.

Please try to answer all the questions, and only leave a blank if you have no experience at all of the object or task.

	LEFT	RIGHT
1. Writing		
2. Throwing		
3. Scissors		
4. Toothbrush		
5. Knife (without a fork)		
6. Spoon		
7. Striking a Match (match)		

L.Q.	

Leave these spaces blank

Appendix C
Demographic Inventory

1. What is your age?

2. What is your gender?

3. What is your race?

4. Are you right or left handed?

5. How many years of school have you completed?

6. What was your primary breadwinner's main occupation during your childhood (0-18)?

Appendix D

Center for Epidemiological Studies Depression Scale (CES-D) 5-item Subtest

Below is a list of ways you may have felt or behaved. Please tell me how you have felt during the past week.

1. "I felt depressed"
    a. 0 = Rarely or none of the time (less than 1 day)
    b. 1 = Some or a little of the time (1-2 days)
    c. 2 = Occasionally or moderate amount of time (3-4 days)
    d. 3 = Most of or all of the time (5-7 days)

2. "My sleep was restless"

    a. 0 = Rarely or none of the time (less than 1 day)
    b. 1 = Some or a little of the time (1-2 days)
    c. 2 = Occasionally or moderate amount of time (3-4 days)
    d. 3 = Most of or all of the time (5-7 days)

3. "I felt lonely"

    a. 0 = Rarely or none of the time (less than 1 day)
    b. 1 = Some or a little of the time (1-2 days)
    c. 2 = Occasionally or moderate amount of time (3-4 days)
    d. 3 = Most of or all of the time (5-7 days)

4. "I had crying spells"

    a. 0 = Rarely or none of the time (less than 1 day)
    b. 1 = Some or a little of the time (1-2 days)
    c. 2 = Occasionally or moderate amount of time (3-4 days)
    d. 3 = Most of or all of the time (5-7 days)

5. "I could not 'get going'"

    a. 0 = Rarely or none of the time (less than 1 day)
    b. 1 = Some or a little of the time (1-2 days)
    c. 2 = Occasionally or moderate amount of time (3-4 days)
    d. 3 = Most of or all of the time (5-7 days)

Note: Individual scores for the five items are summed

Appendix E

Recommendations for Rehabilitation: Speech and Hearing

Referral

It is recommended that (participant name) seek services (i.e., evaluation and/or treatment) for these symptoms. The Speech and Hearing Center at The University of Alabama (348-7131) can provide these services. It is recommended that (participant name) call The Speech and Hearing Center to discuss evaluation and treatment options, inquire about possible fees for services, and potentially set a first appointment.

Use of visual, hearing aids and assistive devices

This includes the use of optical aids, for example, magnifiers, monocular and talking books. Hearing devices include the use of hearing aids and adaptive listening devices, for example induction loops, earphones for television or radio and personal amplifiers.

Visual and auditory training

Visual and auditory training is aimed at improving speech perception through visual cues such as lipreading (visual recognition of consonants), perception of non-speech material (awareness of gestural cues, facial cues, head movements and body posture) and environmental cues. Since the majority of speech sounds are not visible, it has been suggested that visual items should be accompanied by auditory cues. Auditory training includes speech discrimination training and recognition of consonant, vowels and phonemes (speech sounds).

Communication training

The aim of communication training is to encourage older adults with sensory loss and their communication partners to use effective communication strategies to facilitate communication fluency and satisfaction.

Communication training includes:

- Environmental and situational manipulation by decreasing background noise and reducing reverberation, distractions, distance between speakers, glare and interference from extraneous light sources. Group conversations should be limited and dyadic conversations encouraged. Communication partners should also have good face and eye contact.
- The use of effective conversational repair strategies by using specific clarification requests (listener-initiated) and conversational repair strategies (speaker-initiated). Some examples of specific clarification requests include: repeat the message, slow down, talk clearer, come nearer, speak louder and use shorter sentences. Examples of conversational repair strategies include: repeating the message, speaking clearer, elaborating, simplifying the message, changing the syntax or whole message and providing non-verbal clues.

<u>Group participation and social intervention</u>

The aim of group participation is to encourage group identification and self-help strategies. Although group communication is difficult for older adults with sensory loss, identification with other people with similar disabilities often provides coping strategies, encourages problem-solving, improves social interaction and offers an opportunity for social support.

Multi-disciplinary intervention

Team-work and the effective communication between professional disciplines can optimize clients' psychosocial performance. Adaptation to sensory loss, improving physical and mental health, independence, mood and social skills can improve well-being and quality of life.

