Published in final edited form as:
Arch Gerontol Geriatr. 2014 ; 59(2): 429–438. doi:10.1016/j.archger.2014.05.001.

Financial Literacy is Associated with Medial Brain Region Functional Connectivity in Old Age

S. Duke Han[1,2,6], **Patricia A. Boyle**[1,2], **Lei Yu**[2,3], **Debra A. Fleischman**[1,2,3], **Konstantinos Arfanakis**[2,4,5], **Sue Leurgans**[2,3], and **David A. Bennett**[2,3]

[1]Department of Behavioral Sciences, Rush University Medical Center, Chicago, IL, USA

[2]Rush Alzheimer's Disease Center, Rush University Medical Center, Chicago, IL, USA

[3]Department of Neurological Sciences, Rush University Medical Center, Chicago, IL, USA

[4]Department of Biomedical Engineering, Illinois Institute of Technology, Chicago, IL, USA

[5]Department of Radiology, Rush University Medical Center, Chicago, IL, USA

[6]Mental Health Care Group, VA Long Beach Healthcare System, Long Beach, CA USA

Abstract

Financial literacy refers to the ability to access and utilize financial information in ways that promote better outcomes. In old age, financial literacy has been associated with a wide range of positive characteristics; however, the neural correlates remain unclear. Recent work has suggested greater co-activity between anterior-posterior medial brain regions is associated with better brain functioning. We hypothesized financial literacy would be associated with this pattern. We assessed whole-brain functional connectivity to a posterior cingulate cortex (PCC) seed region of interest in 138 participants of the Rush Memory and Aging Project. Results revealed financial literacy was associated with greater functional connectivity between the PCC and three regions: the right ventromedial prefrontal cortex (vmPFC), the left postcentral gyrus, and the right precuneus. Results also revealed financial literacy was associated negatively with functional connectivity between the PCC and left caudate. Post-hoc analyses showed the PCC-vmPFC relationship accounted for the most variance in a regression model adjusted for all four significant functional connectivity relationships, demographic factors, and global cognition. These findings provide information on the neural mechanisms associated with financial literacy in old age.

Contact information: S. Duke Han, PhD, ABPP-CN Rush Alzheimer's Disease Center 600 S. Paulina St., Suite 1022, Chicago, IL 60612 Duke_Han@rush.edu Phone: 312-942-2028 Fax: 312-563-4605.

Conflicts of Interest None.

Keywords

aging; financial literacy; functional connectivity; posterior cingulate; ventromedial prefrontal cortex

1. Introduction

Financial literacy refers to the ability to understand, access, and utilize financial information in ways that contribute to better financial outcomes (Lusardi and Mitchell, 2014; Braunstein and Welch, 2002; Hilgert et al., 2003). Financial literacy has been associated with better mental health outcomes in younger adults (Taylor et al., 2009) and with better financial planning and retirement outcomes in older adults (Lusardi and Mitchell, 2007a; Lusardi and Mitchell, 2007b). Since older adults are the fastest growing demographic of the population and will make important financial decisions about retirement savings and inter-generational transfers of wealth, financial literacy could have a profound impact on families and society. Thus, financial literacy is an important public health issue and understanding the neural substrates of financial literacy in older adults may inform possible interventions that may lead to the preservation or improvement of decision making in old age.

A technique that may assist in elucidating the neural substrates of financial literacy in old age is resting-state fMRI (rs-fMRI). This noninvasive technique elucidates functional connectivity characteristics between specific brain regions through determining the temporal coherence of low frequency fluctuations in the blood-oxygenation-level-dependent (BOLD) signal. Greater temporal coherence between brain regions implicates the regions as functionally related, and the strength of the connections between brain regions may vary according to multiple factors. This brain imaging approach is brief, requires no cognitive engagement, and has been successfully used to illuminate complex mechanisms of the aging and dementia process (Greicius et al., 2004; Buckner et al., 2005).

To our knowledge, functional connectivity neuroimaging approaches have not yet been used to examine financial literacy in old age. In developing a hypothesis of how financial literacy might be associated with a particular functional connectivity pattern in the brain, we reviewed recent reports showing greater anterior-posterior brain region co-activity is associated with better brain functioning outcomes that could have an impact upon financial literacy. For example, in a study of patients who sustained a severe traumatic brain injury, level of awareness was directly associated with synchrony of anterior and posterior brain regions according to electroencephalogram (EEG, Leon-Carrion et al., 2012). Furthermore, older adults with greater insight into their cognitive abilities appear to show greater co-activity of cortical anterior-posterior midline structures according to event-related functional magnetic resonance imaging (fMRI) methods (Ries et al., 2007). A number of reports have also shown that deterioration of functional connectivity between anterior-posterior medial brain regions is associated with suboptimal brain functioning, and in particular, Alzheimer's disease. Applying graph theory to whole-brain resting-state fMRI scans, correlations among 116 regions of interest showed long-distance functional connectivity decreases between frontal and posterior regions among mild Alzheimer's disease patients when compared to healthy age-matched participants (Sanz-Arigita et al., 2010). Fronto-parietal disconnections in alpha and beta signals have also been observed among Alzheimer's disease patients using magnetoencephalography (Stam et al., 2006). Decreased anterior-posterior functional connectivity among medial default network regions was observed in persons with amnestic Mild Cognitive Impairment, and these functional connectivity values were inversely associated with cognitive performance (Wang et al., 2013).

Because financial literacy has been linked with better brain functioning characteristics, we hypothesized that functional connectivity from a posterior medial region of the brain to an anterior medial region of the brain would be positively associated with financial literacy in older adults. Furthermore, because financial literacy has been associated with age, education, sex, and cognition (Finke et al., 2011; Lusardi and Mitchell, 2011b; Bennett et al., 2012; Boyle et al., 2013), we explored whether neuroimaging results remained significant after adjusting for these effects. Using resting-state fMRI and a seed region of interest in the posterior cingulate cortex, we investigated this in 138 non-demented older adults from the Rush Memory and Aging Project, a large clinicopathologic, longitudinal, and community-based study of aging. All participants underwent extensive clinical assessments and questions that assessed financial literacy. Given the strong role the ventromedial prefrontal cortex plays in economic decision making (Fellows and Farah, 2007), and its anatomic location as an anterior medial brain region, we additionally expected any significant functional connectivity neuroimaging findings would include the ventromedial prefrontal cortex.

2. Materials and Methods

2.1. Participants

Participants were enrolled in the Rush Memory and Aging Project, a community-based clinical-pathologic study of aging and dementia (Bennett et al., 2012), which recruits from local residential facilities, including retirement homes, senior housing facilities, and community organizations in the Chicago metropolitan area. All participants are enrolled without known dementia and are followed annually. Participants were determined to be without dementia based on a detailed clinical evaluation (Bennett et al., 2006). Cognitive impairment was assessed with a detailed battery of performance tests, and determined by a clinical neuropsychologist with expertise in aging and AD who reviewed the cognitive data, information about the participant's background (e.g., education/occupation, sensory and motor deficits), and a clinical evaluation of the participant done by a physician with expertise in aging and dementia. Diagnosis of dementia was determined in accordance with NINCDS/ADRDA criteria by the evaluating clinician (Bennett et al., 2002; Boyle et al., 2005).

