Neurocognitive Mechanisms Associated with Real-world Financial Savings among Individuals from Lower Income Households

Ranjita Poudel
Florida International University, rpoud001@fiu.edu

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FLORIDA INTERNATIONAL UNIVERSITY
Miami, Florida

NEUROCOGNITIVE MECHANISMS ASSOCIATED WITH REAL-WORLD FINANCIAL SAVINGS AMONG INDIVIDUALS FROM LOWER INCOME HOUSEHOLDS

A dissertation submitted in partial fulfillment of the requirements for the degree of DOCTOR OF PHILOSOPHY in COGNITIVE NEUROSCIENCE by Ranjita Poudel

2021
To: Dean Michael R. Heithaus  
College of Arts, Science and Education

This dissertation, written by Ranjita Poudel, and entitled Neurocognitive Mechanisms Associated with Real-world Financial Savings among Individuals from Lower Income Households, having been approved in respect to style and intellectual content, is referred to you for judgment.

We have read this dissertation and recommend that it be approved.

_______________________________________
Angela R. Laird

_______________________________________
Raul Gonzalez

_______________________________________
Michelle Hospital

_______________________________________
Matthew T. Sutherland, Major Professor

Date of Defense: July 21, 2021

The dissertation of Ranjita Poudel is approved.

_______________________________________
Dean Michael R. Heithaus  
College of Arts, Science and Education

_______________________________________
Andrés G. Gil  
Vice President for Research and Economic Development and Dean of the University Graduate School

Florida International University, 2021
DEDICATION

This is dedicated to Shiva, my patient husband, and my wonderful daughter, Aurora.
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Special thanks to:

Dr. Matthew T. Sutherland, my mentor, advisor, and extremely talented
Committee members:
Dr. Angela R. Laird
Dr. Raul Gonzalez
Dr. Michelle Hospital

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Lower financial savings among individuals experiencing adverse social determinants of health (SDoH) such as low socioeconomic status (low-SES) increases health inequities during times of crisis. Despite evidence suggesting that economic stability established by better money-saving behavior may minimize socioeconomic disparities, neurocognitive mechanisms that regulate money-saving behavior remains to be understood. In the current studies, we utilized neuroimaging, behavioral, self-report, and real-world behavior data to examine neurocognitive mechanisms associated with money-saving behavior among low-SES population. In study 1, we utilized the Balloon Analogue Risk task (BART) to probe decision-making (DM) related brain activity and further examined the relationship between brain activity, BART-performance, and real-world money-saving behavior. In study 2, we utilized n-back task to probe working memory (WM) mechanism and characterized the relationship between WM-related brain activity, WM-performance, and money-saving behavior. In study 3, we utilized resting-state fMRI data to characterize the resting-state functional connectivity (rsFC) of the brain regions associated with WM and their
relationship with money-saving behavior. Regarding DM related brain-behavior relationship, elevated risk-related amygdala activity was associated with improved strategic-DM (i.e., BART task-performance measure) and improved strategic-DM, in turn, predicted better savings. Additionally, in an exploratory analysis, personality trait (i.e., alexithymia) moderated this mediation such that for individuals with low alexithymia (versus higher alexithymia), elevated risk-related amygdala activity was associated with better savings. Regarding WM-related brain activity and associated behavior, laboratory WM-performance (dprime) mediated the association between WM-related DMN deactivation and real-world savings behavior such that increased DMN deactivation improves dprime which, in turn, results in better savings. Further, considering the rsFC of brain regions related to WM and associated behavior, dprime mediated the effect of fronto-limbic and fronto-frontal connectivity on real-world saving behavior such that higher frontal-limbic connectivity predicted worsened WM performance, which in turn, predicted reduced savings. Similarly, higher fronto-frontal connectivity predicted better WM performance, and, in turn, better WM performance predicted improved savings. This present study provides evidence that interventions targeting brain activity related to higher-order executive function (DM and WM) and associated cognitive performance can augment success in terms of real-world money-saving behavior.
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INTRODUCTION

Despite widely available matched savings programs and accessible banking, the personal saving rate in United States has declined from 11 percent in 1960 to 6.9 percent in 2019 (Hall, 2021; U.S. Bureau of Economic Analysis, 1959), which warrants the focus of financial policies towards long term planning and economic stability. Previous research demonstrates that only 49% of US population have set aside recommended amount of savings for three months in case of financial emergencies (Lusardi & Mitchell, 2011). This is particularly concerning among population with low-SES leaving them vulnerable to health and health-care-related disparities during financial emergencies such as a pandemic.

The scarcity hypothesis suggests that low-SES is a proxy to living in an extremely stressful environment which includes food insecurity, lack of resources, exposure to toxins, and poor neighborhood quality (Mullainathan & Shafir, 2013). Chronic exposure to stressors, in addition to lack of resources to mitigate them, can impair normal hypothalamus-pituitary-adrenal (HPA) functioning, a physiological system responsible for regulating stress ( Lê-Scherban et al., 2018; Stephens & Wand, 2012). Hyperactivity in HPA axis may in turn disrupt higher-order cognitive functions such as WM and DM (Lupien et al., 2001; Oei et al., 2006; Stephens & Wand, 2012). Additionally, the multitude of stressors associated with living in low-SES conditions results in the elevated preoccupation of pressing daily needs that diverts neural resources essential for cognitive processes (Mullainathan & Shafir, 2013a). Previous research has shown that WM and DM mechanism is impacted by low-SES factors including parental education (Akhlaghipour & Assari, 2020), low income (Kokosi et al., 2021), early life adversity (Goodman et al., 2019; Hackman et al., 2014; Leonard et al., 2015), and neighborhood disadvantage (Wright et al.,
Further, impaired WM and DM mechanisms may lead to diverse physical and mental health disparities such as substance abuse, problem gambling, anxiety, and depression (Dehn, 2011; Hackman et al., 2014; Houben et al., 2011a; Riggs et al., 2010; Snyder, 2013; Wu et al., 2017) that may act as a precursor to poverty cycle.

A substantial amount of prior neuroimaging evidence suggests the association between SES, and brain structure and function (Gonzalez et al., 2015, 2016; P. Kim et al., 2017; Liberzon et al., 2015; Yaple & Yu, 2019). Low-SES is associated with structural aspects of the brain including cortical volume, surface area, and thickness in various brain regions (M. J. Farah, 2017). Among the low-SES population, reduced volumes associated with subcortical regions especially the striatum and amygdala have been widely reported (Butterworth et al., 2012; Staff et al., 2012; Yu et al., 2018). The impacts posed by low-SES on the brain during developmental stages such as childhood and adolescence progresses to adulthood irrespective of adult SES (Staff et al., 2012; Yu et al., 2018).

Regarding the impact of low-SES on brain function, SES disparity in terms of neural functioning has been observed in cognitive systems associated with WM (Akhlaghipour & Assari, 2020; Leonard et al., 2015), DM (Sheehy-Skeffington, 2020), reward processing (Ly et al., 2011; Wiers et al., 2016), and emotion regulation (A. M. Gard et al., 2018; Holz et al., 2017; Javanbakht et al., 2015). Robust evidence related to functional differences concerning SES has been provided by neuroimaging metanalytic study that considered a wide range of cognitive paradigms among the low-SES population and demonstrated convergent neural activity in regions linked with executive control (reduced activity) and reward processing (increased activity) (Yaple & Yu, 2019). The consequence of socioeconomic disparity on the neural mechanisms associated with WM, executive
function, DM, and emotion processing results in the socioeconomic achievement gap, increased propensity to risky behaviors such as substance abuse, and disparities related to health behaviors including lower exercise and poor diet (Pampel et al., 2010; Waters et al., 2021; Yaple & Yu, 2019). These consequences of low-SES may act as an underlying factor that perpetuates poverty thus creating a circular relationship between the causes and consequences of poverty resulting in a non-culminating poverty cycle (Adamkovič & Martončik, 2017). Improved localization of neural correlates associated with low-SES could be beneficial for designing and improving interventions targeting related brain substrates directed towards improving financial stability.

Leveraging SES requires policies that will prioritize asset-building capabilities for long-term financial stability which can be achieved by improving individual saving behavior (Hall, 2021). Additionally, empirical studies examining the relationship between asset holding and various forms of well-being (Scanlon & Adams, 2008) have reported positive effects of asset holding on psychological, social, and behavioral outcomes. Sherraden et al., 1991 suggested that assisting an individual with low-SES to develop asset-building behavior could result in alteration in the cognitive schema, thus changing the way an individual thinks about the self, world, and future (Sherraden, 1991). Specifically, the association between psychological and behavioral traits including future orientation and personal efficacy, life satisfaction, enhanced self-esteem, and reduced stress (Scanlon & Adams, 2008) were observed. Previous evidence suggests that improved financial capabilities and asset-building abilities protect from financial shocks, reduce income volatility, and improve health and well-being (Weida et al., 2020). Although financial policies and programs to improve savings for assets building capabilities have been put
into place, a lack of insights from research representing individual differences underlying neurocognitive mechanisms and behavioral biases have led to suboptimal success of such policies (Elma & Baydaş, 2020). Financial stability by building optimal saving behavior is potentially achievable by integrating approaches from interdisciplinary fields including neuroscience that encourage modification of savings behavior.

To this end, we utilized neuroimaging data, task performance data, and real-world money-saving outcome to examine the neurocognitive mechanisms that influence savings behavior. We examined (study 1) risky-DM related brain activity utilizing Balloon Analogue Risk Task (BART) and the relationship between risky-DM related brain activity, task (BART) performance, and real-world money-saving behavior, (study 2) WM-related brain activity utilizing letter n-back task and examined the relationship between WM-related brain activity, WM task performance, and real-world money-saving behavior, (study 3) intrinsic functional connectivity of brain regions associated with WM task and its association with WM task performance and real-world money-saving behavior. An enhanced understanding of the neural mechanisms associated with cognitive mechanisms, its relation to personality traits, and real-world savings behavior among low-SES individuals may provide fundamental steps towards the development of tailored interventions for financial savings, better characterization of individuals who will potentially benefit most from targeted interventions, and improved strategies for behavioral change for successful savings behavior.
Study 1

RISKY DECISION-MAKING STRATEGIES MEDIATE THE RELATIONSHIP BETWEEN AMYGDALA ACTIVITY AND REAL-WORLD FINANCIAL SAVINGS AMONG INDIVIDUALS FROM LOWER INCOME HOUSEHOLDS

Ranjita Poudel¹, Michael J. Tobia², Michael C. Riedel², Taylor Salo¹, Jessica S. Flannery¹, Lauren D. Hill-Bowen¹, Anthony S. Dick¹, Angela R. Laird², Carlos M. Parra³†, Matthew T. Sutherland¹†

¹Department of Psychology, Florida International University, Miami, FL,
²Department of Physics, Florida International University, Miami, FL
³College of Business, Florida International University, Miami FL

† These individuals made equal ‘senior author’ contributions to this work.

*Correspondence:
Matthew T. Sutherland, Ph.D.
Florida International University
Department of Psychology
AHC-4, RM 312
11299 S.W. 8th St
Miami, FL 33199
masuther@fiu.edu
305-348-7962

KEYWORDS: Social determinants of health, socioeconomic status, Balloon Analogue Risk Task, risky decision-making, amygdala, striatum, fMRI, alexithymia, financial savings
Abstract

Background. Lower financial savings among individuals experiencing adverse social determinants of health (SDoH) increases vulnerabilities during times of crisis. SDoH including low socioeconomic status (low-SES), lower education attainment, and experienced discrimination appear to influence a range of cognitive abilities as well as health and life outcomes that may perpetuate poverty and disparities. Despite evidence suggesting a role of financial growth in minimizing SDoH-related disparities and vulnerabilities, neurobiological mechanisms linked with such financial behavior remains to be elucidated. To this end, we examined the relationships between brain activity during risky decision-making (DM), laboratory-based task performance, personality characteristics, and money savings behavior.

Methods. Participants \(N=24, \ 14\ \text{females}) from low-SES households (income<$20,000/year) underwent fMRI scanning while performing a DM paradigm called the Balloon Analogue Risk Task (BART) that probes risky- and strategic-DM. Participants also completed a battery of self-report instruments characterizing relevant personality characteristics and then engaged in a community outreach financial program where amount of money saved was tracked over a 6-month period.

Results. Regarding BART-related brain activity, we observed expected activity in regions implicated in reward and emotional processing including the striatum, insula, and amygdala. Regarding brain-behavior relationships, we found that laboratory-based BART performance mediated the impact of amygdala activity on real-world savings behavior.
That is, elevated amygdala activity was linked with improved BART performance which, in turn, was linked with more money saved after 6 months. In exploratory analyses, this mediation was moderated by personality characteristics (i.e., alexithymia) such that, only individuals reporting low alexithymia appeared to demonstrate a relationship between amygdala activity and savings.

**Conclusions.** These outcomes suggest that interventions targeting DM-related amygdala activity and/or alexithymia characteristics may provide utility for augmenting an individual’s financial savings behavior.