Professional development and education

Staff, carers and family members, relatives and friends who regularly communicate with older adults with sensory loss need to be aware of the sensory, communication and psychosocial consequences of sensory loss. They also need to encourage older adults with sensory loss to use required aids and devices to maximize their visual and listening skills as well as utilize effective communication strategies to optimize their interactions.

Appendix F

Cognitive Screening Recommendations

Normal functioning

- Results of the brief cognitive assessment indicate that (participant's name) performed within the normal range on the brief cognitive screener. To maintain current functioning, it is recommended that (participant name) (engage in/continue to engage in) protective factors against cognitive decline. These protective factors include a diverse range of cognitive activities that provide some degree of cognitive processing (e.g., crossword puzzles or Sudoku), healthy nutrition (e.g., Mediterranean diet & high vegetable intake), and physical exercise.
    - If applicable: Given a current hobby or activity the participant currently engages in, you can add or replace with: It is recommended that participant continue to cultivate her/his hobby in (e.g., reading) to help strengthen her/his skills.)
- Results of the brief cognitive assessment indicate that (participant's name) performed within the normal range on the brief cognitive screener. Thus, (participant name) reported concerns with (name the concerns) do not seem to be related to substantial cognitive decline or impairment. However, if (participant's name) begins to notice increased difficulty with cognitive tasks, it is recommended that he/she discuss the issue with a physician or contact The Geropsychology Clinic in the University of Alabama (348-5000) to undergo another evaluation.

Mild Cognitive Impairment

- The results of a brief assessment of cognitive functioning indicate that (participant's name) may be experiencing mild cognitive impairment. It is recommended that (participant's name) inform and discuss the results of this brief assessment with (his/her) primary care physician. In addition, given the results of testing, it is recommended that (participant's name) be seen by a geriatrician who is specialized to provide medical care for someone with cognitive impairment. It is recommended that (participant's name) contact The Geriatrics Clinic in The University Medical Center [(205) 348-2880].
- The results of a brief assessment of cognitive functioning indicate that (participant's name) may be experiencing mild cognitive impairment. It is recommended that (Participant's name) continue to monitor changes in cognitive functions and consult with a psychologist/geriatrist if further cognitive decline is noticed to further evaluated and identify strengths and weaknesses in his/her cognitive abilities.

<u>Dementia</u>

- The results of a brief assessment of cognitive functioning indicate that (participant's name) may be experiencing substantial cognitive impairment. It is recommended that (participant's name) inform and discuss the results of this brief assessment with (his/her) primary care physician. In addition, given the results of testing, it is recommended that (participant's name) be seen by a geriatrician who is specialized to provide medical care for someone with cognitive impairment. It is recommended that (participant's name) contact The Geriatrics Clinic in The University Medical Center [(205) 348-2880].

<u>Deficit-Specific Recommendations</u>

Visuospatial and executive functioning:

- To improve visuospatial abilities and executive functioning, the use of acronyms to memorize information, repeating or taking notes on information that should be remembered, working riddles, problem solving games, and brain teasers are recommended.

Verbal fluency:

- To improve verbal fluency, it is recommended that (participant's name) engage in activities such as reading, interacting with friends, and playing word games (e.g., crossword puzzles).

Memory domain:

- To improve memory, it is recommended that suggest (participant's name) use acronyms to memorize information, repeating or taking notes on information needed to remembered, and working riddles, problem solving games, and brain teasers.

Appendix G

Mood Screening Recommendations

Depression

- The results of a brief depression screener indicate that (participant's name) may be experiencing substantial depressive symptoms that may be causing impairment in (his/her) daily functioning. It is recommended that (participant name) seek psychotherapeutic intervention (i.e., therapy) for the treatment of these symptoms. The Psychology Clinic at The University of Alabama (348-5000) can provide this service. It is recommended that (participant name) call The Psychology Clinic to discuss treatment options, inquire about a fee for therapy, and potentially set a first appointment.
- During the course of the assessment, (participant's name) indicated (his/her) current use of Pharmacological medication to assist them with (his/her) depressive symptoms. It is recommended that (participant's name) continue the use of pharmacotherapy for symptoms of depression.
    - If applicable: It is also recommended that (Participant's name) use prior tools learned in psychotherapy to challenge persistent negative thoughts. It is likely that if the reduction of the depressive symptoms will result in improvements in (his/her) cognitive functioning.