The Rush Memory and Aging Project began in 1997 and assessments of financial literacy and brain imaging were initiated in 2009. At the time of these analyses, 1299 participants had enrolled and completed their baseline evaluation in the parent study, 443 died, and 77 refused further participation before financial literacy and scan data collection began. Of the remaining 779, 260 had MRI contraindications or were unable to sign informed consent leaving 519 eligible for scanning. Of these, 155 (29.9%) refused, 214 were scanned, and the remaining 150 were still being scheduled for scanning. From the 214 that were scanned, 14 were dropped due to excessive motion, and 4 were dropped due to scanning data acquisition problems, leaving 196 participants. An additional 16 participants were dropped because of quality assurance issues relating to scan data, leaving 180 participants. Forty-two participants of the remaining 180 had not completed financial literacy behavioral assessments, leaving 138 participants without dementia who had undergone neuroimaging and financial literacy assessments. The mean number of days between MRI scan and financial literacy assessments for the remaining 138 participants was 35.26 (SD=66.01) with 75 percent of scans occurring within 3 months of assessment, and all scans occurring within 10 months of financial literacy assessment (minimum to maximum range: -120 days to 281 days). Age (based on date of birth and date of financial literacy assessment), sex, race (white versus non-white) and education (years of schooling) were self-reported. Income was measured using a show card methodology during the baseline assessment of the parent study; participants were shown a card with the following 10 possible categories and asked to choose the option that represented their annual income: (1) USD 0–4,999, (2) USD 5,000–9,999, (3) USD 10,000–14,999, (4) USD 15,000–19,999, (5) USD 20,000–24,999, (6) USD 25,000–29,999, (7) USD 30,000–34,999, (8) USD 35,000–49,999, (9) USD 50,000–74,999, (10) USD > 75,000.

2.2. Assessment of Financial Literacy

Financial literacy was assessed using 23 questions based on information, concepts, and numeracy as previously reported (James et al., 2012; Bennett et al., 2012). These questions included those adapted from materials from the Health and Retirement Survey (Lusardi and Mitchell, 2007a; Lusardi and Mitchell, 2007b), questions of simple monetary calculations such as interest rates and sales, and knowledge of financial concepts such as “stocks”, “bonds”, and “FDIC”. One example of an item is “True or false. Using money in a bank account to pay off credit card debt is usually wise.” Another example is “Imagine that the interest rate on your savings account is 1% per year and inflation is 2% per year. After 1 year, will you be able to buy more than, exactly the same as, or less than today with the money in your account?” We conducted an additional item analysis on the financial literacy measure and found that among our sample, the percent of people that got each individual question correct ranged from 33.33% to 95.83% (mean=73.86%, SD=18.21%), suggesting variability in difficulty across questions. All items and the percent of the study sample that got each question correct are presented as an Appendix. There were no questions that all participants got correct or incorrect. Percent correct across all questions was calculated by each participant and used in accordance with previous studies (Boyle et al., 2013; James et al., 2012; Bennett et al, 2012).

2.3. Image Acquisition and Processing

All participants underwent neuroimaging within approximately 1 year of completing the clinical evaluation and financial literacy assessment. Magnetic resonance imaging (MRI) scans were conducted on a 1.5 Tesla clinical scanner (General Electric, Waukesha, WI), equipped with a standard quadrature head coil, located within the community of the sample. High data quality was ensured through daily tests of the scanner’s performance and thorough quality control tests on the raw data. High-resolution T1-weighted anatomical images were collected with a 3D magnetization-prepared rapid acquisition gradient-echo (MPRAGE) sequence with the following parameters: TR = 6.3 ms; TE = 2.8 ms; preparation time = 1000 ms; flip angle = 8°; 160 sagittal slices; 1 mm slice thickness; field of view (FOV) = 24 cm × 24 cm; acquisition matrix 224 × 192, reconstructed to a 256 × 256 image matrix; scan time = 10 min and 56 secs. Two copies of the T1-weighted data were acquired on each subject and averaged. Resting state MRI data was acquired using a 2D spiral in/out echo-planar imaging (EPI) sequence with the following parameters: TR = 2000 ms; TE = 33 ms; flip angle = 85°; 26 oblique axial slices; 5 mm slice thickness; acquisition/reconstruction matrix 64 × 64; FOV = 24 cm × 24 cm; 240 time-points/volumes; scan time = 8 min. Participants were asked to keep their eyes closed.

The skull was removed from the averaged structural MRI data using FreeSurfer's Hybrid Watershed Algorithm (Segonne et al., 2004). Structural scans were also manually edited when necessary to remove residual non-brain material. Brain segmentation into gray matter, white matter and CSF was also performed using FreeSurfer (http://surfer.nmr.mgh.harvard.edu/). Whole brain volume was derived, and the portion of brain volume occupied by each tissue type was calculated. The first 6 image volumes of resting state data were discarded at the scanner to avoid using data collected before reaching MRI signal equilibrium. Images were reconstructed on Linux machines from the acquired k-space data (Glover et al., 2004). Using the Statistical Parametric Mapping software (Friston et al., 1995; http://www.fil.ion.ucl.ac.uk/spm/) version 8 (SPM8), all volumes were corrected for slice-timing and motion, were co-registered to the corresponding high-resolution T1-weighted data using affine transformation, and spatially normalized to the Montreal Neurological Institute (MNI) template. The normalized image volumes were spatially smoothed with a 7mm full-width half-maximum (FWHM) Gaussian kernel. Next, a band-pass filter of 0.01 to 0.08 Hz was applied to the data in temporal frequency space to minimize low-frequency signal drift and high frequency signal variations due to cardiac and respiratory effects. In order to remove any residual effects of motion and other non-neuronal factors, 6 head motion parameters, as well as parameters for the white matter signal, global mean signal, and cerebrospinal fluid signal were used as nuisance variables (Buckner et al., 2009) in functional connectivity analysis using the Data Processing Assistant for Resting-State fMRI (DPARSF; http://restfmri.net/forum/DPARSF) and SPM8.

To address concerns of head movement, we employed a two-step process of exclusion. All of the participants included in the study had to satisfy exclusion criteria of head movement during the entire fMRI scanning session of less than 2.5mm translation in any axis and less than 2.5° angular rotation in any axis. They also had to satisfy an additional head movement exclusion of 1.9mm translation in any axis and less than 1.9° angular rotation in any axis over any 10 second interval.

2.4. Assessment of Cognition

All participants underwent a battery of 21 neuropsychological measures, 19 of which were used to make composite scores (Bennett et al., 2012). The battery consisted of the Word List Memory, Word List Recall, and Word List Recognition from the CERAD battery, the immediate and delayed recall of Logical memory Story A and the East Boston Story, Verbal

Fluency, Boston Naming Test, a subset of items from the Complex Ideational Material Test, the National Adult Reading Test, Digit Span subtest (forward and backward) of the Wechsler Memory Scale-Revised, Digit Ordering, the Symbol Digit Modalities Test, Number Comparison, Stroop Word Reading, Stroop Color Naming, Mini-Mental Status Examination, the Judgment of Line Orientation Test, and Standard Progressive Matrices. The Mini-Mental Status Examination was used as a cognitive screening measure and the Complex Ideational Material Test was used as a measure of language abilities. These two tests were not included in the calculation of composite scores because they are used only for diagnostic classification purposes. A global cognition score was calculated by averaging the z-scores across all other measures of cognitive function.

2.5. Statistical analyses

A spherical seed region of interest (ROI) with a radius of 4mm was prescribed in the posterior cingulate cortex, with MNI coordinates of x = 0, y = -53, z = 26 (posterior cingulate cortex: PCC) in accordance with previous work (Hedden et al., 2009). A mean signal time course for the seed ROI was calculated and used as a reference. Analyses were then conducted by examining the partial correlations between the reference signal time course and the time series of each other voxel in the brain. The voxels showing significant functional connectivity to the seed ROIs were identified as those voxels whose partial correlation differed significantly from 0, based on whole-brain Fisher's z-transformation of the correlations at the individual level. In order to interrogate brain regions functionally connected to the seed ROI, AlphaSim Monte Carlo simulations (10,000 permutations) as determined by the AlphaSim program in AFNI (http://afni.nimh.nih.gov) were employed to correct for multiple comparisons at cluster $p<0.05$. This corresponded to a cluster size > 39 voxels for a voxel threshold $p<0.004$ for the PCC seed ROI. Next, results of the whole-brain Fisher's z-transformation were then correlated with financial literacy, while controlling for age, education, sex, and global cognition using the same parameters for correction for multiple comparisons. Age, education, and sex are known to correlate with multiple outcomes in epidemiologic studies. Results were also adjusted for global cognition as this has been found to be associated with financial literacy (Bennett et al., 2012). Seed-based functional connectivity analysis was conducted with Resting-State fMRI Data Analysis Toolkit (REST: http://restfmri.net/forum/REST).