**Introduction**

Social determinants of health (SDoH) encompass economic and social attributes that influence the quality of life for individuals and communities which can also contribute to health-related inequities (*Frequently Asked Questions | Social Determinants of Health | NCHHSTP | CDC, 2019*). Factors such as low socioeconomic status (low-SES), lower education attainment, childhood adversity, neighborhood quality, and discrimination are predictive of health disparities, including mental health (e.g., substance abuse, depression, and anxiety), and appear to influence a range of cognitive processes (i.e., executive functions, decision-making [DM]) (Adler et al., 2016; Finn et al., 2017; Haushofer & Fehr, 2014; Payne et al., 2017). Noteworthy, pre-existing financial, occupational, and/or health-related stressors among people from low-SES and/or minority households can be exacerbated due to widening income, health, and racial disparities during uncertain times (e.g., a pandemic) (Clouston et al., 2021; Palacio & Tamariz, 2020; Singu et al., 2020). On
the other hand, evidence suggests that policies focused on SDoH, including financial
growth, can improve a range of health-related outcomes (Adler et al., 2016; Allan et al.,
2016). Coming from a psychological and neuroscientific perspective, we suggest that
insight into brain-behavior relationships regarding cognitive processes (e.g., DM) and/or
real-world behaviors (e.g., money saving) may provide utility for enhancing strategies to
further improve financial stability. Unfortunately, insights from psychological and brain
sciences have rarely been considered when formulating such strategies (Hall, 2021).

SES is a multidimensional construct based on household income, education,
occupation, material resources, and neighborhood characteristics (Hackman et al., 2010;
Leonard et al., 2015). Stress related to low-SES settings can compromise an individual’s
cognitive abilities which is thought to lead to a “scarcity mentality” (Adamkovič &
Martončik, 2017; Hackman et al., 2010; Mullainathan & Shafir, 2013b). Scarcity mentality
refers to a mindset in which the reduction of resources (e.g., food, money, time) negatively
affects the appropriate allocation of attention to relevant task-related stimuli and executive
functions (e.g., DM, working memory) (Huijsmans et al., 2019; Mullainathan & Shafir,
2013b). That is, the cognitive load associated with low-SES settings may compromise
“cognitive bandwidth” and, in turn, inhibit prospective goal-directed behavior (Mani et al.,
2013; Mullainathan & Shafir, 2013a). This tax on cognitive capacity may also hamper self-
control mechanisms, such as the ability to defer gratification (i.e., impulsivity) (Bernheim
et al., 2015; Mullainathan & Shafir, 2013b) and contribute to risky health-related or
financial decisions (Adamkovič & Martončik, 2017; Haushofer & Fehr, 2014;
Mullainathan & Shafir, 2013b). Such cascading effects may eventually create a feedback
loop perpetuating poverty (Hackman et al., 2010).
Neuroimaging studies suggest that SDoH also impact brain structure and function (Gonzalez et al., 2015, 2016; P. Kim et al., 2017; Liberzon et al., 2015; Yaple & Yu, 2019) which may convey a lasting vulnerability for the development of psychopathology (Lorant et al., 2003; Wadsworth et al., 2016). For example, low-SES settings have been associated with reduced gray-matter volume in the anterior cingulate cortex (ACC) and ventromedial prefrontal cortex (vmPFC) (Gianaros et al., 2007), regions commonly implicated across multiple neuropsychiatric conditions (Menon, 2011). Furthermore, reduced hippocampal and amygdala volume have been linked with financial hardships (Butterworth et al., 2012), particularly when experienced in childhood (Staff et al., 2012; Yu et al., 2018). Regarding functional brain alterations, low-SES settings appear to be linked with altered brain activity related to several cognitive processes, including reward processing (Ly et al., 2011; Wiers et al., 2016), emotion regulation (A. M. Gard et al., 2018; Holz et al., 2017; Javanbakht et al., 2015), working memory (Aklaghipour & Assari, 2020; Leonard et al., 2015), and DM (Sheehy-Skeffington, 2020). Noteworthy, the impact of financial hardships on brain function experienced during childhood and adolescence have been detected in adulthood irrespective of an individual’s adult SES (Gonzalez et al., 2016). Similarly, neuroimaging meta-analytic work considering a wide range of cognitive paradigms among individuals from low-SES households has highlighted brain activity alterations in regions linked with executive control (reduced activity) and reward processing (increased activity) (Yaple & Yu, 2019). Such SES-related functional brain alterations may have real-world consequences as compromised emotional processing and executive function abilities can contribute to lower academic achievement and higher prevalence of maladaptive behaviors such as substance use or physical inactivity (Pampel et al., 2010; Waters et al., 2021; Yaple
These consequences of low-SES may further act as a poverty trigger creating a poverty cycle (Adamkovič & Martončik, 2017). Delineating brain alterations linked with SES and potential relationships with cognitive performance and money-related decisions may provide insights useful for the design and/or improvement of strategies to enhance individuals’ financial stability.

Noteworthy, lower SES conditions have been associated with an increased propensity for risk-taking behavior in the real-world (Adamkovič & Martončik, 2017; Boričić et al., 2015; Karriker-Jaffe, 2013; Kipping et al., 2015; Maas, 2016; Payne et al., 2017; Sheehy-Skeffington, 2020). For example, lower SES has been shown to be associated with elevated incidence of substance abuse (Wellman et al., 2018) and behavioral addiction (Hahmann et al., 2020). From a neuroscientific perspective, a propensity for risk-taking has been commonly attributed to two DM-related brain systems: (1) a cognitive control system involving brain regions in the dorsolateral prefrontal (dLPFC) and parietal cortices, and (2) a reward system involving brain regions including the striatum, amygdala, and ventromedial prefrontal cortex (vmPFC) (L. Clark et al., 2008; Krain et al., 2006; Shulman et al., 2016). Altered activity within, or interactions between, these two systems may contribute to reduced self-control and/or increased impulsivity (Lawrence et al., 2009; Limbrick-Oldfield et al., 2013; Peters & Büchel, 2011; Sonuga-Barke & Fairchild, 2012). Specifically, hypoactivity in brain regions associated with cognitive control (i.e., dLPFC) and hyperactivity in regions associated with reward processing (i.e., striatum, amygdala, vmPFC) during DM is believed to contribute to higher levels of impulsivity, which in turn, may lead to more risk-taking behaviors (Lejuez et al., 2002a; Moeller et al., 2001; Rao et al., 2008a; Ursache & Raver, 2015).
The Balloon Analogue Risk Task (BART) is a commonly adopted risky-DM paradigm to assess risk-taking behaviors in the laboratory and to interrogate associated brain activity (Lejuez et al., 2002a). Emerging evidence suggests that BART performance in the laboratory correlates with risky behavior in the real-world (Galván et al., 2013; Kohno et al., 2014). For example, BART behavioral measures have been reportedly associated with nicotine and cannabis use (K. L. Hanson et al., 2014; Lejuez, Aklin, Jones, et al., 2003), alcohol abuse (Canning et al., 2021), risky sexual practices (Lejuez et al., 2004), and unsafe driving (Vaca et al., 2013). Regarding BART-related brain activity, increased activity in mesocorticolimbic regions including the striatum, ACC, amygdala, and insula is commonly observed (Fukunaga et al., 2012b; Hulvershorn et al., 2015; Rao et al., 2008a; Telzer et al., 2013). Interestingly, dissociations across these regions in terms of potential behavioral implications have been suggested by previous work such that, for example, increased BART-related striatal activity has been linked with poorer task performance and higher impulsivity (Congdon et al., 2013), while increased amygdala activity has been linked with responsivity to the degree of risk (Wagels et al., 2017). Other neuroimaging findings implicate a role for the amygdala in emotion-related DM processes specifically when evaluating reward magnitudes and risk levels (De Martino et al., 2006; Gupta et al., 2011; Smith et al., 2009). Noteworthy, amygdala activity also has been linked with real-world risky behaviors, including alcohol abuse (Glahn et al., 2007; Marinkovic et al., 2009), drug addiction (Koob, 2009), and risky sexual behavior (Victor et al., 2015).

Understanding the impact of low-SES conditions on striatal and amygdala function during DM and putative associations with real-world financial behavior may provide insight into strategies for the development and/or refinement of interventions targeting
financial stability. The amygdala has been linked with multiple SES factors, including income level (J. L. Hanson et al., 2019; White et al., 2019), childhood adversity (Calem et al., 2017; Herringa et al., 2016), and neighborhood quality (A. M. Gard et al., 2021; Ramphal et al., 2020). For example, structural neuroimaging studies have identified reduced amygdala volume among children from households with lower income and parental education (Merz et al., 2018; Noble et al., 2012). Functionally, task-based findings suggest that low-SES conditions are associated with altered amygdala activity during emotional processing (Javanbakht et al., 2015; P. Kim et al., 2013) and attention regulation (de Gelder et al., 2012; Ferri & Hajcak, 2015; Javanbakht et al., 2015), mental operations both relevant for prospective goal-directed behavior. Additionally, resting-state functional connectivity (rsFC) evidence implicates SES-related alterations in amygdala-hippocampus and amygdala-vmPFC coupling in the domain of emotional processing [32, 69] and amygdala-posterior cingulate cortex coupling in the domain of attention regulation (Sripada et al., 2014).

Cytoarchitectonic parcellations have converged on the view that the amygdala can be decomposed into at least 3 subregions: the laterobasal (LBA), centromedial (CMA), and superficial amygdala (SFA) (Bloom et al., 1997; L. W. Swanson & Petrovich, 1998). In humans, neuroimaging metanalytic work has also parcellated the amygdala into 3 corresponding subregions (Bzdok, Langner, et al., 2013), and delineated potential behavioral roles differentially linked with each subregion. Specifically, the LBA subregion has been linked with coordinating high-level sensory input, the CMA with mediating attentional and motor responses, and the SFA with olfactory and social information processing (Bzdok, Laird, et al., 2013). Similarly, sub-specialization of striatum, a region
widely implicated in risky-DM, utilizing data-driven approach showed five distinct subregions that exhibited discrete patterns of coactivation with cortical brain regions and were found to be related to different psychological processes. In general, the ventral striatal and caudate regions were found to be associated with reward related functions while putamen was found to be associated with executive functions (Pauli et al., 2016). Regarding amygdala subdivision, the CMA subdivision appears to be of particular interest as SES-related epigenetic alterations have been associated with increased CMA activity during threat (Swartz et al., 2017). Additionally, individuals from low-SES households demonstrate higher rsFC between the CMA and prefrontal regions (i.e., mPFC and dIPFC) (Tian et al., 2021). Further, task-dependent connectivity analyses have detected reduced CMA-dIPFC coupling during negative emotion processing (Tian et al., 2021) further implicating a critical impact of low-SES conditions in the context of affect regulation and amygdala function (Ochsner & Gross, 2008).

In this small-scale proof of principle (pilot) study, we assessed BART-related brain activity and examined the interrelations between risk-related brain activity, laboratory performance, and real-world savings behavior among individuals from low-SES households. We anticipated that the BART would engage expected brain regions linked with reward and emotion processing (Fukunaga et al., 2012a; Rao et al., 2008b; Wagels et al., 2017). Subsequently, we addressed three main empirical questions involving brain-behavior relationships regarding strategic risky-DM in the laboratory, financial savings in the real-world, and the degree to which such relationships are modulated by relevant personality factors. Regarding laboratory behavior, we expected laboratory task performance would mediate the relationship between risk-related brain activity and real-
world savings. Regarding money savings behavior, we expected that better task performance would predict higher saving outcome (Elma & Baydaş, 2020). Finally, regarding personality characteristics, we expected that clinically relevant personality trait would moderate the relationship between risk-related brain activity, laboratory performance, and real-world savings behavior. An enhanced understanding of the neurocognitive mechanisms associated with risky-DM, its relation to personality trait, and real-world savings behavior among low-SES individuals may provide a principled first step towards better characterization of individuals who may benefit most from targeted interventions for financial savings, development of tailored interventions, and improved strategies for behavioral change for successful savings behavior.

Methods

Participants. Participants were recruited and enrolled in collaboration with Catalyst Miami, a non-profit organization whose mission is to improve health, education, and economic opportunities in the community. Catalyst Miami connects low-SES households with financial services such as tax preparation, credit building, savings opportunities, and financial coaching through various community outreach programs. We recruited participants from these outreach programs using study flyers and word-of-mouth notification from Catalyst Miami staff to their clients. Given this was a small-scale proof-of-concept study, a sample of 27 participants from low-SES households were recruited (for demographics see: Supplemental Table S1). A low-SES household was operationalized based on income (<20,000$/year) and education attainment (high school or no college degree). Participants were adults (age range: 24 - 60 years) to minimize potential aging-
related effects on brain function, were drug free (confirmed via urine toxicology screening) and endorsed no presence or history of any medical, neurological, or psychiatric disorder. All participants signed a written informed consent approved by the Institutional Review Board at Florida International University, FIU.