Appendix H

Speech and Hearing Center
205-348-7131
Box 870242
FAX: 205-348-1845

The University of Alabama | **Tuscaloosa, Alabama 35487**

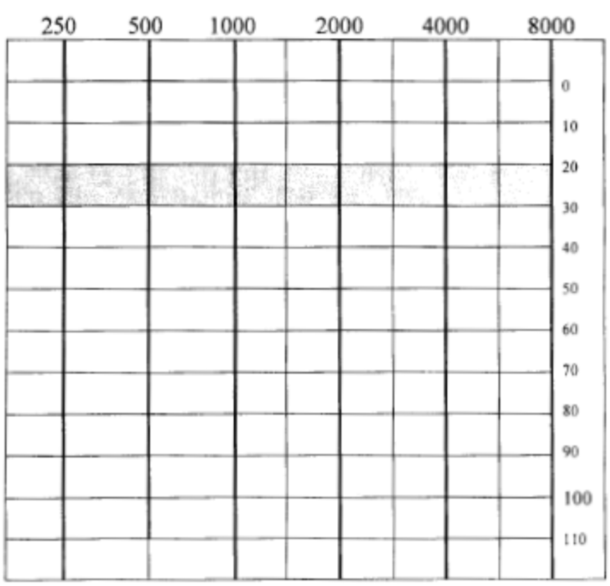
Name: | **Examiner:**

File #: | **Date:**

Key		Right Ear	Left Ear
O AC X			
< BC >	Pure tone average	________ dB	________ dB
Δ AC masked □			
[BC masked]	Speech Recognition Threshold	________ dB	________ dB
S: sound field			
L: left aided			
R: right aided	Word Intelligibility Threshold	________ %	________ %
↓ no response		______ dB HL	______ dB HL
Impressions: ( ) right ( ) left	Loudness Discomfort Level	________ dB	________ dB
Reliability: ( ) good ( ) fair ( ) poor	Otoacoutstic Emissions	__________	__________
Method: ( ) standard ( ) play	Tympanometry	__________	__________
Earphone: ( ) TDH ( ) insert	Otoscopy	( ) unoccluded ( ) partly occluded ( ) occluded	( ) unoccluded ( ) partly occluded ( ) occluded