3. Results

Descriptive data for the sample of 138 participants who completed neuroimaging and financial literacy assessments are displayed in Table 1 next to descriptive data for participants that completed the financial literacy assessments but not neuroimaging.

Using a seed region of interest in the posterior cingulate cortex (MNI coordinates: x = 0, y = -53, z = 26, radius = 4mm) and adjusting for age, education, sex, and global cognition, significant functional connectivity clusters were observed in the right ventromedial prefrontal cortex, left caudate, right precuneus, right middle temporal gyrus, and left postcentral gyrus. Clusters in the right ventromedial prefrontal cortex, right precuneus, right middle temporal gyrus, and left postcentral gyrus were associated directly with financial literacy, while the cluster observed in the left caudate was associated inversely with financial literacy (Table 2, Figure 1).

Adjustment for multiple comparisons at a stricter cluster level ($p<0.0002$) revealed that clusters in the ventromedial prefrontal cortex (vmPFC), left caudate, left postcentral gyrus, and right precuneus were most significantly related to financial literacy when using a posterior cingulate cortex (PCC) seed region of interest (Figure 2). Scatterplots are presented for these four regions (Figure 3).

In post-hoc analyses, we ran linear regression models to investigate whether the significant functional connectivity relationships we observed (PCC-vmPFC, PCC-precuneus, PCC-postcentral, PCC-caudate) have independent associations with financial literacy. In models that adjusted for age, education, sex, and global cognition, functional connectivity pathways generally attenuated each other, and none fully accounts for the effect of the PCC-vmPFC, PCC-caudate, and PCC-precuneus pathways on financial literacy (Table 3). The functional connectivity of PCC-vmPFC accounted for more variation in financial literacy than the connectivity of the other three pathways in a model that included all four significant pathways, demographic factors, and global cognition.

4. Discussion

Our results show that functional connectivity between posterior cingulate cortex (PCC) and right ventromedial prefrontal cortex (vmPFC) is associated with greater financial literacy after adjusting for age, education, sex, and global cognition. Functional connectivity between the posterior cingulate cortex and two regions, the left postcentral gyrus and right precuneus, were also observed to be positively associated with financial literacy, whereas functional connectivity between the posterior cingulate cortex and left caudate was observed to be negatively associated with financial literacy. Finally we observed that three functional connectivity relationships (PCC-vmPFC, PCC-precuneus, PCC-caudate) were independently associated with financial literacy, though the PCC-vmPFC relationship accounted for most of the association in a model adjusted for all four significant functional connectivity relationships, demographic factors, and global cognition.

Financial literacy has been associated with multiple beneficial health and well-being outcomes, including better cognition, cognitive and physical activity, and ability to complete activities of daily living (Boyle et al., 2013; Bennett et al., 2012; James et al., 2012; Taylor et al., 2009). Because financial literacy is associated with beneficial outcomes in old age, we reasoned that financial literacy would be associated with greater functional connectivity of cortical anterior-posterior midline structures in resting-state fMRI findings. Specifically, we hypothesized that greater financial literacy would be associated with increased functional connectivity between the posterior cingulate cortex and some part of the ventromedial prefrontal cortex given this region’s well-established role in decision making (Fellows and Farah, 2007). The results of our study support this notion and expand the literature in three important ways.

The first important implication of the present results is in the meaning of this increased anterior-posterior cortical midline neural signature. Financial literacy is conceptualized as having specific knowledge of financial topics needed for optimal outcomes. This definition of financial literacy may be therefore viewed as the coordination of two subprocesses: (1) the retaining and access to prior learned contextual knowledge (in this case financially-related knowledge), and (2) the utilization and manipulation of that knowledge to provide the best answer to the questions posed. This two-subprocess viewpoint of financial literacy provides a potential theoretical rationale for the functional involvement of the posterior cingulate cortex with the ventromedial prefrontal cortex. The posterior cingulate cortex has direct structural and functional connectivity to hippocampal structures and has been implicated as a hub of an autobiographical subnetwork of the default network, which includes the precuneus, the medial and lateral parietal, and medial temporal lobe regions (Buckner et al., 2008). The ventromedial prefrontal cortex has direct and indirect connections to inferio-lateral frontal, anterior basal ganglia, insula, and dorsolateral prefrontal regions (Decety and Michalska, 2010), and has strong anatomical and functional connections to the posterior cingulate cortex (Buckner et al., 2008). The ventromedial prefrontal cortex, inferio-lateral frontal cortex, anterior cingulate, and dorsolateral prefrontal cortex comprise a network of regions involved in conscious and effortful processing of information stemming from internal mentation (Hurliman et al., 2005). Therefore those who perform better on the measure of financial literacy may have a greater functional integration between these two functional networks.

The second important contribution of the present study is the implication of changes in functional connectivity between posterior cingulate cortex and caudate structures as important for financial literacy. The caudate has multiple anatomical connections with dorsolateral prefrontal and ventral-anterior prefrontal cortex structures (Leh et al., 2007). Diminished functional connectivity values between the posterior cingulate and caudate structures were previously shown to be associated with mild cognitive impairment, and these values were found to be associated with measures of cognition in a separate sample (Han et al., 2011). Our study again points to the caudal structures as potentially important for aging. In the present study, functional connectivity values between the posterior cingulate cortex and left caudate were inversely associated with financial literacy while values between the posterior cingulate cortex and right ventromedial prefrontal cortex, postcentral gyrus, and precuneus were positively associated with financial literacy. While both the caudate and ventromedial prefrontal cortex have direct and indirect projections to frontal cortical structures, the ventromedial prefrontal cortex is believed to exert control over anterior basal ganglia structures. Because of this, it may be that greater connectivity of anterior-posterior medial brain regions has an effect of dampening or diminishing the functional role of the caudate in whole brain functional networks. We explored whether this was the case in post-hoc analyses, and our results suggest that these functional connectivity pathways are relatively independent. It should be noted, however, that our post-hoc results do not speak to whether there is an effect of *activity* of the ventromedial prefrontal cortex on the *activity* of the caudate, as activity and functional connectivity are conceptually and experimentally different properties. We further speculate that our observation of less connectivity between the posterior cingulate cortex and caudate structures when considering financial literacy may be linked in some way with the role of the basal ganglia in implicit learning (Stillman et al., 2013; Lieberman, 2000). It is feasible that basal-ganglia-mediated procedural knowledge may give way to higher-level explicit or declarative knowledge as financial literacy develops. Thus, as someone becomes explicitly knowledgeable in financial literacy matters, it is possible that less demand will be made on implicit processing networks, although both implicit and explicit processes are likely still involved in some capacity (Sun et al., 2001; Fisher et al., 2006; Destrebecqz et al., 2005). Future research is needed to clarify the role of the caudate in normal and pathological aging.