**Procedures.** Participants completed two study components: 1) an MRI visit at FIU (one visit approximately 4 hours), and 2) a bank savings program through Catalyst Miami (over a period of 6 months). Upon arrival at the neuroimaging visit, participants completed substance use screening including a breathalyzer testing (BACtrack S80 Breathalyzer) and urine toxicology (Drug Check Cup, NXStep). Next, participants completed a series of self-report questionnaires probing cognitive functions and personality traits. Further, participants completed task training and practice in a mock MRI environment before a 1-hour MRI scan session. Finally, participants were compensated and debriefed. After the Neuroimaging session, Catalyst employee accompanied the participants to the bank and helped them set up a bank account which was tracked for 6 months.

**Bank savings program.** Real-life savings behavior data were tracked for 24 participants who successfully opened and used savings accounts for this study (3 participants were not eligible to open the account). Participants were instructed by both the neuroimaging research team and Catalyst employee to save $20 each month for the following 6 months which would reward them $10 match for each successful savings. Additionally, participants received a $60 final reward for successfully completing the savings program without any interim withdrawals. Each participant’s total savings at the end of this savings
program (i.e., money accrued in the savings account at the end of 6 months) was the main savings indicator considered.

**Decision-making task (BART).** To assess behavioral and neuronal indices of DM, participants completed the Balloon Analogue Risk Task (BART) in the MRI scanner following task training and practice [Fig. 1]. During scanning, participants completed 3 BART runs of 20 trials each (~8mins per run) while behavioral responses were collected with an MRI-compatible scroll device. In the BART, participants were presented with a "virtual" balloon which they inflated to win as much money as possible. Participants could give 1 to 128 “pumps” per balloon by scrolling upwards or downwards to the desired value on the response device. Instructions informed participants that each pump corresponded to one cent and that each balloon would “pop” if too many pumps were given. Participants were not informed that the “pop” value for each balloon was randomly generated between 1 and 128 pumps, while the average “pop” value for each of the balloon was 64. Thus, more pumps increased the potential amount of money to be won, but also increased the likelihood that the balloon would pop. Each BART trial began with a “think phase” (average stimulus time: 4 secs) during which participants were instructed to reflect on the task rules. The “think phase” was followed by the “pump phase” (average stimulus time: 5 sec) during which participant chose the number of pumps they decided to give to the balloon using the response device. The “pump phase” was followed by “wait phase” (average stimulus time: 3 sec) during which participant waited. The “wait phase” was followed by an “inflate phase” (average stimulus time:4 secs) during which participant could see the balloon inflate. The “inflate phase” was followed by the “outcome phase”
(average stimulus time: 3 secs) during which participant could see one of the two outcomes: either the balloon pop or they won the money. If the balloon did not pop, the won amount (one cent per pump) was added to the accumulating total which remained visible on the lower right quadrant of the screen (Fig. 1 Green box). However, if the balloon popped, money was not won (nor lost), the accumulating total earning remained unchanged. Finally, the “outcome phase” was followed by “rest phase” (average stimulus time: 4 secs) during which participants waited for the next trial. The next trial continued with a new balloon beginning with the think phase. In the current study, BART performance indicator characterizing each participant’s ability to place winning bets termed as “effective pump bet [EPB]” was utilized. This indicator takes the ratio of each participant’s total BART earnings to average pump in all 60 trials and quantifies the objective measure of strategic-DM during BART.

Self-report assessment. In total, we collected 8 self-report measures assessing aspects of cognition, reward, and emotion. Given we were particularly interested in emotion-related characteristics and given a known association between low-SES settings and alexithymia (Kokkonen et al., 2001), here we focused on total scores from the previously validated 20-item Toronto Alexithymia Scale (TAS-20) (Bagby et al., 1994). Alexithymia is a personality trait associated with difficulty identifying and describing subjective emotional experiences. When considering brain-behavior relationships, previous work has identified links between higher alexithymia characteristics and reduced amygdala responsivity to negative emotional stimuli, suggesting blunted emotional responses in alexithymic individuals (Kugel et al., 2013). In terms of laboratory-based behavior, individuals with
higher alexithymia levels reportedly make more disadvantageous choices in DM tasks. In terms of real-world behaviors, higher alexithymia appears to correlate with various risky behaviors including drug and behavioral addiction severity (Marchetti et al., 2019; Panno et al., 2019; Sutherland et al., 2013), and other health-related outcomes (Tolmunen et al., 2011).

**Data-analysis**

**Behavioral data.** In total, we collected 8 self-report measures assessing aspects of cognition, reward, and emotion. Given we were particularly interested in emotion-related characteristics and given a known association between low-SES settings and alexithymia, here, we focused on total scores from the previously validated 20-item Toronto Alexithymia Scale (TAS-20). Alexithymia is a personality trait associated with difficulty identifying and describing subjective emotional experiences. When considering brain-behavior relationships, previous work has identified links between higher alexithymia characteristics and reduced amygdala responsivity to negative emotional stimuli, suggesting blunted emotional responses. In terms of laboratory-based behavior, individuals with higher alexithymia levels appear to make more disadvantageous choices in DM tasks. In terms of real-world behaviors, higher alexithymia appears to correlate with various risky behaviors including drug and behavioral addiction severity, and other health-related outcomes.

**Preprocessing.** MRI data were preprocessed using standard fMRIPrep, a Nipype-based tool (version 1.1.5). (Abraham et al., 2014; Esteban et al., 2019; Gorgolewski et al., 2011).
Fieldmap images were utilized for distortion correction. T1-weighted structural volumes were skull-stripped (antsBrainExtraction.sh v2.1.0) and corrected for intensity non-uniformity (N4BiasFieldCorrection v2.1.0) (Tustison et al., 2010). The structural volumes were spatially normalized via nonlinear registration to the ICBM-152 asymmetrical template v2009c (ANTs v2.1.0) (Fonov et al., 2009). Slice-time correction was implemented for each functional volume to the middle of each TR utilizing AFNI’s 3dTshift (AFNI v16.2.07). Regarding motion correction, we used MCFLIRT to correct for motion in functional volumes (FSL v5.0.9) [95]. Distortion correction, constrained by an average field map template (Treiber et al., 2016), was performed by co-registering functional images to corresponding anatomical volumes (Huntenburg et al., 2014; S. Wang et al., 2017). Finally, bbregister (FreeSurfer v6.0.1) was used to co-register functional images to corresponding T1-weighted volumes via boundary-based registration (Greve & Fischl, 2009). Lanczos interpolation was applied to conduct motion and distortion correction, functional-to-anatomical transformation, and anatomical-to-template registration, all in a single step (antsApplyTransforms ANTs v2.1.0). Further preprocessing was conducted in AFNI version 17.3.06. The functional data were further spatially blurred to 6-mm FWHM utilizing AFNI’s 3dBlurTOFWHM (Cox, 1996). We censored functional time frames with Euclidean norm mean displacement greater than 0.35mm. Additionally, volumes immediately adjacent to these censored volumes and those with fewer than three contiguous uncensored neighbors were also discarded. Individual neuroimaging scan sessions with more than 25% of the functional volume censored were discarded from further analysis (Flannery et al., 2019). Based on these criteria, none of the participants
(except the ones who did not have access to the bank account) were discarded from further neuroimaging analysis.

**MRI data: BART-related task effects.** Voxel-wise multiple regression analyses were conducted for functional data utilizing general linear models (GLM). For participant-level GLMs, task-related regressors were modeled as blocks or impulse functions: (1) decision-making phase (block), (2) win outcome (impulse), and (3) pop outcome (impulse). Regressors were convolved with a hemodynamic response function (HRF) and its temporal derivatives time-locked to block/stimulus onset. Six motion-correction parameters, capturing residual head motion, and a fourth order polynomial regressor, capturing baseline trends in the BOLD signal, were added as regressors of no interest. We utilized AFNI’s 3dDeconvolve with 3dREMLfit for subject-level analyses thereby accounting for temporal autocorrelations. Individual participant beta weights were then submitted to a group-level, whole-brain, one-sample t-test (two tailed, 3dTtest++). The resulting statistical maps were thresholded correcting for family-wise error at p_corrected < 0.05 [p_voxel-wise < 0.001, cluster extent: 26 voxels], with the spatial autocorrelation correction of 3dClustSim.

**MRI data: ROI definition.** Given prior evidence suggesting the implication of amygdala and striatum in adverse SDoH in existing literature (Fareri & Tottenham, 2016; Holz et al., 2017), we examined the brain activity in those specific regions to probe brain-behavior relationship. We utilized amygdala seeds that were defined and named based on a previous study; (i) CMA, (ii) SFA, (iii) LBA (Roy et al., 2009). A total of 6 ROIs (3 per hemisphere) were placed at amygdala. Similarly, given the extensively reported association of striatum in SDoH in addition to risk-related behaviors, we utilized functional striatum seeds that
were defined and named based in a previous study; (i) posterior putamen, (ii) anterior putamen, (iii) anterior caudate, (iv) ventral striatum, and (v) posterior caudate (Pauli et al., 2016). For graphical examination and follow-up analyses in terms of brain-behavior relationship, we extracted the mean β coefficients associated with specific task-effect (i.e., DM phase) from amygdala and striatal ROIs. The task-related β-values were then correlated with clinically relevant personality metrics (i.e., alexithymia), laboratory behavior (i.e., objective measure of strategic-DM), and real-world savings behavior (i.e., savings outcome at the end of 6 months).

**Mediation.** To identify the potential relationship between neurocognitive mechanism associated with risky-DM and real-world savings behavior, we initially performed correlation analyses between real-world savings behavior and brain activity (i.e., amygdala and striatum subregions) as well as objective measure of strategic-DM in BART. We then conducted mediation analysis using SPSS PROCESS V3.4 to examine whether the relationship between risky-DM related brain activity (X) and real-life savings behavior (Y) was explained by objective measure of strategic-DM (M) [MODEL: brain activity (X) \( \rightarrow \) strategic-DM (M) \( \rightarrow \) savings (Y)] [Fig. S1A]. Theoretically, total effect of brain activity on saving outcome is denoted by path “c”, the impact of brain activity on task performance is denoted by path “a”, and the effect of task performance on savings outcome is represented by path “b”. The mediation analysis decomposes the total effect of risk-related brain activity on savings (path “c”) into i) direct effect (path “c’”) and ii) indirect effects (path “ab”: i.e., c=c’ + ab). The indirect effect (path “ab”), that is the path from independent variable to the dependent variable via mediator is considered significant if the
bootstrapped confidence interval (bias-corrected 95%) does not incorporate zero or rejects the null hypothesis.

**Moderated mediation.** We further conducted moderated mediation analysis to examine the relationship between a clinically relevant personality trait (i.e., alexithymia) and above-mentioned mediation. Moderated mediation was modeled by entering the amygdala activity as a predictor, total alexithymia score as a moderator, and objective measure of strategic-DM as the outcome variable [MODEL: amygdala activity (X) → alexithymia (W) → strategic-DM (M) → savings (Y)] [Fig. S1B]. A bootstrapping method was utilized to test for significance of the index of moderated mediation. The index of moderated mediation (i.e., that indirect path from the interaction term, via the mediator, to the dependent variable) is significant if the 95% confidence interval (computed via bootstrapping) does not encompass zero or rejects the null hypothesis.

**Results**

**Laboratory risky-DM behavior and real-world financial savings.** Correlation analysis was conducted to examine the relationship between BART performance (i.e., an objective measure of strategic-DM) and real-world savings behavior. Strategic-DM positively correlated with amount of money saved at the end of the 6-month financial program (r[24]=0.59, p=0.003) such that as strategic-DM increased, the amount of money saved also increased. When considering total explosions in the BART (i.e., an objective measure of risky-DM in BART) and savings, we observed a negative correlation (r[24]=-0.51, p=0.03] such that as the number of BART explosions increased, amount of money saved decreased (Table 1).
**Whole-brain DM-related brain activity.** Consistent with prior BART neuroimaging findings (Hulvershorn et al., 2015; Rao et al., 2008b; Schonberg et al., 2012), DM-related activity (pump vs. baseline) was observed across multiple regions including the ACC, striatum, thalamus, amygdala, and frontal areas (Fig. 2A). Positive outcomes (win vs. baseline) were linked with activity in wide range of brain regions including cingulate, striatum, precuneus, inferior and medial frontal gyrus (Fig. 2B). Negative outcomes (pop vs. baseline) were linked with activity in the medial frontal gyrus and inferior frontal gyrus (Fig. 2C). These results are largely consistent with previous neuroimaging findings related to BART (Hulvershorn et al., 2015; Rao et al., 2008b) [Table S2].

**Amygdala and striatal ROI activity: Brain-behavior relationships.** Given the link between adverse SDoH and amygdala activity highlighted in previous literature (Butterworth et al., 2012; A. M. Gard et al., 2018; Holz et al., 2017; Javanbakht et al., 2015), we examined the DM related activity in amygdala and striatal subregions. DM-related activity in the right CMA region positively correlated with strategic-DM in the BART ($r[24]=0.44, p=0.03$; Fig. 3A) such that as the risk-related CMA activity increases, task performance improves. However, the CMA activity was not associated with the personality (i.e., alexithymia) or real-world savings measures. On the other hand, DM-related activity in the right LBA is negatively correlated with alexithymia scores ($r[24]=-0.53, p=0.02$; Fig. 3C) such that as risk-related LBA activity increases, alexithymia score decreases. However, the risk-related activity in the LBA subregion was not associated with strategic-DM or savings behavior. No significant relationships between activity in any of
the left amygdala subregions with task behavior, personality, or savings measures were detected.