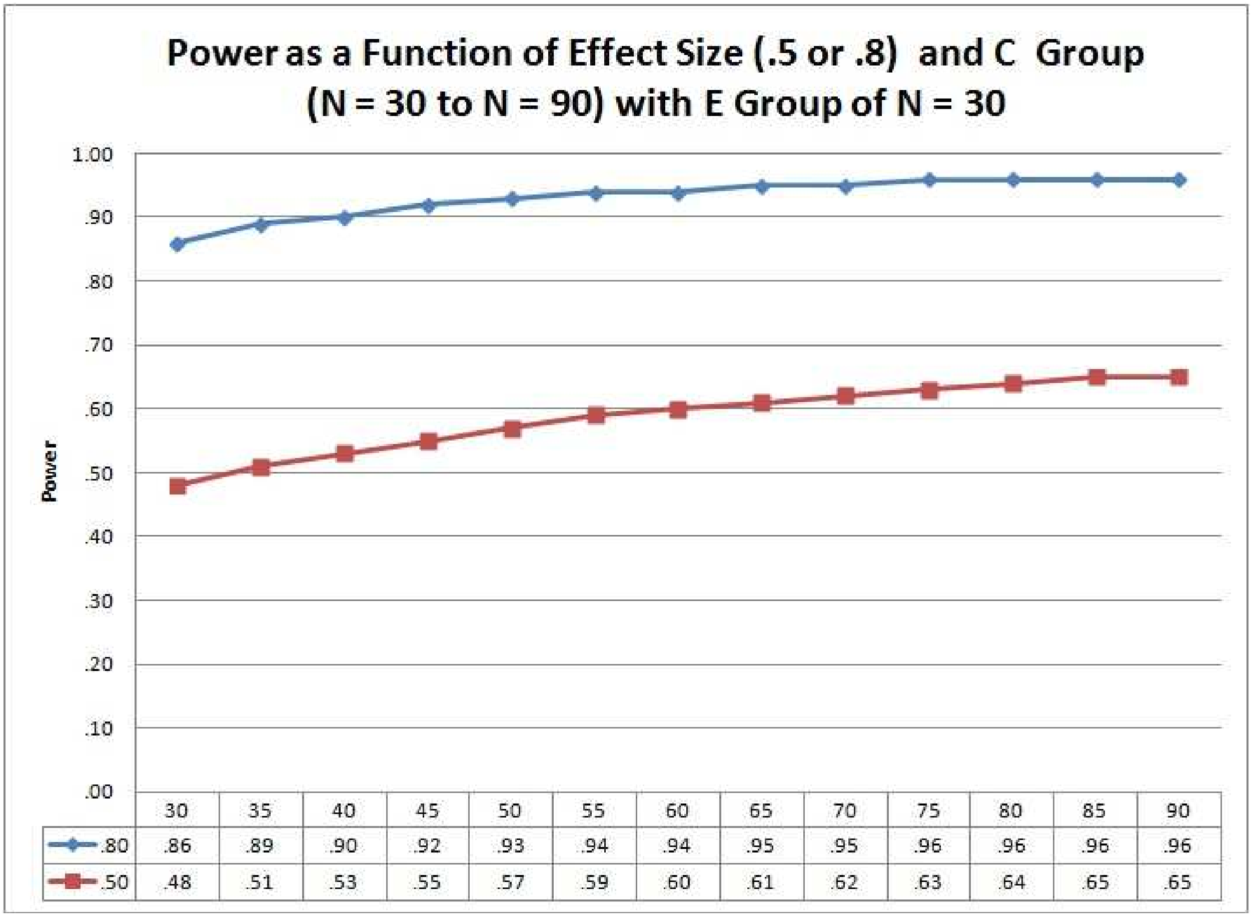
---

Frequency in Hz



Appendix I

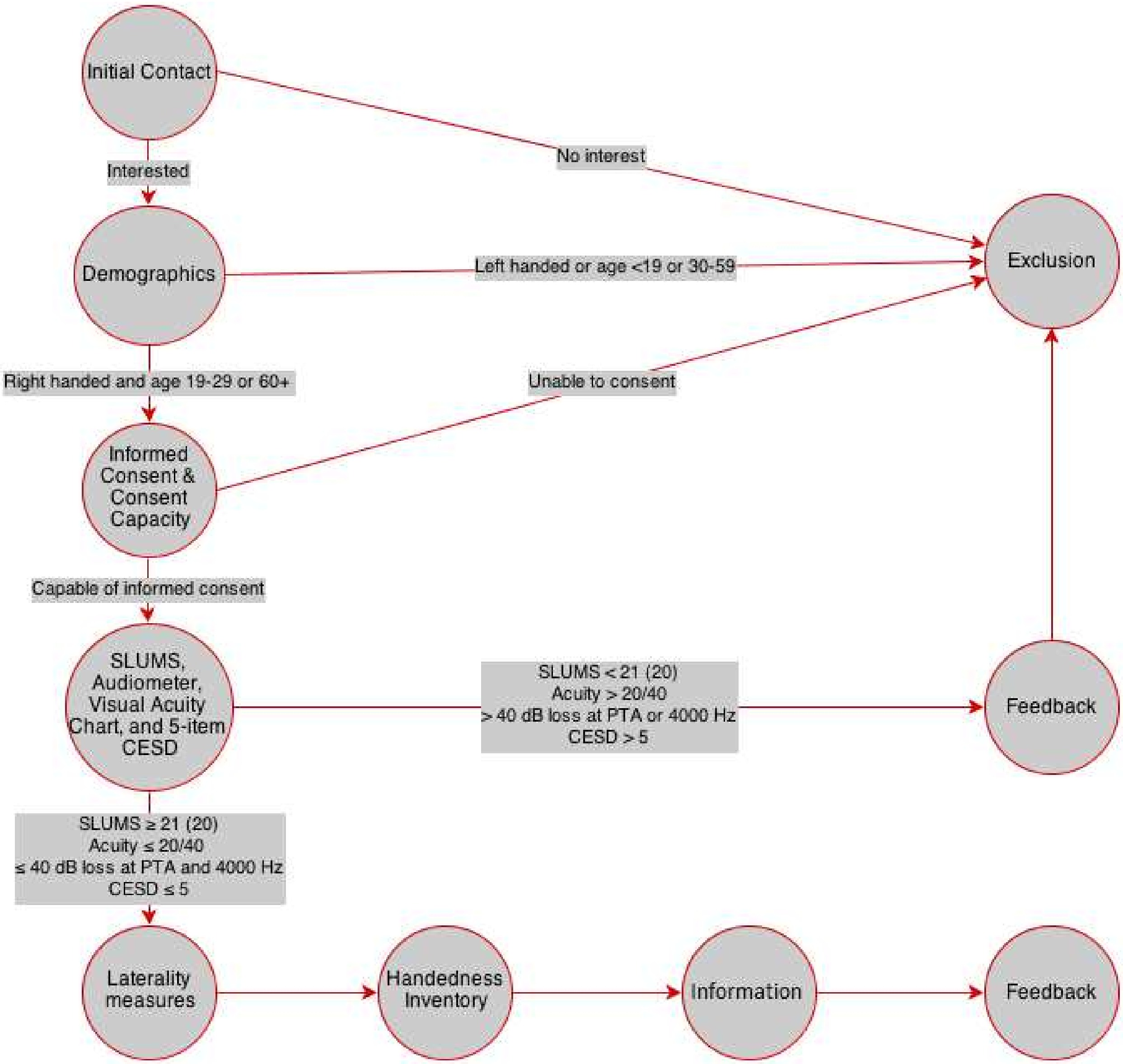
Power analyses of a 2-group t-test as a function of Effect Size.