The third contribution of the present work is the observation that this neural signature is associated with financial literacy after considering the effects of global cognition. Financial literacy has often been conceptualized as being closely linked with cognitive functioning. While this link has been established in previous work from our group (Boyle et al., 2013; Bennett et al., 2012), it is interesting to note that neural correlates with financial literacy exist that are beyond the effects of global cognitive functioning. An implication of this finding is that financial literacy and cognitive functioning may be at least partially distinguishable constructs that may have some different neuroanatomical correlates. This may be particularly encouraging in that those who may be low in cognitive functioning may be able to show greater aptitude in financial literacy, and financial literacy may be amenable to alternate forms of intervention. Further work is needed to explore the specific associations and disassociations between cognitive ability and financial literacy, and under what conditions dissociations occur.

It should be noted that the neuroimaging results we observed may not be specific to financial literacy per se, but may also apply to the application of other complex knowledge areas. This is consistent with reports of an apparent association of anterior-posterior functional connectivity values with performance on cognitive measures (Wang et al., 2013). Applied knowledge areas that require the coordination of multiple neural subsystems may be more sensitive to neural disease progression than other more specific disease considerations since they require efficient and intact processing of all components of the systems involved. Brain processing associated with the application of multiple knowledge areas may be broader in scope, and therefore any disturbance in the subcomponents of a system might manifest in a deterioration of functional connectivity between anterior-posterior medial brain regions since access and utilization of information might be coordinated between these network hubs. Future studies are needed to examine whether there is support for this viewpoint.

Limitations of the present study include the selected nature of the sample. The sample was highly selected from the parent study and selection factors could account for some of the variance that we observed in our study, thus potentially limiting the generalizability of results. Another limitation was the majority of the sample being female. As has been previously reported, females exhibit lower financial literacy (Lusardi and Mitchell, 2011b; Lusardi and Mitchell, 2008). Furthermore, we were not able to compare our results to a younger cohort to investigate directly any effects of aging. These likely have implications for the generalizability of our results, and future studies are needed to explore the present set of findings in cohorts with greater male and younger persons represented. Also, the direction of the causality in the observed associations is unclear. The most compelling support for the assertion that greater financial literacy leads to strengthened anterior-posterior medial brain functional connectivity would have come from a longitudinal model showing an increase in financial literacy resulting in a later increase in functional connectivity. It could be that persons with greater anterior-posterior functional connectivity may be more predisposed to be financially literate. Another limitation of the present study is the lack of real-word indicators of financial success. However, many items from the measure of financial literacy have been linked to real-world financial outcomes (Lusardi and Mitchell, 2011a), and this measure is associated with a number of positive factors that are generally associated with financial success, such as cognition, cognitive and physical activity, activities of daily living, mental health, and decision making (Bennett et al., 2012; James et al., 2012).

Strengths of the present study include the utilization of a community-based sample, large sample size, and the control of multiple characteristics – such as age, education, gender, and global cognition – that may be associated with financial literacy and brain network analyses. Our results suggest financial literacy is associated with a functional brain signature that may be important to successful aging. Future studies are needed to examine the temporal direction of this relationship, and if found that financial literacy is associated with anterior-posterior medial brain region functional connectivity, determine whether poorer financial literacy may be associated with greater Alzheimer's disease pathology. If so, then change in this neural signature may serve as a potential biomarker for impending Alzheimer's disease. The implication that financial literacy may be associated with specific neural signatures also suggests the possibility that targeted pharmacological or behavioral interventions that can modify the neural signatures might also have an effect on the ability to develop or maintain financial literacy. Furthermore, the development of methods to improve financial literacy could also have the effect of increasing anterior-posterior functional connectivity in the brain, which may arguably facilitate greater cognitive reserve. Consistent with this idea, our group has noted that the beneficial effects of financial literacy on decision making is stronger in persons with lower cognition (James et al., 2012). Future studies are needed to support these viewpoints. To our knowledge, this is the first neuroimaging study of financial literacy in old age.

Acknowledgments

This research was supported by National Institute on Aging grants R01AG17917, R01AG33678, K23AG40625, the American Federation for Aging Research, the Illinois Department of Public Health, and The Marsha K. Dowd Philanthropic Fund. The authors gratefully acknowledge the assistance of Dr. Randy Buckner, Dr. Gary Glover, and Dr. Jeffrey Rosengarten with this project. We thank Niranjini Rajendran, MS, and Woojeong Bang, MS, for image post-processing and statistical analyses. We also thank the Rush Memory and Aging Project staff and participants.

APPENDIX

Financial literacy assessment (note question 9 counts as 4 points)

1. *Question:* Which of these percentages represents the biggest risk of getting a disease?

1 1%

2 10%

3 5%

78.99% of sample got this item correct.

2. *Question:* A store is offering 15% off a television that is normally priced at USD 1,000.

How much money would you save on the TV during this sale?

1 15

2 150

3 1,500

50.72% of sample got this item correct.

3. *Question:* If a television set is on sale for USD 899, which is USD 200 off its normal price, what is the normal price?

1 USD 699

2 USD 1,099

3 USD 1,299

81.02% of sample got this item correct.

4. *Question:* If 5 people all have the winning numbers in the lottery and the prize is USD 2 million, how much will each of them receive?

1 USD 200,000

2 USD 400,000

3 USD 600,000

93.48% of sample got this item correct.

5. *Question:* If the chance of getting a disease is 10%, how many people out of 1,000 would be expected to get the disease?

1 100

2 10

3 90

4 900

67.39% of sample got this item correct.

6. *Question:* Suppose you had USD 100 in a savings account and the interest rate was 2% per year. After 5 years, how much do you think you would have in the account if you left the money to grow: more than USD 102, exactly USD 102, or less than USD 102?

1 more than USD 102

2 Exactly USD 102

3 Less than USD 102

78.99% of sample got this item correct.

7. *Question:* Again, suppose you had USD 100 in a savings account and the interest rate was 2% per year. After 5 years, how much do you think you would have in the account if you left the money to grow: more than USD 110, exactly USD 110, or less than USD 110?

1 more than USD 110

2 Exactly USD 110

3 Less than USD 110

95.83% of sample got this item correct.

8. *Question:* Imagine that the interest rate on your savings account is 1% per year and inflation is 2% per year. After 1 year, will you be able to buy more than, exactly the same as, or less than today with the money in your account?

1 More than today

2 Exactly the same as today

3 Less than today

50.00% of sample got this item correct.

9–12. *Question:* What do the initials FDIC stand for?

1 Federal

2 Deposit

3 Insurance

4 Corporation

37.50% of sample got the “Federal” item correct.

33.33% of sample got the “Deposit” item correct.

75.00% of sample got the “Insurance” item correct.

69.57% of sample got the “Corporation” item correct.

13. *Question:* What does the FDIC do?

1 Approves new drugs for clinical use

2 Protects the funds people or depositors place in banks and savings Institutions

3 Underwrites mortgages and other loans

79.71% of sample got this item correct.

14. *Question:* A mutual fund is an investment that holds what – only stocks, only bonds, or stocks AND bonds?

1 Only stocks

2 Only bonds

3 Stocks and bonds

86.23% of sample got this item correct.

15. *Question:* When interest rates go up, what do bond prices do: go down, go up, or stay the same?

1 Go down

2 Go up

3 Do not change

85.51% of sample got this item correct.

16. *Question:* True or false. Buying a single company stock usually provides a better return than a stock mutual fund.

1 True

2 False

74.64% of sample got this item correct.

17. *Question:* True or false. An older person with USD 100,000 to invest should hold riskier financial investments than a younger person with USD 100,000 to invest.

1 True

2 False

87.68% of sample got this item correct.

18. *Question:* True or false. Using money in a bank account to pay off credit card debt is usually wise.

1 True

2 False

94.20% of sample got this item correct.

19. *Question:* True or false. To make money in the stock market, you have to buy and sell stocks often.

1 True

2 False

83.33% of sample got this item correct.

20. *Question:* True or false. Stocks and mutual funds generally produce higher average returns above inflation compared to fixed-income investments such as bonds.