Similarly, given the link between social adversity and elevated striatal activity highlighted in previous literature (Fareri & Tottenham, 2016; Holz et al., 2017; Ly et al., 2011), we examined the DM related activity in striatal subregion. DM related activity in striatal subregions (i.e., bilateral posterior putamen) was significantly negatively correlated with real-world savings behavior [right striatum-savings: $r(22) = -0.41, p = 0.04$, left striatum-savings: $r(22) = -0.41, p = 0.02$] [Fig. 3D,E] such that as the risk-related activity in striatal subregion increases, saving outcome decreases. The activity in striatal subregion was not associated with alexithymia and objective measure of strategic-DM, indicating specificity of increased risk-related striatum activity with poor real-world savings behavior.

**Simple Mediation.** Given that right CMA activity correlated with strategic-DM in the laboratory, we examined the relationship between CMA activity during DM, objective measure of strategic-DM in BART, and real-life savings behavior. As the measure of strategic-DM was significantly correlated with brain function and savings behavior, we examined if strategic-DM mediates the effect of CMA activity on real-world savings behavior [Fig. 4A, B]. Objective measure of strategic-DM was entered as a mediator (M) between right CMA activity (X) and real-life savings behavior (Y). The mediation model examined: (1) significant indirect effect of right CMA activity on real-world savings behavior via strategic-DM, (2) and whether this indirect effect completely accounts for the association between amygdala activity and real-world savings behavior (no significant
direct effect). The weights for the paths in the mediation model are reported [Fig 4]. When strategic-DM was included as a mediator in the model, right CMA’s direct effect on savings failed to reach significance (c’ path: $\beta = -175.345$, $p = 0.432$), whereas the indirect effect was significant (ab path = 327.5: 95% CI = 51.96, 799.7134) [Fig. 4C]. The results indicate that higher CMA activity predicts better real-world savings behavior which is increased by improving strategic-DM. The lack of direct significant effect further shows that strategic-DM fully accounts for the savings differences.

**Moderated Mediation.** Given the role of alexithymia in real-world risk-taking behavior (Marchetti et al., 2019; Stasiewicz et al., 2012; Sutherland et al., 2013), we incorporated alexithymia as a moderating variable into the aforementioned mediation model to test a moderated mediation model, where self-reported alexithymia scores (W) moderated the indirect path between right CMA activity (X) and real-world savings behavior (Y) via objective measure of strategic-DM (M). The moderated mediation model showed that: (1) increased right CMA activity was associated with better strategic-DM, (2) the association between right CMA activity and strategic-DM is moderated by the levels of alexithymia, and (3) the association between right CMA activity and real-world savings behavior is mediated by BART performance. The result confirmed that the index of moderated mediation was significant ($\beta = 39.662$, 95% CI [3.55, 70.75]), indicating that alexithymic trait moderated the indirect effect of right CMA activity on real-world savings behavior via strategic-DM such that any two conditional indirect effects estimated at different levels of alexithymia were significantly different from each other. That is, when alexithymia scores were low, the effect of right CMA activity on savings behavior via strategic-DM was significant in a positive direction and reached its peak level ($\beta=895.27$, 95% CI [176.98,
In contrast, when alexithymia scores were high, the effect was non-significant ($\beta = -105.38$, 95% CI [-620.52, 550.82]) [Fig 4D, Table 2]. In sum, lower level of alexithymia increases the positive effect of amygdala activity on strategic-DM, which may be related to improved real-world savings behavior.

**Discussion**

Our results suggest that risk-related brain activity during the BART among individuals with low-SES is associated with a wide range of brain regions including the striatum, ACC, insula, and amygdala, regions widely implicated in reward, emotion, and salience attribution. Considering the brain-behavior relationship, an objective measure of strategic-DM was found to mediate the effect of right CMA activity on real-world savings behavior, such that elevated CMA activity improved strategic-DM which, in turn, improved savings behavior. Additionally, our exploratory analysis indicated that different levels of alexithymia moderated this mediation, such that the indirect effect of right CMA activity on real-world savings behavior via strategic-DM was significant when alexithymia was low and moderate indicating that individuals with lower alexithymia (versus higher alexithymia) had better savings outcomes. Finally, we investigated the association between risk-related brain activity and real-world savings behavior in striatal subregions. We found that risk-related activity in the striatum subregion (i.e., putamen) was significantly negatively correlated with real-world savings indicating that reduced risk-related striatal activity predicts better savings outcome. In sum, our results suggest that increased amygdala activity during risky-DM and lower alexithymia characteristics may be relevant factors related to success associated with real-world money-savings behavior. These results
bridge the gap between risk-related neurocognitive mechanisms, personality trait (a risk factor for aberrant DM), and real-world behavior among individuals with low-SES conditions.

Consistent with previous reports, our findings indicate that BART-related DM is associated with a wide range of brain regions including reward processing and emotion regulation such as the striatum, amygdala, ACC, and insula (Fishbein et al., 2005; Hsu et al., 2005). Specifically, the amygdala is considered to induce emotional responses to outcomes during risky-DM as a component of the “impulsive system” (A. Bechara et al., 2005; Yan & Li, 2009) given damage related to this region results in impaired performance in risky-DM tasks such as Game of Dice Task (Brand et al., 2007) and cups task (Weller et al., 2007). Additionally, clinical studies associating amygdala lesion in relation to risky-DM showed that amygdala damage is associated with a significant reduction in loss aversion in an economic task (Martino et al., 2010). Further, patients with the amygdala lesions fail to learn to avoid risky decks of cards (vs. less risky decks) that lead to greater losses over a course of time in Iowa Gambling Task (Antoine Bechara et al., 1999; L. Clark et al., 2008). Prior evidence suggests the role of the amygdala in the regulation of losses (i.e., to evaluate and avoid them) during risky-DM thus acting as a “cautionary brake” on risky behaviors (Martino et al., 2010). Moving beyond the role of the amygdala in a laboratory task, the amygdala has been widely linked with substance abuse (Gilpin et al., 2015; Mihov & Hurlemann, 2012), behavioral addiction (Quester & Romanczuk-Seiferth, 2015; Rahman et al., 2014; Takeuchi et al., 2019), internet and gaming disorder (Cheng & Liu, 2020; Ko et al., 2015). In addition to predicting real-world risky behaviors, amygdala function has also been shown to predict real-world treatment program adherence such that
elevated response to negative feedback in bilateral amygdala predicted relapse among individuals attending community-based substance abuse treatment program (Forster et al., 2017). Similarly, pre- to post-treatment amygdala-frontal cortex functional connectivity predicted success in social anxiety disorder treatment (Klumpp & Fitzgerald, 2018). Considering the prior evidence suggesting the likelihood of adherence to therapeutic intervention (and in behavioral savings program in the context of the current study) predicted by baseline amygdala function, the amygdala could act as a potential substrate for novel interventions designed for financial growth (Klumpp & Fitzgerald, 2018).

Our findings showed that laboratory BART performance mediates the effect of amygdala activity on real-world money-saving behavior. Previous reports have demonstrated the relationship between an objective measure of risk-taking in BART and a wide range of risk-related personality metrics such as sensation seeking, impulsivity, and anxiety which consistently predict real-world risky behaviors (Lejuez, Aklin, Jones, et al., 2003; Lejuez, Aklin, Zvolensky, et al., 2003; Lejuez et al., 2002b). Further, relating BART performance directly to real-world behavior, increased risky-DM in the BART predicted real-world MDMA use (Hopko et al., 2006) and mediated the effect of childhood adversity on risk behaviors associated with HIV (Bornovalova et al., 2008). However, in the current study objective measure of strategic-DM which confers more towards the adaptive form of DM was associated with better savings behavior (Bell et al., 2019; Blair et al., 2018; Dean et al., 2011). Measures of adaptive DM during BART are a potential metric of self-regulation and thought to be contingent upon better executive function (Bell et al., 2019; Blair et al., 2018; Dean et al., 2011). Additionally, given the fact that BART is the most naturalistic measure of risk-taking laboratory (Harrison et al., 2005), recent reports have
suggested the utility of BART in mobile platforms to evaluate risk-taking propensity and real-world behavior (Harrison et al., 2005; MacLean et al., 2018). Thus, BART behavioral measure including the strategic-DM carries the potential to be used virtually to identify individuals who are in most need of intervention for financial success.

While considering the influence of underlying personality traits on financial growth and its relationship with brain function and laboratory performance, our results indicate that alexithymia moderates the mediating role of strategic-DM on the effect of CMA activity on real-world savings behavior such that individuals with lower alexithymia (vs. higher alexithymia) have better savings outcomes. Speaking to the neural underpinning of alexithymia, consistent with our findings, individuals with higher (vs. lower alexithymia) have reportedly shown task-related activity in the right amygdala during emotional stimulation task (Kugel et al., 2008; Leweke et al., 2004). Further, signifying the implication of amygdala structure in the incidence of alexithymia, reduced amygdala volume was shown to be associated with higher alexithymic characteristics (Goerlich-Dobre et al., 2015; van der Velde et al., 2013; P. Xu et al., 2018). Alexithymic trait, in addition to being widely associated with behaviors such as substance abuse, gambling, and poorer health behaviors (Marchetti et al., 2019; Nowakowski et al., 2013; Stasiewicz et al., 2012; Sutherland et al., 2013), also consistently predicts poorer adherence to therapeutic and treatment programs. Alexithymia has been widely reported as a hindering factor in terms of maintenance and continuation of therapeutic and treatment programs. Specifically, alexithymic traits predict dropouts from treatment programs in patients with eating disorders, HIV, and substance abuse (Berrocal et al., 2009; Cleland et al., 2005; McIntosh et al., 2016; Morie et al., 2016). In terms of adherence to substance-abuse intervention
(Cleland et al., 2005; Morie et al., 2016), individuals with higher alexithymia (versus lower alexithymia scores) showed poorer outcomes and reported higher relapse rate (Loas et al., 1997; Ziółkowski et al., 1995). The association of alexithymic traits with discontinuation of treatment may be potentially attributed to difficulties, among alexithymic individuals, in building collaborative relationships (Berrocal et al., 2009; De Panfilis et al., 2008; H. Grabe et al., 2001; Pinna et al., 2014; Vanheule et al., 2011) and adaptive healthy behaviors (Lumley et al., 2007; Wheeler et al., 2005). Prevalence of alexithymic characteristics including lack of insight and externally oriented thinking style interferes with treatment compliance and patient’s ability to benefit from psychotherapeutic interventions (H. J. Grabe et al., 2008; Krystal, 1982). In the context of the current study, an individual with higher alexithymic trait might have issues adhering to the savings program and/or comply with the protocol of the program and thus fail to consistently save over a period resulting in poorer savings outcomes. Based on prior evidence, we speculate that alexithymia is a relevant treatment target while considering the improvement of savings behavior. While further research is warranted, interventions focusing on the treatment of alexithymia may be efficacious towards increased financial growth.

Our findings further indicated a direct negative correlation between striatal subregion activity during risky-DM and savings outcome indicating that the increases in risk-related striatal activity is linked with reduced real-world money-saving behavior. The striatum is implicated in reward processing, goal-directed, and motivating behaviors (Balleine et al., 2007; Liljeholm & O’Doherty, 2012; Palmiter, 2008). While striatum is consistently associated with a wide range of risky behaviors including substance abuse (Barrett et al., 2004; David et al., 2005; Sweitzer et al., 2016), altered striatal activity has
also been shown to predict treatment outcomes. Previous results from a study suggest that atypically increased striatum activation during a risky-DM task prior to drug abuse was found to be associated with failure to learn from adverse consequences promoting continuous drug use (Hulvershorn et al., 2015). Our result indicates that significant activity in the striatum subregion during BART is associated with reduced savings outcomes which might be either related to impaired motivation regulation, poor self-control mechanisms, and/or inability to learn from consequences (Liljeholm & O’Doherty, 2012). Additionally, as striatal activity was directly correlated with savings behavior and not correlated with personality metrics and laboratory performance, risk-related activity in this region could be a potential neural biomarker of real-world financial savings behavior suggesting its role as a potential treatment target.