E Group = older adults

C Group = young adults

Appendix J


Initial Contact
Interested
No interest
Demographics
Left handed or age <19 or 30-59
Exclusion
Right handed and age 19-29 or 60+
Unable to consent
Informed Consent & Consent Capacity
Capable of informed consent
SLUMS, Audiometer, Visual Acuity Chart, and 5-item CESD
SLUMS < 21 (20)
Acuity > 20/40
> 40 dB loss at PTA or 4000 Hz
CESD > 5
Feedback
SLUMS ≥ 21 (20)
Acuity ≤ 20/40
≤ 40 dB loss at PTA and 4000 Hz
CESD ≤ 5
Laterality measures
Handedness Inventory
Information
Feedback

Appendix K

AAHRPP DOCUMENT # 19

THE UNIVERSITY OF ALABAMA
HUMAN RESEARCH PROTECTIONS PROGRAM

FORM: Decision-Making Capacity Assessment Tool

Note: Systematic assessment of participants' decision-making capacity is encouraged. This form is optional but recommended; PI may use another tool if desired—please append.

Prospect Name:_________________________________ Date:________

Brief Protocol Title:____ IRB #________

There are four key elements of decision-making capacity to assess. Please ask prospect the questions following the element or make the requested observation or judgment.

1. **Understanding.**
   What is the purpose of the study—what are we trying to learn?

   What will happen to you—what will you be asked to do—in this study?

2. **Appreciation**
   What are the risks or dangers of this study?

   What are the possible benefits—good things—from this study?

   Are these benefits/good things for you or mainly for others?

3. **Reasoning**
   What alternative is there if you decide not to be in this study?
   (If you do not want to be in the study, can you choose something else to treat your problem?)

4. **Expressing a Choice**
   (Observe). Does the person voluntarily express a choice about whether to participate? YES NO
   IF YES, why do you think you want to be in this study?

   IF NO, do you think you want to be in this study?

5. **Judgment: Based on the sample criteria and the person's responses, do you believe s/he has the decision-making capacity to give informed consent for this study? YES NO Is a second opinion needed? YES NO**

____

Signature of Evaluator Date

Appendix L

Office for Research

Institutional Review Board for the
Protection of Human Subjects

THE UNIVERSITY OF
ALABAMA
RESEARCH

April 2, 2014

Jesse McPherron
Department of Psychology
College of Arts and Sciences
Box 870348

Re: IRB# 14-003
"Reduced Laterality among Older Adults: Building on the HAROLD Model"

Dear Mr. McPherron:

The University of Alabama IRB has received the revisions requested by the full board on 3/14/14. The board has reviewed the revisions and your protocol is now approved for a one-year period. Please be advised that your protocol will expire one year from the date of approval, 3/14/14.

If your research will continue beyond this date, complete the IRB Renewal Application by the 15th of the month prior to project expiration. If you need to modify the study, please submit the Modification of An Approved Protocol Form. Changes in this study cannot be initiated without IRB approval, except when necessary to eliminate apparent immediate hazards to participants. When the study closes, please complete the Request for Study Closure Form.

Should you need to submit any further correspondence regarding this proposal, please include the assigned IRB application number.

Good luck with your research.

Sincerely,

[redacted]

Stuart Usdan, PhD.
Chair, Non- Medical Institutional Review Board
The University of Alabama

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