1 True

2 False

47.83% of sample got this item correct.

21. *Question:* Imagine you receive a gift of USD 10,000. If you were to invest the money on your own for the next 5 years, what percentage on average do you think you could earn per year? Please provide a number from 0 to 100.

91.30% of sample got this item correct.

22. *Question:* Again, imagine you receive a gift of USD 10,000. If you were to invest the money in a government bond, what percentage on average do you think you could earn per year? Please provide a number from 0 to 100.

69.57% of sample got this item correct.

23. *Question:* Again, imagine you receive a gift of USD 10,000. If you were to invest the money in a mutual fund, what percentage on average do you think you would earn per year? Please provide a number from 0 to 100.

86.96% of sample got this item correct.

References

1. Ainslie G. Specious reward: A behavioral theory of impulsiveness and impulse control. Psychological Bulletin. 1975; 82:463–496. [PubMed: 1099599]

NIH-PA Author Manuscript

NIH-PA Author Manuscript

NIH-PA Author Manuscript

NIH-PA Author Manuscript

2. Allman JM, Tetreault NA, Hakeem AY, Manaye KF, Semendeferi K, Erwin JM, Park S, Goubert V, Hof PR. The von Economo neurons in frontoinsular and anterior cingulate cortex in great apes and humans. Brain Structure and Function. 2010; 214:495–517. [PubMed: 20512377]
3. Bajo R, Maestu F, Nevado A, et al. Functional connectivity in mild cognitive impairment during a memory task: implications for the disconnection hypothesis. J Alzheimers Dis. 2010; 22(1):183–193. [PubMed: 20847450]
4. Bennett DA, Schneider JA, Buchman AS, Barnes LL, Boyle PA, Wilson RS. Overview and findings from the rush Memory and Aging Project. Curr Alzheimer Res. 2012; 9(6):646–663. [PubMed: 22471867]
5. Bennett JS, Boyle PA, James BD, Bennett DA. Correlates of health care financial literacy in older adults without dementia. BMC Geriatrics. 2012; 12:30. [PubMed: 22691341]
6. Bennett DA, Schneider JA, Arvanitakis Z, Kelly JF, Aggarwal NT, Shah RC, et al. Neuropathology of older person without cognitive impairment from two community-based studies. Neurology. 2006; 27:1837–1844. [PubMed: 16801647]
7. Bennett DA, Wilson RS, Schneider JA, Evans DA, Beckett LA, Aggarwal NT, et al. Natural history of mild cognitive impairment in older persons. Neurology. 2002; 59:198–205. [PubMed: 12136057]
8. Bickel WK, Miller ML, Yi R, Kowal BP, Lindquist DM, Pitcock JA. Behavioral and neuroeconomics of drug addiction: Competing neural systems and financial literacy processes. Drug and Alcohol Dependence. 2007; 908:S85–S91. [PubMed: 17101239]
9. Blakemore S-J, Robbins TW. Decision-making in the adolescent brain. Nature Neuroscience. 2012; 15:1184–1191.
10. Boyle PA, Wilson RS, Aggarwal NT, Arvanitakis Z, Kelly J, Bienias JL, Bennett DA. Parkinsonian signs in subjects with mild cognitive impairment. Neurology. 2005; 65:1901–1906. [PubMed: 16380610]
11. Boyle PA, Yu L, Segawa E, Wilson RS, Buchman AS, Laibson DI, Bennett DA. Association of cognition with financial literacy in community based older persons. BMC Geriatrics. 2012; 12:48. [PubMed: 22938391]
12. Boyle PA, Yu L, Wilson RS, Segawa E, Buchman AS, Bennett DA. Cognitive decline impairs financial and health literacy among community-based older persons without dementia. Psychology and Aging. 2013; 28:614–624. [PubMed: 23957225]
13. Braunstein S, Welch C. Financial literacy: an overview of practice, research, and policy. Fed Reserve Bull. 2002; 88:445.
14. Bucher-Koenen T, Ziegelmeyer M. Once burned, twice shy? Financial literacy and wealth losses during the financial crisis. Review of Finance. 2013 Epub Ahead of Print. doi:10.1093/rof/rft052.
15. Buckner RL, Krienen FM, Castellanos A, Diaz JC, Yeo BTT. The organization of the human cerebellum estimated by intrinsic functional connectivity. J Neurophysiology. 2011; 106:2322–2345.
16. Buckner RL, Synder AZ, Shannon BJ, LaRossa G, Sachs R, Fotenos AF, Sheline YI, Klunk WE, Mathis CA, Morris JC, Mintun MA. Molecular, structural, and functional characterization of Alzheimer's disease: Evidence for a relationship between default activity, amyloid, and memory. J Neurosci. 2005; 25:7709–7717. [PubMed: 16120771]
17. Buckner RL, Andrews-Hanna JR, Schacter DL. The brain's default network: anatomy, function, and relevance to disease. N Y Acad Sci. 2008; 1124:1–38.
18. Cardinal RN, Pennicott DR, Sugathapala CL, Robbins TW, Everitt BJ. Impulsive choice induced in rats by lesions of the nucleus accumbens core. Science. 2001; 292:2499–2501. [PubMed: 11375482]
19. Christakou A, Brammer M, Rubia K. Maturation of limbic corticostriatal activation and connectivity associated with developmental changes in financial literacy. NeuroImage. 2011; 54:1344–1354. [PubMed: 20816974]
20. Decety J, Michalska KJ. Neurodevelopmental changes in the circuits underlying empathy and sympathy from childhood to adulthood. Developmental Science. 2010; 13:886–899. [PubMed: 20977559]
21. Destrebecqz A, Peigneux P, Laureys S, Degueldre C, Fiore GD, Aerts J, Luxen A, Van Der Liden M, Cleeremans A, Maquet P. The neural correlates of implicit and explicit sequence learning:

Interacting networks revealed by the process dissociation procedure. Learning and Memory. 2005; 12:480–490. [PubMed: 16166397]