**Limitations.** The current results should be considered with several limitations. Our study interrogating risky-DM-related brain activity among low-SES individuals lacks a comparison group and has a relatively small sample size limiting referential interpretation of the outcomes. Similarly, we have utilized three factors (income, education, and the number of dependents) to operationalize SES, however, SES has been operationalized using multiple constructs (social prestige, neighborhood quality, parental interaction, childhood adversity, occupation, and urbanicity) in the existing literature (Lawson et al., 2018; Yaple & Yu, 2019). Further, we utilized hypothetical monetary reward in the BART employed in this study, however higher risk aversion was observed when a large amount of real money was used (S. Xu et al., 2019). Whether same DM mechanism underlie task performance with hypothetical (vs. real) monetary reward is a topic of continuous debate.
Similarly, we have utilized a mediation model to demonstrate the underlying role of EPB by which brain function affects savings behavior. Although previously methodological work emphasizes against examining mediation in cross-sectional data with no experimental manipulation (A. F. Hayes, 2017). However, we argue that examining the effects of low-SES related stress on cognitive function measured at future timepoint might alter with changes in SES level, as brain activity at a later time-point might exacerbate the negative impact (Duval et al., 2017; Gonzalez et al., 2016; P. Kim et al., 2013).

**Conclusion.** Our findings indicate that increased risky-DM-related activity in CMA was associated with better real-world savings outcomes. Further, this relationship was found to be significant among individuals with low alexithymia, such that individuals with lower alexithymia (versus higher alexithymia) had better strategic-DM with higher real-world savings. Overall, our results suggest that higher risk-related amygdala activity and/or lower levels of alexithymia may be relevant factors associated with success linked to real-world money-saving behavior. Given the role of aberrant amygdala function in alexithymia (T. Farah et al., 2018; Kugel et al., 2008), our results suggest that the inability to save money could be associated with impaired DM related to alexithymia (Marchetti et al., 2019; Stasiewicz et al., 2012; Sutherland et al., 2013). Understanding underlying brain-behavior relationships associated with savings behavior among low-SES individuals may provide principled first steps toward the development of tailored interventions aiming to increase financial stability and facilitate adaptive behavioral change for financial success geared towards minimizing SDoH related disparity.
Fig 1. Modified BART. In each trial, participants had to pump a virtual balloon during the “pump phase” to win money. Each pump increased the likelihood of winning more money but also conferred greater risk as the probability that the balloon would pop increased. The pump phase was followed by a “wait phase” (i.e., where participant waited for few seconds). Next, participants were presented with an animation of balloon being inflated in the “inflate phase”. An “outcome” phase followed the inflate phase, in which the participants were presented with the outcome to indicate that they have either won the reward or the balloon popped. This was followed by Rest phase (baseline) where participants waited for the next trial to begin.
Task effect:

**Fig 2. Brain activity related to BART.**  
(A) Brain activity related to risky decision-making (Decision phase, $p_{\text{corrected}}<0.05$) was observed in multiple brain regions including bilateral middle temporal gyrus, bilateral amygdala, bilateral striatum, bilateral cingulate gyrus, left precuneus, left angular gyrus.  
(B) Brain activity related to the positive outcome (positive outcome/win phase, $p_{\text{corrected}}<0.05$) was observed in bilateral cingulate, bilateral caudate, bilateral middle frontal gyrus, bilateral angular gyrus, left fusiform gyrus, left supramarginal gyrus, right lentiform nucleus, and right thalamus.  
(C) Brain activity related to negative outcome (negative outcome/pop phase, $p_{\text{corrected}}<0.05$) was observed in bilateral inferior frontal gyrus, bilateral lingual gyrus, bilateral precentral gyrus, bilateral inferior frontal gyrus, left angular gyrus, left precuneus, left medial frontal gyrus, right inferior parietal lobe.  
[see Table S1 for detailed list of brain regions]
Brain-Behavior relationship:

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<th>Brain regions</th>
<th>BART Behavior</th>
<th>Personality</th>
<th>Real-world behavior</th>
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(A) Risk-related activity (pump vs. baseline) in right CMA was significantly positively correlated with objective measure of strategic-DM in BART \[ r(22)=0.44, p_{\text{Bonferroni-corrected}}=0.03 \], where increased CMA activity was associated with higher strategic-DM in BART. (B) Risk related activity in right SFA was not correlated with either BART performance, personality metrics, or real-world behavior. (C) Risk related activity in right LBA was negatively significantly correlated with measure of alexithymia \[ r(22)=-0.53, p_{\text{Bonferroni-corrected}}=0.02 \], where increased LBA activity was associated with lower self-report measure of alexithymia. (D, E) Risk related activity in bilateral posterior putamen is negatively significantly correlated with real-world savings behavior [right striatum-money saved: \( r(22)=-0.41, p_{\text{Bonferroni-corrected}}=0.04 \), left striatum-money saved: \( r(22)=-0.41, p=0.02 \)], where increased striatal activity was associated with lower savings outcome. **Abbreviations** lt; left, rt; right.
Brain-Behavior relationship:

Fig 4. Objective measure of strategic-DM mediated right CMA’s influence on Saving behaviors. (A, B) As measure of strategic-DM (i.e., effective pump bet) was correlated with both right CMA activity and savings, we subsequently conducted a mediation analysis to test the hypothesis that the effect of right CMA activity (X) on real-world financial behavior (Y) was mediated by BART performance (M). (C) BART performance fully mediated the influence of right CMA activity on real-world savings behavior. Specifically, when including BART performance as a mediator in the model, right CMA’s direct effect on real-world financial behavior was not significant (c’ path: \( \beta = -0.176, p = 0.432 \)), while the indirect effect was significant (ab path: \( \beta = 327.5, 95\% \ CI = 51.96, 799.7134 \)). Additionally, alexithymia score moderated the mediation such that the indirect effect of CMA activity on real-world financial behavior through BART performance is moderated by alexithymia. (D) When alexithymia score is low, the conditional indirect effect of amygdala activity on real-world financial behavior via BART performance was significant in a positive direction (\( \beta = 895.27, 95\% \ CI = 176.98, 1471.16 \)). In contrast, when alexithymia score was high, the effect was non-significant (\( \beta = -105.38, 95\% \ CI = -620.52, 550.82 \)). Abbreviations: CMA; centromedial amygdala, alex; alexithymia
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<th>Variables</th>
<th>M</th>
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<td>.526**</td>
<td>.488*</td>
<td>.464*</td>
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<td>-.511*</td>
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** Table 1. Correlation between BART performance, personality trait measure, and real-world financial behavior **

** Correlation significant at the 0.01 level (2-tailed)
* Correlation significant at 0.05 level (2-tailed)
Table 2: Indirect effects of the study variables (Bootstrap sample size = 5,000. 95% CI = 95% confidence interval)

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<tr>
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<td>251.98</td>
<td>-620.52, 550.82</td>
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<tr>
<td>M+1 SD (57.07)</td>
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<td>Index of moderated mediation</td>
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<td>16.94</td>
<td>3.55, 70.75</td>
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Number of bootstrap samples for percentile bootstrap confidence intervals: 5000
SUPPLEMENTAL

Table S1. Demographics table for participants included in the study

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<th>Demographics</th>
<th>Participants (n=27)</th>
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<td>41.22 ± 12.65</td>
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<td>12</td>
</tr>
<tr>
<td>Female</td>
<td>15</td>
</tr>
<tr>
<td>Income</td>
<td>13,872 ± 8020.43</td>
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<tr>
<td>Race</td>
<td>14AA, 13C</td>
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<tr>
<td>Ethnicity</td>
<td>9NH, 18H</td>
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<tr>
<td>Education</td>
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<tr>
<td>High School Diploma</td>
<td>14 (52%)</td>
</tr>
<tr>
<td>Associates</td>
<td>8 (30%)</td>
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<tr>
<td>Some college</td>
<td>5 (18%)</td>
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Table S2. BART decision-making and outcome cluster coordinates. Regions showing activity during decision making, positive outcome, and negative outcome phase (n=24): 3 participants from the total sample (n=27) that did not participate in the savings program were excluded.

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<th>Region</th>
<th>Volume</th>
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<td>putamen and thalamus)</td>
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<tr>
<td>frontal gyrus)</td>
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**Positive outcome (win)**

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**Negative outcome (pop)**

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<td>95</td>
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<td>-9.6</td>
</tr>
<tr>
<td>18</td>
<td>Inferior temporal gyrus</td>
<td>R</td>
<td>93</td>
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</tr>
<tr>
<td>19</td>
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<td>78</td>
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</tr>
<tr>
<td>21</td>
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<td>R</td>
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<tr>
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<tr>
<td>24</td>
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<td>47</td>
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<tr>
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<td>L</td>
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<td>Caudate</td>
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<td>Parahippocampal gyrus</td>
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<tr>
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<td>L</td>
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<td>-33.6</td>
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</table>

**NOTE.** X: Left (-), Right (+); Y: Posterior (-), Anterior (+); Z: Inferior (-), Superior (+). Region labels come from the AFNI Talairach daemon atlas. See Figure 2A, B, C for graphical representation.
**Fig S1.** Mediation and moderated mediation model. (A) Mediation model where objective measure of strategic risk-taking potentially mediates the relation between brain function and real-world savings behavior. (B) Moderated mediation model where underlying personality moderates the above-mentioned mediation.
Study 2

WORKING MEMORY PERFORMANCE MEDIATES THE RELATIONSHIP BETWEEN DEFAULT MODE NETWORK DEACTIVATION AND REAL-WORLD FINANCIAL SAVINGS AMONG INDIVIDUALS FROM LOWER INCOME HOUSEHOLDS

Ranjita Poudel1, Michael J. Tobia2, Michael C. Riedel2, Taylor Salo1, Jessica S. Flannery1, Lauren D. Hill-Bowen1, Anthony S. Dick1, Angela R. Laird2, Carlos M. Parra3†, Matthew T. Sutherland1†

1Department of Psychology, Florida International University, Miami, FL
2Department of Physics, Florida International University, Miami, FL
3College of Business, Florida International University, Miami FL

† These individuals made ‘senior author’ contributions to this work.

*Correspondence:
Matthew T. Sutherland, Ph.D.
Florida International University
Department of Psychology
AHC-4, RM 312
11299 S.W. 8th St
Miami, FL 33199
masuther@fiu.edu
305-348-7962

KEYWORDS: working memory, default mode network, socioeconomic status, executive function, financial decision-making, money-saving
Abstract

**Background.** Social Determinants of Health (SDoH) such as low socioeconomic status (low-SES) impacts a wide range of cognitive functions including working memory (WM). Disrupted WM mechanisms are widely implicated in socioeconomic achievement gap and disparities related to health behaviors which may result in a non-culminating poverty cycle that may promulgate health inequity. Despite evidence suggesting the role of WM constructs in money-saving behavior which may leverage SES, neurocognitive mechanisms associated with money-saving behavior remains to be understood. To this end, we interrogated WM-related brain activity and its association with real-world savings outcome to identify potential neurocognitive markers linked with savings behavior.

**Methods.** Participants with low-SES (N=27; income < $20,000/yr) underwent fMRI scanning while performing letter n-back task to quantify brain activity and behavioral indices related to WM mechanism. Participants also completed a self-report instrument probing everyday cognitive failure and participated in a savings program where their real-world money-saving behavior was tracked for 6 months.

**Results.** Regarding the WM-related task effect, elevated deactivation in default mode network (DMN) nodes and elevated activation in central executive network (CEN) nodes modulated by WM load was observed. Regarding brain-behavior relationship, increased DMN deactivation was positively correlated with objective measure of WM (dprime), indicating that as WM-related DMN deactivation increases, WM performance improves. Whereas, increased CEN activation was negatively correlated to a self-reported measure
of cognitive failure subscale, indicating that as subjective cognitive failure decreases, WM-related activation increases. Further, considering the brain-behavior relationship, we found that objective measure of WM (i.e., dprime) mediates the effect of DMN deactivation on real-world savings behavior such that increased DMN deactivation improves dprime which, in turn, results in better savings.

**Conclusions.** These results demonstrate that intervention targeting DMN activity and/or laboratory WM performance may translate to success in terms of real-world financial saving behavior.

**Introduction**

Financial crises including economic recession and pandemic have emphasized the importance of emergency savings funds particularly among individuals with low socioeconomic status (SES) (Adams & West, 2015; Hall, 2021; Palacio & Tamariz, 2020; Singu et al., 2020, p. 1). Research examining American’s financial capabilities has demonstrated that only 49% of participants have set aside savings for three months in case of financial emergencies (Lusardi & Mitchell, 2011). Importantly, most households lack enough assets to replace one month of income (Despard et al., 2020). Even with widely available matched savings programs and accessible banking, the personal savings rate in the United States has declined from 11 percent in 1960 to 6.9 percent in 2019 (Hall, 2021; U.S. Bureau of Economic Analysis, 1959), which warrants the focus on financial policies towards long term planning and economic stability by encouraging modification of financial savings behavior informed by brain-behavior research. However, previous
literature suggests that research targeting brain-behavior relation contributes minimally towards building financial policies (Hall, 2021).

Day-to-day stress related to low-SES conditions has consequences on a range of cognitive mechanisms including working memory (WM) (Evans & Schamberg, 2009). The scarcity hypothesis suggests that low-SES is a proxy to living in a highly stressful environment (including food insecurity, economic insecurity, lack of resources, exposure to toxins, and poor neighborhood quality) that jeopardizes the developmental trajectory as well as current mental health state (Mullainathan & Shafir, 2013a) which may impair the WM mechanisms (Darke, 1988; Goodman et al., 2019; Luethi et al., 2009; Marazziti et al., 2010; Shields et al., 2019). Previous research has shown that WM mechanism is impacted by low-SES factors including parental education (Akhlaghipour & Assari, 2020), low income (Kokosi et al., 2021), early life adversity (Goodman et al., 2019; Hackman et al., 2014; Leonard et al., 2015), and neighborhood disadvantage (Wright et al., 2020). Further, impaired WM function may lead to diverse health disparities such as substance abuse, problem gambling, anxiety, and depression that are over-represented among low-SES populations (Dehn, 2011; Hackman et al., 2014; Houben et al., 2011a; Riggs et al., 2010; Snyder, 2013; Wu et al., 2017). These disparities among low-SES populations progressively widen over developmental phases of an individual’s life because of continuous exposure to poverty-related stress and create a feedback loop perpetuating a vicious poverty cycle.

WM refers to active short-term maintenance and manipulation of information critical for a wide range of cognitive abilities including IQ, mathematical skills, and reading comprehension (Cowan, 2014; Hackman et al., 2014). WM has been shown to be a good
indicator of academic success as this measure predicts improved mathematical performance (Simmons et al., 2012; L. Swanson & Kim, 2007) and academic success (Cortés Pascual et al., 2019) which is critical for leveraging SES. Speaking to the role of WM in economic behaviors, previous reports have demonstrated that less mind wandering, characteristic of higher WM capacity (McVay et al., 2009; Oberauer, 2019), is associated with better money management behavior (Elma & Baydaş, 2020). Similarly, higher WM span, another measure of WM performance, predicted better task performance in a laboratory savings paradigm (Ballinger et al., 2011). Based on the available evidence, understanding the role of WM performance measures on the real-world money-saving behavior could provide initial insights on characterizing individuals who may need or benefit from the interventions targeted for building financial savings behavior.

Neuroimaging studies have shown the association of WM task performance and increased activation in central executive network (CEN) nodes (Hu et al., 2013; Owen et al., 2005) specifically in dorsolateral prefrontal cortex (dIPFC) (Cannon et al., 2005; Collette & Van der Linden, 2002) and posterior parietal regions (Schmidt et al., 2009). The CEN is responsible for task-related (top-down) processing and show increased activation during cognitively demanding tasks. Regarding WM task, CEN is responsible for maintaining and manipulating information, and decision-making for goal-directed behaviors (Berryhill et al., 2011; Koechlin & Summerfield, 2007; Müller & Knight, 2006). WM performance among low-SES individuals is associated with disproportionately elevated activation in CEN node as compared to high-SES individuals thus requiring higher neural resources to maintain a similar level of performance during WM task (M. J. Farah, 2017; Sheridan et al., 2012). Aberrant CEN activity during WM task have been previously
reported in psychopathological conditions such as depression, anxiety, and stress related disorders that are highly prevalent in low-SES population (Balderston et al., 2017; Harvey et al., 2005).

In contrast, enhanced deactivation, during WM performance, was observed in default mode network (DMN) nodes such as posterior cingulate cortex (PCC) and medial prefrontal cortex (mPFC) (Hu et al., 2013). DMN is a set of brain regions that show task-induced deactivation across a wide range of cognitive paradigms including WM (Mayer et al., 2010). Theoretically, DMN deactivation suppressed spontaneous brain activity for relocation of resources during attention-demanding tasks, thereby, increasing the resource allocation to CEN as attention demands increase (Hu et al., 2013; Singh & Fawcett, 2008). DMN deactivation has been shown to correlate with WM task performance suggesting that higher DMN deactivation is associated with better WM performance (anticivic et al., 2010). However, acute psychological stress, characteristic of low-SES, has been shown to reduce DMN deactivation during WM performance (Qin et al., 2009). Performing WM-task while coping with day-to-day stress related to low-SES could be considered a continual dual processing which may result in difficulty inhibiting task-irrelevant internal thoughts thus by relocating resources away from CEN to DMN (Hu et al., 2013; McKiernan et al., 2003; Singh & Fawcett, 2008). This dual processing also impacts the accuracy and response time of the task (Oei et al., 2006). While failure to deactivate DMN has been observed in certain stress-related psychopathology highly prevalent among low-SES population such as bipolar depression (Bartova et al., 2015; Fernández-Corcuera et al., 2013), enhanced DMN deactivation during task performance has been associated with academic and personal success (Immordino-Yang, 2016). The role of WM-related DMN
deactivation in money-saving behavior could shed light into insights for the development of novel interventions targeted for financial success.

In this small-scale pilot study, we assessed WM-related brain activity and examined its relationship with laboratory performance, and real-world savings behavior among individuals from low-SES households. We anticipated that the WM would be related to increased DMN deactivation and increased CEN activation, modulated by WM load (Bartova et al., 2015; Hu et al., 2013). Additionally, we addressed two empirical questions involving brain-behavior relationships regarding WM, laboratory performance, and real-world money-saving behavior. Regarding laboratory behavior, we hypothesized that DMN and CEN activity correlated with WM task performance. Regarding money savings behavior, we hypothesized that DMN and CEN activity predicts money saved and that this relationship is mediated by the measure of laboratory WM performance in the lab. Enhanced understanding of brain correlates and cognitive processes related to WM and their influence on financial behavior may provide initial insights into the design and development of interventions geared towards improving financial savings behavior in low-SES populations.

Methods

Participants. Participants (N=27) with low-SES background (<20,000$/yr household income) were enrolled in collaboration with Catalyst Miami. Catalyst Miami is a non-profit organization with a mission to improve health, education, and economic opportunities in the community. Catalyst, through their community outreach programs, works towards connecting low-income families with financial services such as tax
preparation, credit building, savings opportunities, and financial coaching. We recruited individuals from different community outreach programs within Catalyst Miami as well as from the community via advertisement flyer. All participants were 24 to 60 years old to minimize the effect of aging-related conditions on brain function. Participants were drug-free as confirmed by urine and breathalyzer test and had no presence or history of any medical, neurological, or psychiatric disorder or contraindications related to fMRI. All participants signed a written informed consent approved by the Ethical Committee of Florida International University, FIU.

** Procedures.** The current study consisted of two segments: (A) neuroimaging session with self-report questionnaire survey (one visit approximately 4 hours), and (B) savings program (approximately 6 months). The neuroimaging session initiated with substance use screening to confirm participants were free of drug influence via breathalyzer testing (BACtrack S80 Breathalyzer) and urine toxicology (Drug Check Cup, NXStep). During the neuroimaging session, participants completed fMRI scan while performing a WM task (letter n-back task) and self-report questionnaire probing everyday cognitive failure. After completion of the neuroimaging session, participants were enrolled in Catalysts’ matched savings program which involved saving $20 each month for the subsequent 6 months.

**Savings program.** After completing the neuroimaging session, all participants were enrolled in a savings program and instructed to achieve a savings goal each month ($20/month), for the following 6 months. Financial savings behavior data were collected for 24 participants who completed a 6-month savings program. Participants received a $10
reward for meeting each month’s savings goal, and a $60 reward for successfully completing the 6-month savings program without any interim withdrawals. Each participant’s total savings at the end of this program was considered as the main financial savings behavior indicator. Three participants (2 males and a female were excluded as they were not eligible for savings account).

**Neuroimaging data collection.** fMRI Data were acquired with a 3T Siemens Prisma scanner. During the MRI session, participants were prepped/loaded into the machine, and neuroimaging data were collected while the participants performed the WM (letter n-back) task (as well as a risky decision-making task and a resting state scan [not described further here]). Additionally, structural scans (T1-weighted scans) were also collected. A standard echo-planner imaging sequence was used to acquire BOLD fMRI data while participants performed n-back (TR= 800ms, TE= 30 ms, FOV = 216 mm, slice thickness = 2.4 mm). Participants also underwent a high-resolution anatomical T1 sequence with the following parameters repetition time = 9.9 ms; echo time = 4.6 ms; flip angle = 2Åã; voxel size = 2.4 mm³ (32 slices), slice thickness = 8mm, FoV= 256mm.

**Self-report measures.** In total, we collected 8 self-report measures assessing aspects of cognition, reward, and Emotion. We further assessed clinically relevant self-report measure of cognitive failure to examine the relationship between the WM-related brain activity and self-reported cognitive failure in everyday life. We utilized a standardized self-report measure called cognitive failure questionnaire (CFQ) to measure lapses in perception,
memory, and motor function (Broadbent et al., 1982). This questionnaire consists of three subscales namely forgetfulness, distractibility, and false triggering (Rast et al., 2009).

**Working memory task (n-back task).** To assess behavioral and neural indices of WM, participants completed the letter n-back task, a widely used cognitive paradigm to probe WM under increasing memory loads. Each run included four [i.e., 0-back (0b), 1-back (1b), 2-back (2b), and 3-back (3b)] levels, during which participants saw a letter appear on the screen one at a time [Fig. 1]. During the 0-back level, participants had to respond with a button press each time a predetermined target (letter) appeared on the screen and avoid responding to other non-target stimuli. Participants were required to respond to the letter if it was the same as one letter ago (1-back task), two letters ago (2-back task), or three letters ago (3-back task) depending on the level. Participants completed three runs [5mins each] of the task. Each WM task run consist of eight blocks while each task level (0b, 1b, 2b, or 3b) was presented twice. Each block consisted of 15 consecutive trials, 33% of which included targets. Before each condition, a visual instruction (2 sec) indicating the upcoming condition was presented. Each of the runs started with 0b level and the 1b, 2b, and 3b levels were presented in a counterbalanced manner. All subjects were trained and had an opportunity to practice a brief version of the n-back task in a mock scanner before imaging. The objective measure of task performance at each task condition was d′prime which was estimated by the hit rate (proportion of the hits when a signal is present [hits/(hits + misses)]), penalized by the false alarm rate (proportion of false alarms when a signal is absent [false alarms/(false alarms + correct negative)]) (Haatveit et al., 2010).
Data-analysis:

Preprocessing. MRI data were preprocessed using standard fMRIPrep, a Nipype-based tool, (version 1.1.5). (Abraham et al., 2014; Esteban et al., 2019; Gorgolewski et al., 2011). Fieldmap images were utilized for distortion correction. T1-weighted structural volumes were skull-stripped (antsBrainExtraction.sh v2.1.0), corrected for intensity non-uniformity (N4BiasFieldCorrection v2.1.0) (Tustison et al., 2010), and were spatially normalized to the ICBM-152 asymmetrical template v2009c utilizing nonlinear registration (ANTs v2.1.0) (Fonov et al., 2009). Motion correction was implemented utilizing MCFLIRT (FSL v5.0.9) [95]. Slice-time correction to the middle of each TR was performed using 3dTshift (AFNI v16.2.07) (Cox, 1996). Functional images were co-registered to corresponding anatomical volumes (Treiber et al., 2016) utilizing average field map template to correct for distortion (Huntenburg et al., 2014; S. Wang et al., 2017). Finally, bbregister (FreeSurfer v6.0.1) that implements boundary-based registration was utilized to co-register functional volumes to T1-weighted volumes (Greve & Fischl, 2009). Lanczos interpolation was implemented to correct for motion and distortion, functional-to-anatomical registration, and anatomical-to-template transformation all in one single step (antsApplyTransforms ANTs v2.1.0). Further preprocessing was conducted in AFNI version 17.3.06. The data were further spatially blurred to 6-mm FWHM using AFNI’s 3dBlurTOFWHM (Cox, 1996). To control for motion, motion-censoring was implemented such that functional volumes with greater than 0.35-mm Euclidean norm mean displacement were discarded. Additionally, functional volumes immediately adjacent to the discarded volume and those with fewer than three contiguous uncensored neighbors were also censored. Further, individual neuroimaging scan sessions were excluded if
greater than 25% of the functional volumes from that session were censored. Two participants were discarded from further analysis after motion censoring (i.e., included the ones that had no access to savings account).

**fMRI data analysis.** Task-related activation during the 1b, 2b, and 3b levels of WM task compared with the control 0b level activation were obtained by utilizing general linear models (GLM). To account for motion, we submitted six motion parameters to the GLM as covariates and temporal autocorrelation in the residuals was accounted by implementing 3dREMLfit. At group level, whole-brain voxel wise fMRI brain activity patterns were examined by ANOVA (3dANOVA2). Group-level analysis utilized the contrast maps estimated from the first-level analysis (i.e., 1b versus 0b, 2b versus 0b, and 3b versus 0b) modeled as three levels of WM load ($P_{\text{corrected}} < 0.05$, $P_{\text{voxel-wise}} < 0.001$; cluster extent: 28 voxels). To examine brain activity related to WM performance in detail, regions of interest (ROIs) were defined based on the main effect revealed from the whole-brain voxel wise ANOVA analysis. Post-hoc tests on BOLD signal alteration at different WM loads were conducted to elucidate the brain activity modulation by WM load at each level.