22. Fellows LK, Farah MJ. The role of the ventromedial prefrontal cortex in decision making: Judgment under uncertainty or judgment per se? Cerebral Cortex. 2007; 17:2669–2674. [PubMed: 17259643]
23. Finke; Michael, S.; Howe; John, S.; Huston; Sandra, J. [August 24, 2011] Old Age and the Decline in Financial Literacy. Available at SSRN: http://ssrn.com/abstract=1948627http://dx.doi.org/10.2139/ssrn.1948627
24. Fisher S, Drosopoulos S, Tsen J, Born J. Implicit learning-explicit knowing: A role for sleep in memory system interaction. Journal of Cognitive Neuroscience. 2006; 18:311–319. [PubMed: 16602193]
25. Frederick S, Loewenstein G, O'Donoghue T. Time discounting and time preference: a critical review. J Econ Lit. 2002; 40:351–401.
26. Gottwalk B, Wilde B, Mihajlovic Z, Mehdorn HM. Evidence for distinct cognitive deficits after focal cerebellar lesions. JNNP. 2004; 75:1524–1531.
27. Greicius MD, Srivastava G, Reiss AL, Menon V. Default-mode network activity distinguishes Alzheimer's disease from healthy aging: Evidence from functional MRI. Proc Natl Acad Sci. 2004; 101:4637–4642. [PubMed: 15070770]
28. Hariri AR, Brown SM, Williamson DE, Flory JD, de Wit H, Manuck SB. Preference for immediate over delayed rewards is associated with magnitude of ventral striatal activity. J Neuroscience. 2006; 26:13213–13217.
29. Hilgert MA, Hogarth JM, Beverly SG. Household financial management: the connection between knowledge and behavior. Fed Reserve Bull. Jul.2003 309:322.
30. Hurliman E, Nagode JC, Pardo JV. Double dissociation of exteroceptive and interoceptive feedback systems in the orbital and ventromedial prefrontal cortex of humans. Journal of Neuroscience. 2005; 25:4641–4648. [PubMed: 15872112]
31. James BD, Boyle PA, Bennett JS, Bennett DA. The impact of health and financial literacy on decision making in community-based older adults. Gerontology. 2012; 58:531–539. [PubMed: 22739454]
32. Johnson MW, Bickel WK. Within-subject comparison of real and hypothetical money rewards in delay discounting. Journal of the Experimental Analysis of Behavior. 2002; 77:129–146. [PubMed: 11936247]
33. Kable JW, Glimcher PW. The neural correlates of subjective value during intertemporal choice. Nat Neuroscience. 2007; 10:1625–1633.
34. Kable JW, Glimcher PW. An "as soon as possible" effect in human inter-temporal decision making: Behavioral evidence and neural mechanisms. J Neurophysiology. 2010; 103:2513–2531.
35. Kirby KN. Bidding on the future: evidence against normative discounting of delayed rewards. J Exp Psychol. 1997; 126(1):54–70.
36. Kirby KN, Petry NM, Bickel WK. Heroin addicts have higher discount rates for delayed rewards than non-drug-using controls. J Exp Psychol. 1999; 128:78–87.
37. Kishinevsky FI, Cox JE, Murdaugh DL, Stoeckel LE, Cook EW, Weller RE. fMRI reactivity on a delay discounting task predicts weight gain in obese women. Appetite. 2012; 58:582–592. [PubMed: 22166676]
38. Leh SE, Ptito A, Charkravarty MM, Strafella AP. Fronto-striatal connections in the human brain: a probabilistic diffusion tractography study. Neurosci Lett. 2007; 419(2):113–118. [PubMed: 17485168]
39. Leon-Carrion J, Leon-Domiguez U, Pollonini L, Wu M-H, Frye RE, Dominguez-Morales MR, Zouridakis G. Synchronization between the anterior and posterior cortex determines consciousness level in patients with traumatic brain injury (TBI). Brain Research. 2012; 1476:22–30. [PubMed: 22534483]
40. Levy H, Weir DR. Take-up of Medicare Part D: results from the Health and Retirement Study. J Gerontol B Psychol Sci Soc Sci. 2010; 65(4):492–501. [PubMed: 20034992]

41. Liang P, Wang Z, Yang Y, Jia X, Li K. Functional disconnection and compensation in mild cognitive impairment: evidence from DLPFC connectivity using resting-state fMRI. PLoS ONE. 2011; 6(7):e22153. [PubMed: 21811568]
42. Lieberman MD. Intuition: A social cognitive neuroscience approach. Psychological Bulletin. 2000; 126(1):109–137. [PubMed: 10668352]
43. Lusardi A, Mitchell OS. Baby boomer retirement security: the roles of planning, financial literacy, and housing wealth. J Monet Econom. 2007a; 54:205–224.
44. Lusardi A, Mitchell OS. Financial literacy and retirement preparedness: evidence and implications for financial education. Business Econom. 2007b; 42:35–44.
45. Lusardi A, Mitchell OS. Planning and financial literacy: How do women fare? American Economic Review. 2008; 98:413–417.
46. Lusardi, A.; Mitchell, OS. Financial literacy and planning: implications for retirement wellbeing. In: Mitchell, OS.; Lusardi, A., editors. Financial Literacy. Implications for Retirement Security and the Financial Marketplace. Oxford University Press, Inc.; New York, NY: 2011a. p. 17-39.
47. Lusardi A, Mitchell OS. Financial literacy and retirement planning in the United States. Journal of Pension Economics and Finance. 2011b; 10:509–525.
48. Lusardi A, Mitchell OS. The economic importance of financial literacy: Theory and evidence. Journal of Economic Literature. 2014; 52:5–44.
49. Neufang S, Akhrif A, Riedl V, et al. Disconnection of frontal and parietal areas contributes to impaired attention in very early Alzheimer's disease. J Alzheimers Dis. 2011; 25(2):309–321. [PubMed: 21422523]
50. Ries ML, Jabbar BM, Schmitz TW, Trivedi MA, Gleason CE, Carlsson CM, Rowley HA, Asthana S, Johnson SC. Anosognosia in mild cognitive impairment: Relationship to activation of cortical midline structures involved in self-appraisal. JINS. 2007; 13:450–461. [PubMed: 17445294]
51. Sanz-Arigita EJ, Schoonheim MM, Damoiseaux JS, et al. Loss of 'small-world' networks in Alzheimer's disease: graph analysis of FMRI resting-state functional connectivity. PLoS ONE. 2010; 5(11):e13788. [PubMed: 21072180]
52. Stam CJ, Jones BF, Manshanden I, et al. Magnetoencephalographic evaluation of resting-state functional connectivity in Alzheimer's disease. Neuroimage. 2006; 32(3):1335–1344. [PubMed: 16815039]
53. Stillman CM, Gordon EM, Simon JR, Vaidya CJ, Howard DV, Howard JH Jr. Caudate resting connectivity predicts implicit probabilistic sequence learning. Brain Connectivity. 2013; 3:601–610. [PubMed: 24090214]
54. Sun R, Merrill E, Peterson T. From implicit skills to explicit knowledge: A bottom-up model of skill learning. Cognitive Science. 2001; 25:203–244.
55. Taylor M, Jenkins S, Sacker A. Financial capability and wellbeing. Evidence from the BHPS. 2009 Financial Services Authority.
56. Van Dijk KRA, Hedden T, Venkataraman A, Evans KC, Lazar SW, Buckner RL. Intrinsic functional connectivity as a tool for human connectomics: Theory, properties, and optimization. J Neurophysiol. 2010; 103:297–321. [PubMed: 19889849]
57. Wang K, Liang M, Wang L, et al. Altered functional connectivity in early Alzheimer's disease: a resting-state fMRI study. Human Brain Mapping. 2007; 28(10):967–978. [PubMed: 17133390]
58. Wang L, Li H, Liang Y, Zhang J, Li X, Shu N, Wang YY, Zhang ZJ. Amnestic mild cognitive impairment: topological reorganization of the Default-Mode Network. Radiology. 2013 doi: 10.1148/radiol.13121573.
59. Whittman M, Lovero KL, Lane SD, Paulus M. Now or later? Striatum and insula activation to immediate versus delayed rewards. Journal of Neuroscience, Psychology, and Economics. 2010; 3:15–26.
60. Wible CG. Hippocampal temporal-parietal junction interaction in the production of psychotic symptoms: a framework for understanding the schizophrenic syndrome. Frontiers in Human Neuroscience. 2012; 6:1–30. [PubMed: 22279433]
61. Wilson RS, Barnes LL, Bennett DA. Assessment of lifetime participation in cognitively stimulating activities. Journal of Clinical and Experimental Neuropsychology. 2003; 25:634–642. [PubMed: 12815501]

62. Yerys B, Abrams DN, Gordon EM, Weinblatt R, Jankowski KF, Strang JF, Kenworthy L, Schultz RT, Vaidya CJ, Gaillard WD. Increased connectivity in children with autism spectrum disorders: Evidence consistent with poor network segregation. Oral presentation on May. 2012; 17:2012. at the annual meeting of the International Society for Autism Research (ISAR)

NIH-PA Author Manuscript
NIH-PA Author Manuscript

Highlights

- Financial literacy was associated with brain region functional connectivity.
- Functional connectivity of the PCC-vmPFC accounted for the most variance.
- Results occurred beyond the effects of demographics and cognitive abilities.