**Brain Behavior relationship.** In addition to the task-based effect on brain function, to examine the brain-behavioral relationship, the correlation between the BOLD signal change in brain regions showing significant WM task-effect and measure of WM task performance (i.e., dprime) was examined. We further conducted bivariate Pearson’s correlation analysis using SPSS (version 26) to assess the relationships between brain activity and subjective measure of everyday cognitive failure (i.e., self-
report scores in CFQ (Broadbent et al., 1982) as well as real-world money-saving behavior (saving outcome at the end of 6 months period).

**Mediation analysis.** We conducted mediation analysis using SPSS PROCESS V3.4 to examine whether the relation between brain activity during WM task (X) and real-life money-saving behavior (i.e., money saved over the course of 6 month) (Y) was explained by laboratory performance in WM task (i.e., dprime) (M) [MODEL: WM-related brain activity (X) $\rightarrow$ laboratory WM performance/dprime (M) $\rightarrow$ real world behavior/savings (Y)]. By convention, path “c” in the mediation model denotes to the total effect of brain activity on savings outcome. Path “a” is the impact of brain activity on dprime and path “b” denotes the effect of laboratory performance on real-world behaviors. The total effect (path “c”) of WM-related brain activity on savings was decomposed into direct effect (path c’) and indirect effects (path ab: i.e., c=c’ + ab). The indirect path (i.e., ‘ab’ path) constituting the effect of brain activity on real-word saving via task performance is significant if bias-corrected 95% confidence interval, calculated via bootstrapping, does not constitute zero or rejects the null hypothesis (A. Hayes, 2012; A. F. Hayes, 2017).

**Results**

**Behavioral Results.** We found that WM performance (i.e., dprime) was modulated by WM load such that dprime increased with increasing WM load (Fig. 2A; $F_{(3,104)} =221.610, p < 0.05$ ). Further, post-hoc comparison of dprime between each condition showed that dprime was significantly different between conditions. Similarly, WM load was also found to modulate response time (Fig. 2B; $F_{(3,104)} =20.014, p < 0.05$).
**fMRI results.** Significant main effect of WM task was observed in brain regions including bilateral medial frontal gyrus, bilateral inferior parietal lobe, left PCC, and left middle frontal gyrus. To represent the brain activity associated to WM task, brain activations and deactivations at the contrast 3b versus 0b are demonstrated [Fig. 3A]. Specifically, increased activation was observed in brain regions associated with CEN including dorsolateral prefrontal cortex (dIPFC) and parietal cortex (PC) (orange), and increased deactivation was observed in brain regions associated with DMN including PCC, precuneus, and mPFC (blue) [Fig 3A]. This finding is widely consisted with previous studies probing WM-related brain activity (Hu et al., 2013; Rocca et al., 2014).

ROIs obtained from the main effect of the WM task at p<0.05 (corrected for family-wise error and spatial autocorrelation) were selected in the PCC/Precuneus (210 voxels), mPFC (554 voxels) (blue), right dIPFC (249 voxels), and right PC (1024 voxels) (orange). Post-hoc analysis utilizing β-values from the ROIs demonstrated that the WM-related brain activity is modulated by WM load such that DMN deactivation under 3b level were stronger compared to 1b and 2b levels [Fig. 3A, 3B].

**Brain-behavioral relationship.** Task-related deactivation in DMN nodes such as precuneus and mPFC was significantly correlated with WM task performance (i.e., dprime) [Precuneus: r(22)=-0.5, p=0.04, mPFC: r(22)=-0.52, p=0.03] and not with self-reported personality metric [Precuneus: r(22)=-0.146, p=0.49, mPFC: r(22)=-0.375, p=0.071] [Fig 3C] indicating that as WM-related DMN deactivation increases, task-performance improves. However, the activation in CEN nodes such as PFC and PC was significantly
negatively correlated with measure of self-reported cognitive failure (i.e., false trigger: subscale of cognitive failure questionnaire), [PFC: r(22)=-0.5, p=0.04, PC: r(22)=-0.41, p=0.05], and not with task-performance [PFC: r(22)=-0.15, p=0.48, PC: r(22)=-0.032, p=0.88] [Fig 3D], indicating that as subjective measure of cognitive failure decreases, CEN activity increases. The association of the PC cluster with measure of cognitive failure was not significant when corrected for multiple comparison. None of the significant clusters showing WM-related activity was directly associated with real-world money-saving behavior [Fig 3E].

**Simple Mediation Analysis.** As laboratory behavioral measure of 3b WM performance (dprime) was correlated with both precuneus and mPFC deactivation and real-world savings behavior, we subsequently conducted a mediation analysis to test the hypothesis that the effect of brain activity on real-world savings behavior was mediated by WM performance (M) [Model: brain activity (X) → WM performance (i.e., dprime) (M) → real-world savings behavior (Y)]. Task performance fully mediated the influence of precuneus and mPFC deactivation on real-world money-saving behavior. Specifically, when including objective measure of WM performance (i.e., dprime) as a mediator in the model, precuneus and mPFC’s direct effect on real-world money-saving behavior was not significant (Precuneus: c’ path: β=34.43, p=0.39, mPFC: c’ path: β=130.61, p=0.22), whereas the indirect effect was significant (Precuneus: ab path: β= -112, 95% CI= -229.22, -32.06, mPFC: ab path: β= -181.08: 95% CI= -421.35, -20.76) [Fig 4A,B, Table 1] indicating that as WM-related DMN deactivation increases, task performance improves which, in turn is related to better money-saving behavior. This effect, however, was not
observed when considering the effect of CEN activation on money-saving behavior mediated by WM performance (Frontal: ab path: β=-43, 95% CI= -194.6, 96.7) [Fig 4C, Table 1].

Discussion

We examined brain activity associated with WM during the letter n-back task and its association with laboratory WM performance and real-world money-saving behavior among individuals with low-SES. Regarding task effect, increased WM-related deactivation with increasing memory load was observed in the precuneus, PCC, lateral frontal gyrus, and mPFC, brain regions that are components of DMN. Similarly, increased WM-related activation modulated by WM load was observed in bilateral PFC and PC, brain regions that are components of CEN. Further, considering brain-behavior relationships, we observed that increased WM-related DMN deactivation is associated with laboratory WM task performance while increased WM-related CEN activation was associated with subjective cognitive failure. Further, considering the relationship between brain function, task performance, and real-world behavior, we found that the measure of laboratory WM performance (i.e., dprime) mediated the effect of DMN deactivation (Precuneus and mPFC) on real-world savings behavior such that increased WM-related deactivation is associated with improved task performance which, in turn was associated with better savings outcome. However, such a relationship was not observed for WM-related CEN activation. These results suggest that individual differences in WM-related activity in DMN and/or laboratory WM performance may be relevant factors linked to the success in terms of real-world money-saving behavior. These results bridge the gap
between neurocognitive mechanisms related to WM construct among individuals with low-SES, personality trait that predispose WM mechanisms, and real-world financial behavior.

Consistent with previous reports, our results suggest robust engagement of frontoparietal regions during WM task (Owen et al., 2005). Previous meta-analytic report probing WM paradigms has reported convergent activation in dIPFC, bilateral posterior PC, and anterior cingulate cortex (Owen et al., 2005) modulated by memory load (Rypma et al., 2002; Tomasi et al., 2007). Network analysis has collectively attributed these regions as nodes of CEN and has reported their involvement in exogenously driven, cognitively demanding goal-oriented behavior (Cocchi et al., 2013). The lateral PFC is linked with mechanisms including information encoding, manipulation, and response selection. In contrast, the parietal region is linked with encoding, maintaining, and retrieval of information (D’Esposito et al., 2000; Guerin & Miller, 2011). The concomitant activation of the frontal and parietal regions as observed in our results, have been previously reported during WM performance, is important for maintaining temporal information, switching of attention, and recruiting other neural regions critical for attention regulation (Owen et al., 2005; Ravizza et al., 2004). Further, resting-state connectivity analysis has demonstrated increased integration or coupling of CEN nodes (i.e., dIPFC and PPC regions) with increasing WM load (Dima et al., 2014; Ma et al., 2012) which is further associated with WM task performance (J. Shen et al., 2015). The association of WM-related activation in the CEN nodes, although modulated by WM load was not associated with WM performance in the current study. Instead, we observed that this WM-related activation was associated with a self-report measure of everyday cognitive failure. While the cognitive failure has been shown to be associated with a poorer objective measure of WM and
increased lapses in attention during task-performance (Kane et al., 2007; McVay et al., 2009), further research interrogating association between WM-related brain function and self-reported measure of the cognitive failure is warranted.

As suggested by prior studies, we observed increased DMN deactivation (suppression) with increasing WM load during the WM task (Sambataro et al., 2010). Prior studies have interpreted increased DMN deactivation as a mechanism of suppressing brain activities to internal activity (i.e., mind wandering) while reallocating attentional resources for optimization of relevant goal-oriented behaviors (Menon, 2011; Sridharan et al., 2008). As memory load increases with increasing task difficulty, higher suppression of DMN is observed with increasing WM load (Čeko et al., 2015). Elevated DMN deactivation modulated by memory load suggests the flexible and dynamic nature of DMN nodes based on task demand (Anticevic et al., 2012; Hu et al., 2013) indicating the critical role of task based DMN activity suppression for improved task performance. Deficient deactivation of DMN during WM performance is supposedly associated with acute psychological stress (Qin et al., 2009) generally prevalent in lower SES conditions. Stress related to low-SES is shown to alter the regulation of hypothalamic-pituitary-adrenocortical axis (HPA axis), by inducing high cortisol levels with consequences on WM mechanisms (Oei et al., 2006).

Further, aberration related to DMN activity has been widely implicated in real-world behaviors such as substance abuse (R. Zhang & Volkow, 2019) and psychopathologies including depression (Bartova et al., 2015; Gärtner et al., 2018), factors that may act as a precursor for the poverty cycle.

Our results suggest that enhanced task-related DMN deactivation is associated with better WM performance and better WM performance further predicted higher savings.
Previously poorer WM performance has been shown to predict greater delay discounting (Hendershot et al., 2018) and higher impulsivity, increasing the vulnerability to substance use disorder (Khurana et al., 2013) and problematic spending habits (DeHart et al., 2016). Further speaking to the role of WM performance in low-SES, a previous study suggested that individuals with housing compared to homeless performed better in WM task (Fry et al., 2020). Additionally, WM among homeless individuals predicted future housing situation such that individuals with longer WM spans had a higher likelihood of progression into independent housing after six months rather than maintaining their current homeless situation (Fry et al., 2020). These findings indicate that WM performance predicts maladaptive financial behavior suggesting its utility in identifying individuals who may need intervention and assistance to improve their financial situations. Our findings indicating the association between the WM performance and money-saving behavior may further shed light on prospective thinking ability among individuals with better WM performance (X.-H. Zhao et al., 2007). Overall, based on previous evidence and our findings, WM mechanisms could be a potential cognitive substrate for intervention in terms of building successful savings behavior.

Comparison of brain-behavior relationship with a higher SES group was out of scope for the current study, however, prior research suggests an association of low-SES (versus high-SES) with poorer WM performance potentially mediated via stress related to low-SES conditions (Leonard et al., 2015). Prior studies have suggested that poorer WM predicts poorer life outcomes with a higher risk of perpetuating the poverty cycle (Evans & Schamberg, 2009; Vohs, 2013). Recent findings from a large sample of adolescent study (Adolescent Brain Cognitive Development study) showed a significant effect of household
income in WM such that White children with highly educated parents have better WM, contrarily, Black children, regardless of parental education, demonstrated lower WM. This inequality in WM is mainly insinuated because of differential income in highly educated White and Black families (Akhlaghipour & Assari, 2020). This finding suggests the need of equalizing income to eliminate disparities related to children’s cognitive outcomes. Evidently, the impact of preexisting SES-related disparities is more evident following a crisis such as COVID-19 leaving individuals vulnerable to increased disparities in terms of disease susceptibility as well as health and health-care related inequity.

Based on prior evidence, it is important to address SES-related disparity and challenges related to financial growth in research aimed to develop intervention targeted for financial success. Although savings programs have been proven to be effective for successful savings with policies that promote financial education and matched savings programs, individual differences related to the savings behaviors poses a challenge when considering optimal savings outcome. Neuroscience research associated with interrogating the neural correlates of savings behavior could shed light on the neurobiological and cognitive mechanisms for informing financial policies and for developing and refining interventions for financial success aimed to leverage SES. For example, behavioral therapies such as mindfulness and WM training could be directed to alter the brain mechanism that regulate financial behavior. Mindfulness-based programs have been shown to modulate DMN connectivity by decreasing DMN activity during external task performance (Baer, 2003) with potential utility in improving money management behavior (Elma & Baydaş, 2020). Similarly, WM training reduced delay discounting (Bickel et al., 2011) and showed suppressed risk-taking during risky-DM task (Rosenbaum et al., 2017),
indicating that improved WM predicts prospect thinking and reduced impulsivity suggesting a potential utility of WM training as an intervention for successful savings behavior.