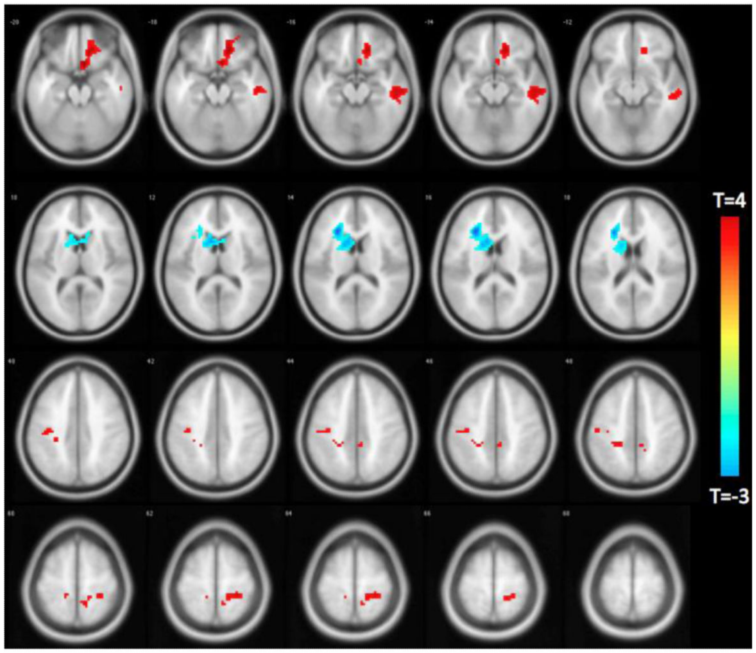

Figure 1.

Functionally connected clusters associated with financial literacy after adjusting for age, education, sex, and global cognition, as indicated by a seed region of interest (ROI) prescribed in the posterior cingulate cortex. Seed ROI MNI coordinates: x = 0, y = -53, z = 26; radius = 4 mm; voxel $p < 0.004$; cluster size > 39 voxels. Corrected for multiple comparisons using AlphaSim Monte Carlo simulations at a cluster level threshold of $p<0.05$. Values shown in scale correspond to t-scores.

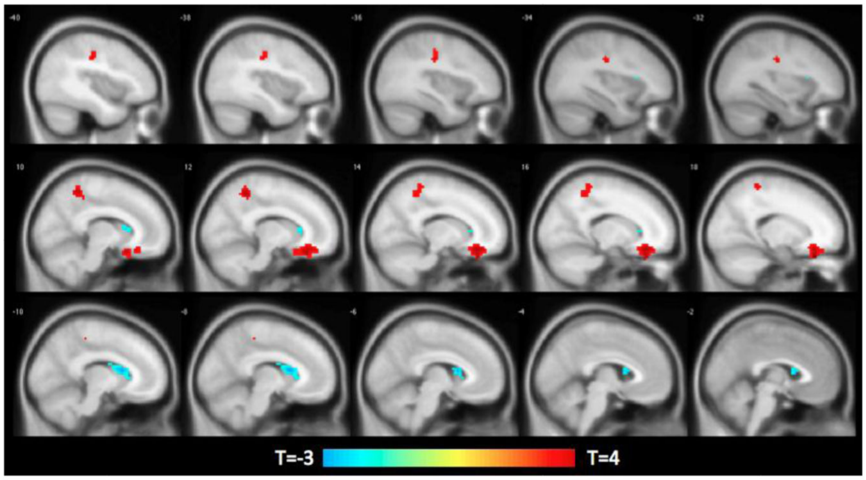

Figure 2.

Functionally connected clusters associated with financial literacy after adjusting for age, education, sex, and global cognition, as indicated by a seed region of interest (ROI) prescribed in the posterior cingulate cortex. Seed ROI MNI coordinates: x = 0, y = -53, z = 26; radius = 4 mm; voxel p < 0.004. Corrected for multiple comparisons using AlphaSim Monte Carlo simulations at a cluster level threshold of p<0.0002 (cluster size > 75 voxels). Values shown in scale correspond to t-scores.

NIH-PA Author Manuscript
NIH-PA Author Manuscript

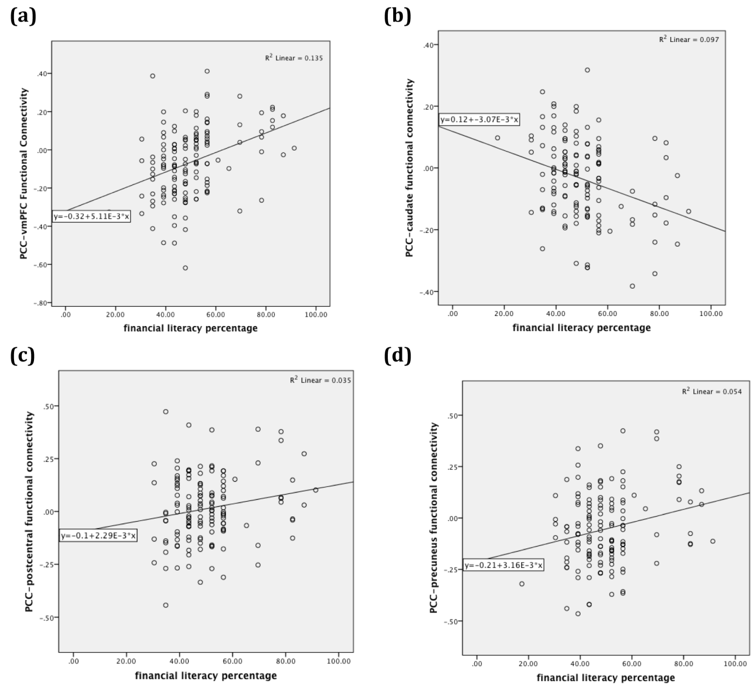

Figure 3.

Scatterplot of financial literacy percentage correct and Fisher's z-transformed functional connectivity values between the seed region of interest (ROI) in the posterior cingulate cortex (MNI coordinates: x = 0, y = -53, z = 26; radius = 4 mm) and maximum intensity voxels in the (a) right ventromedial prefrontal cortex cluster, (b) left caudate cluster, (c) left postcentral gyrus, and (d) right precuneus cluster.

Table 1

Demographic and cognitive variables for the financial literacy sample

	Imaging sample (*n* = 138)	**Non-imaging sample (*n* = 392)**
Age (years)		
Mean (*SD*)	82.09 (7.20)	83.18 (7.56)
Range	60 – 98	58-100
Education (years)*		
Mean (*SD*)	15.70 (3.30)	14.91 (2.92)
Range	8 – 28	7-28
Sex (% Female)	80.4% (*n* = 111)	74.5% (*n* = 292)
Race (% White)*	98.6% (*n* = 136)	89.3% (*n* = 349)
MMSE (total score)*		
Mean (*SD*)	28.60 (1.49)	27.98 (2.11)
Range	23 – 30	16-30
Global Cognition Z-score*		
Mean (*SD*)	0.36 (0.49)	0.21 (0.57)
Range	−1.18 – 1.45	−1.61 – 1.56
Income Category When Enrolled		
Median Interval	8	8
Range	1-10	1-10
Financial Literacy Percentage*		
Mean (*SD*)	50.13 (13.15)	54.30 (18.34)
Range	17.39 – 91.30	4.35-100

Note: Data are summarized as Mean (standard deviation = *SD*), unless otherwise indicated. Income categories: (1) USD 0–4,999, (2) USD 5,000–9,999, (3) USD 10,000–14,999, (4) USD 15,000–19,999, (5) USD 20,000–24,999, (6) USD 25,000–29,999, (7) USD 30,000–34,999, (8) USD 35,000–49,999, (9) USD 50,000–74,999, (10) USD > 75,000. The non-imaging cohort refers to older adults who completed the financial literacy measure but did not undergo neuroimaging.

*indicates significant difference of $p<0.05$.

NIH-PA Author Manuscript
NIH-PA Author Manuscript

Table 2

Functionally connected clusters associated with financial literacy, as indicated by a seed region of interest (ROI) prescribed in the posterior cingulate cortex cortex (MNI coordinates: x = 0, y = −53, z = 26, radius = 4mm; voxel p < 0.004; cluster size > 39 voxels), adjusting for age, education, sex, and global cognition. Corrected for multiple comparisons using AlphaSim Monte Carlo simulations at a cluster level threshold of p<0.05.

Seed ROI	Region of Maximum Intensity Voxel	Maximum Intensity Voxel Coordinates (MNI)			Cluster Size	t-value
		X	Y	Z	(# of voxels)	
PCC						
	Rventromedial prefrontal	18	36	−27	87	4.5059
	L caudate	−24	27	15	224	−4.8298
	R precuneus	12	−48	54	86	3.7089
	R middle temporal	51	−18	−15	73	3.5426
	L postcentral	−36	−21	36	88	3.4467

NIH-PA Author Manuscript
NIH-PA Author Manuscript

Table 3

Linear regression models to determine the independence of the associations of functional connectivity values of significant pathways (PCC-vmPFC, PCC-caudate, PCC-precuneus) with financial literacy. Model 0 (Core Model) included age, education, sex, and cognition, but no functional connectivity values. Model 1 included the PCC-vmPFC functional connectivity values. Model 2 included the PCC-caudate functional connectivity values. Model 3 included PCC-postcentral functional connectivity values. Model 4 included PCC-precuneus functional connectivity values. Model 5 included PCC-vmPFC and PCC-caudate functional connectivity values. Model 6 included PCC-vmPFC and PCC-postcentral functional connectivity values. Model 7 included PCC-vmPFC and PCC-precuneus functional connectivity values. Model 8 included PCC-caudate and PCC-postcentral functional connectivity values. Model 9 included PCC-caudate and PCC-precuneus functional connectivity values. Model 10 included PCC-postcentral and PCC-precuneus functional connectivity values. Model 11 included PCC-vmPFC, PCC-caudate and PCC-postcentral functional connectivity values. Model 12 included PCC-vmPFC, PCC-caudate and PCC-precuneus functional connectivity values. Model 13 included PCC-vmPFC, PCC-postcentral and PCC-precuneus functional connectivity values. Model 14 included PCC-caudate, PCC-postcentral and PCC-precuneus functional connectivity values. Model 15 included PCC-vmPFC, PCC-caudate, PCC-postcentral, and PCC-precuneus functional connectivity values.

Model	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**
N	**138**															
Adjusted R^2	0.0682	0.1867	0.1897	0.1110	0.1504	0.2715	0.2163	0.2743	0.1980	0.2258	0.1665	0.2772	0.3181	0.2813	0.2267	0.3168
Statistical Values	**β (SE, p-value)**															
Intercept	47.5682 (1.5673, 0.000)	49.0445 (1.5004, 0.000)	45.9656 (1.5029, 0.000)	47.4944 (1.5312, 0.000)	48.4981 (1.5173, 0.000)	47.4543 (1.4735, 0.000)	48.9028 (1.4739, 0.000)	50.0174 (1.4369, 0.000)	46.0948 (1.4976, 0.000)	46.9039 (1.5104, 0.000)	48.3196 (1.5058, 0.000)	47.5418 (1.4690, 0.000)	48.5799 (1.4694, 0.000)	49.8324 (1.4351, 0.000)	46.9200 (1.5096, 0.000)	48.5704 (1.4709, 0.000)
Age	−0.3445 (0.1572, 0.030)	−0.2046 (0.1501, 0.175)	−0.3436 (0.1466, 0.021)	−0.4059 (0.1552, 0.010)	−0.4278 (0.1518, 0.006)	−0.2252 (0.1422, 0.116)	−0.2642 (0.1493, 0.079)	−0.2876 (0.1432, 0.047)	−0.3783 (0.1476, 0.011)	−0.4034 (0.1450, 0.006)	−0.4592 (0.1512, 0.003)	−0.2579 (0.1434, 0.075)	−0.2850 (0.1388, 0.042)	−0.3158 (0.1437, 0.030)	−0.4228 (0.1461, 0.004)	−0.3012 (0.1402, 0.034)
Sex	5.6321 (2.9232, 0.056)	3.5393 (2.7701, 0.204)	7.1390 (2.7458, 0.010)	4.1625 (2.9061, 0.154)	6.9760 (2.8145, 0.014)	5.1422 (2.6516, 0.055)	2.4027 (2.7585, 0.385)	4.8799 (2.6369, 0.066)	6.1490 (2.8063, 0.030)	7.8439 (2.6968, 0.004)	5.7694 (2.8602, 0.046)	4.3056 (2.7056, 0.114)	5.8134 (2.5740, 0.026)	4.0482 (2.6813, 0.134)	7.0991 (2.7836, 0.012)	5.2756 (2.6512, 0.049)
Education	−0.0879 (0.3726, 0.814)	−0.0342 (0.3483, 0.922)	0.0796 (0.3494, 0.820)	−0.0000 (0.3654, 1.000)	−0.0534 (0.3559, 0.881)	0.1003 (0.3313, 0.763)	0.0376 (0.3432, 0.913)	0.0019 (0.3291, 0.995)	0.1113 (0.3482, 0.750)	0.0758 (0.3415, 0.825)	0.0030 (0.3538, 0.993)	0.1278 (0.3306, 0.700)	0.0971 (0.3205, 0.762)	0.0422 (0.3286, 0.898)	0.0982 (0.3420, 0.775)	0.1138 (0.3214, 0.724)
Global Cognition	4.0349 (2.4489, 0.102)	5.7372 (2.3188, 0.015)	4.1982 (2.2839, 0.068)	4.4292 (2.3964, 0.067)	3.9764 (2.3384, 0.091)	5.6162 (2.1948, 0.012)	5.9811 (2.2783, 0.010)	5.7038 (2.1904, 0.010)	4.4033 (2.2761, 0.055)	4.1285 (2.2327, 0.067)	4.2589 (2.3210, 0.069)	5.7719 (2.1890, 0.009)	5.6183 (2.1234, 0.009)	5.8567 (2.1821, 0.008)	4.2769 (2.2357, 0.058)	5.7114 (2.1282, 0.008)
PCC-vmPFC		26.0601 (5.7740, 0.000)				22.0793 (5.5528, 0.000)	24.6647 (5.6964, 0.000)	26.4627 (5.4551, 0.000)				21.6897 (5.5378, 0.000)	23.3157 (5.3862, 0.000)	25.5670 (5.4610, 0.000)		23.0144 (5.4030, 0.000)

Model	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
PCC-caudate			−36.4456 (7.9647, 0.000)			−31.0370 (7.6738, 0.000)			−32.5605 (8.3161, 0.000)	−30.2379 (8.1240, 0.000)		−27.7109 (7.9917, 0.001)	−23.8390 (7.7662, 0.003)		−28.0217 (8.3791, 0.001)	−22.2433 (7.9918, 0.006)
PCC-postcentral				18.6890 (6.8739, 0.007)			15.8788 (6.4862, 0.016)		10.5463 (6.8518, 0.126)		13.0076 (6.8985, 0.062)	9.2879 (6.5130, 0.156)		9.7305 (6.4441, 0.133)	7.3431 (6.8575, 0.286)	5.5613 (6.4592, 0.391)
PCC-precuneus					21.9623 (5.8984, 0.000)			22.4367 (5.4523, 0.000)		15.7143 (5.8755, 0.008)	18.9588 (6.0554, 0.002)		17.4545 (5.5287, 0.002)	20.1738 (5.6290, 0.000)	14.4767 (5.9849, 0.017)	16.4947 (5.6454, 0.004)