**Limitations.** The current results should be considered in light of limitations. First, the absence of a comparison group and a relatively small sample size limits our ability to interpret the potential differential outcomes compared to the control group. Second, we operationalized SES based on the demographic’s information including household income, education, and number of dependents. However, prior studies have utilized multiple constructs such as social prestige, neighborhood quality, parental interaction, childhood adversity, occupation, and urbanicity to operationalize SES (Lawson et al., 2018; Yaple & Yu, 2019). Further, future studies should seek to examine the relationship between allostatic load related to physiological markers of stress and brain-behavior relationship (Evans & Schamberg, 2009) to better identify the neurobiological marker of financial savings behavior.

**Conclusions.** Our findings suggest that better WM performance and/or increased WM-related DMN deactivation may be relevant aspects associated with successful money-saving behavior. As DMN suppression is suggestive of increased attention towards an external task, we suggest that saving behavior is hindered by the inability to direct attention to relevant external stimuli (Elma & Baydaş, 2020; Hu et al., 2013). Overall, neurocognitive mechanisms associated with WM could be a potential cognitive construct of interest for therapy towards improving financial savings behavior.
Tables and Figures

Fig 1. N-back task. Each run of the n-back task included four (i.e., 0-back, 1-back, 2-back, and 3-back) levels, during which participants saw a letter appear on the screen one at a time. During the 0-back level, participants had to respond with a button press each time a predetermined target (letter) appeared on the screen and avoid responding to other non-target stimuli. Depending on the level, participants were required to respond to the letter if it was the same as one letter ago (1-back task), two letters ago (2-back task), or three letters ago (3-back task). Participants completed 3 runs (5mins each) of the n-back task.
Behavioral results:

**Fig 2. Working memory (WM) behavioral results. (A)** Behavioral performance (dprime) during the WM task demonstrated a significant effect of memory load such that as the WM load increases, dprime decreases (F(3,104) = 221.610, p < 0.05). **(B)** Response time during WM task demonstrated a significant effect of memory load such that as the WM load increases, response time increases F(3,104) = 20.014, p < 0.05).
Brain-behavior relationship:

**Fig 3. Brain-behavioral relations.** (A) Brain areas showing main effect of the working memory (WM) task, brain activities within these areas at the 3b vs. 0b level are shown for illustration purposes ($p_{FWE-corrected} < 0.05$, cluster extent:28). (B) Graphical representation of beta values from regions showing significant brain activity with increasing WM load. Elevated deactivation with increasing WM load was observed in left precuneus, and left mPFC (blue) and increased activation with increasing WM load was observed in right dlPFC, and PC (orange). (C) The left precuneus and left mPFC deactivation was significantly correlated with 3-back WM task performance [left Precuneus: $r(22)=-0.50$, $p=0.04$, left mPFC: $r(22)=-0.52$, $p=0.03$] such that as brain deactivation increases, WM performance improves. (D) The activation in right dlPFC and PC was significantly negatively correlated with subjective measure of cognitive failure [right dlPFC: $r(22)=-0.5$, $p=0.04$, right PC: $r(22)=-0.41$, $p=0.05$] such that as subjective cognitive failure increases, task-related brain activation decreases. (E) Brain activity related to WM was not directly correlated with real-world money-saving behavior. Abbreviations: mPFC; medial prefrontal cortex, dlPFC; dorsolateral prefrontal cortex, PC; parietal cortex, WM; working memory, Cog. Failure; Cognitive Failure, DMN; Default mode network, CEN; central executive network.
Brain-behavior relationship:

**Fig 4.** Behavioral performance in WM task (i.e., dprime) mediated the effect of left Precuneus and mPFC deactivation on real-world savings behavior. *(A, B)* As WM performance in laboratory was correlated with DMN deactivation and real-world financial behavior, we subsequently conducted a mediation analysis to test the hypothesis that the effect of precuneus and medial prefrontal cortex (mPFC) deactivation (X) on real-world savings behavior (Y) was mediated by n-back performance (i.e., dprime) (M). WM performance fully mediated the influence of precuneus and mPFC deactivation on real-world savings behavior. Specifically, when including WM performance as a mediator in the model, precuneus’s and mPFC’s direct effect on real-world savings behavior did not reach significance (Precuneus: c’ path: β=34.43, p =0.39; mPFC: c’ path: β=130.61, p =0.22), whereas the indirect effect was significant (Precuneus: ab path: β= -112.12: 95% CI= -229.22, -32.95; mPFC: ab path: β= -181.76: 95% CI= -421.08, -20.76). *(C)* Control analysis indicating the effect of CEN activation on real world savings behavior was not mediated by laboratory behavior.
**Table 1:** Indirect effects of the study variables (Bootstrap sample size = 5,000. 95% CI = 95% confidence interval)

<table>
<thead>
<tr>
<th>Variables</th>
<th>B</th>
<th>SE</th>
<th>95% CI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Indirect effect of DMN deactivation on savings</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Precuneus</td>
<td>-112.12</td>
<td>49.12</td>
<td>-229.36, -32.95</td>
</tr>
<tr>
<td>mPFC</td>
<td>-181.76</td>
<td>101.58</td>
<td>-421.08, -20.76</td>
</tr>
<tr>
<td>Prefrontal cortex</td>
<td>-43.38</td>
<td>69.15</td>
<td>-194.6, 96.7</td>
</tr>
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Study 3

WORKING MEMORY PERFORMANCE MEDIATES THE RELATIONSHIP BETWEEN DEFAULT MODE NETWORK CONNECTIVITY AND REAL-WORLD FINANCIAL SAVINGS AMONG INDIVIDUALS FROM LOWER INCOME HOUSEHOLDS

Ranjita Poudel¹, Michael J. Tobia², Michael C. Riedel², Taylor Salo¹, Jessica S. Flannery¹, Lauren D. Hill-Bowen¹, Anthony S. Dick¹, Angela R. Laird², Carlos M. Parra³†, Matthew T. Sutherland¹†

¹Department of Psychology, Florida International University, Miami, FL,
²Department of Physics, Florida International University, Miami, FL
³College of Business, Florida International University, Miami FL

† These individuals made ‘senior author’ contributions to this work.

*Correspondence:
Matthew T. Sutherland, Ph.D.
Florida International University
Department of Psychology
AHC-4, RM 312
11299 S.W. 8th St
Miami, FL 33199
masuther@fiu.edu
305-348-7962

KEYWORDS: Socioeconomic status, resting state functional connectivity, default mode network, medial prefrontal cortex, functional Magnetic Resonance Imaging, Thalamus, Savings
Abstract

**Background.** Individuals with low-SES likely have lower personal savings and are highly impacted by financial emergencies such as a pandemic, rendering them susceptible to health and health-care related disparities. Prior research has demonstrated that stress related to low socioeconomic status (low-SES) impacts intrinsic brain connectivity that predicts maladaptive behaviors such as substance abuse and predisposes psychopathological conditions such as depression and anxiety, which further aggravate health inequities. Although, savings behaviors may leverage SES and abate health-related disparities, neurocognitive mechanisms linked to money-saving behavior is not well understood.

**Methods.** Informed by working memory (WM) task effect in the same participant pool, we utilized default mode network (DMN) and central executive network (CEN) nodes as regions of interest (ROIs) and conducted seed-based functional connectivity analysis to quantify intrinsic brain connectivity among low-SES individuals. Further, we examined the relationship between brain connectivity and objective measure of WM, self-reported cognitive failure, and real-world money-saving behaviors.

**Results.** Regarding regional effects, we found that DMN nodes showed increased connectivity with other brain regions associated with the task-negative network and CEN nodes demonstrated increased connectivity with other brain regions associated with the task-positive network. Further considering the brain-behavior relationship, we found that the WM task performance (dprime) partially mediated the effect of the brain’s intrinsic connectivity on real-world money-saving behavior. Specifically, higher frontal-limbic
connectivity predicted worsened task performance, and, in turn, worsened task performance predicted reduced savings outcome (potentially modulated by appetitive nature of the fronto-limbic circuitry). Additionally, higher intra-regional frontal connectivity predicted better task performance, and, in turn, better task performance predicted improved savings outcome (potentially modulated by the regulatory nature of the frontal circuitry).

**Conclusions.** Overall, our findings suggest that either lower frontal-limbic intrinsic connectivity or higher intra-regional frontal connectivity is associated with success related to savings program.

**Introduction**

Lack of personal savings in the United States is a major concern as it renders families vulnerable to financial emergencies. Prior data has demonstrated that less than 50% of Americans have set aside savings for three months in case of financial crises (Despard et al., 2020; Lusardi & Mitchell, 2011). Low socioeconomic status (low-SES) population who face a multitude of daily life stressors are disproportionately impacted by the financial crisis which amplifies health and health-care related disparities. Policies focused on leveraging social determinants of health (SDoH), including policies related to financial growth by building money-saving behavior, can improve a range of health-related outcomes (Adler et al., 2016; Allan et al., 2016). However, insights from psychological and brain sciences contribute insignificantly to the formulation of financial policies (Hall, 2021).
Dealing with day-to-day stressors associated with low-SES impairs the hypothalamo-pituitary-adrenocortical (HPA) axis; the physiological system that regulates the biological response to stressful stimuli (D’angiulli et al., 2012; Lê-Scherban et al., 2018; Lupien et al., 2001). Prior research has shown that disrupted HPA axis function can impact both structural and functional aspects of the brain, however, recent evidence suggests the impact on large-scale functional networks rather than a single specific region (Lipina & Posner, 2012; Sripada et al., 2014). It is well documented that higher cognition such as working memory (WM) and decision-making (DM) depend on intrinsic connectivity of large functionally coherent networks identified by functional connectivity. Specifically, resting-state functional connectivity (rsFC) has been widely utilized to interrogate the functional coherence between brain regions measured by the correlated dynamics of the fMRI (functional magnetic resonance imaging) time-series which potentially informs functional organization of the brain (Biswal et al., 1995; Sutherland et al., 2012; van den Heuvel & Hulshoff Pol, 2010).

Brain intrinsic connectivity associated with a wide range of cognitive functions including emotion regulation, reward, salience, (U. S. Clark et al., 2018; Demers et al., 2018; Herzberg & Gunnar, 2020; Jedd et al., 2015; Ramphal et al., 2020), and WM (Sripada et al., 2014) has been previously shown to be impacted by stress related to low-SES factors including low-income (Sripada et al., 2014), neighborhood deprivation (T. Gard et al., 2012; Ramphal et al., 2020), discrimination (U. S. Clark et al., 2018), childhood maltreatment (Demers et al., 2018; Jedd et al., 2015), and parental education (Gianaros et al., 2011). Alteration in brain intrinsic connectivity as a consequence of low-SES is extensively associated with psychopathology such as substance abuse and mood disorders.
(Altinay et al., 2015; Greicius et al., 2007; Janes et al., 2012; Sutherland et al., 2012) that may act a precursor for poverty creating a poverty cycle. The understanding of brain intrinsic functional connectivity its relation to cognition and real-world money-saving behavior may help to develop new approaches to modify financial behaviors and minimize the gap related to the socioeconomic disparity.

Aberrant default mode network (DMN) connectivity related to low-SES has been previously reported, such that childhood poverty predicted reduced connectivity between posterior cingulate cortex (PCC) and hippocampus, as well as between PCC and ventromedial prefrontal cortex (vmPFC) (Sripada et al., 2014). This reduced intrinsic connectivity was associated with higher biological cortisol levels suggesting exaggerated stress sensitivity linked to low-SES conditions. Further, reduced connectivity was observed in a brain network associated with CEN and emotional regulation among adults with severe childhood poverty (Brody et al., 2019). Similarly, childhood poverty independent of current adult income was found to be associated with reduced functional connectivity between the left amygdala (i.e., region associated with emotional processing) and medial prefrontal cortex (mPFC) (i.e., regions associated with attentional processes) (Javanbakht et al., 2015). Evidence further suggests that SES related impact on brain connectivity can act as a precursor to psychopathology as prior report has shown that lower income-to-need ratio among preschool age is associated with reduced connectivity between hippocampus and amygdala, which further predicted higher negative mood and depression later in school-age (Barch et al., 2016). Improved financial standing has been shown to ameliorate brain circuitry related to attentional processes that might have been impacted by financial deprivation such that low-income adolescents demonstrated greater connectivity between
the nodes of DMN and frontal regions as a result of increase in household income (Weissman et al., 2018). This observed alteration in functional connectivity, due to increased household income, indicates that low income is one of the prominent stressors that may impede the normative development of functional brain networks during adolescents. These findings suggest that intrinsic functional connectivity of brain networks, specifically the DMN, could act as a potential biomarker of SES-related disparities, and enhance our understanding on how SES impacts developing and adult brains.

Previous reports have demonstrated that higher default mode network (DMN), nodes deactivation during higher cognitive demands is associated with increased connectivity among these nodes during resting-state (Luo et al., 2016). Demonstrating the functional relevance of DMN connectivity during task performance, DMN connectivity have shown to predict task performance in subsequent WM task such that higher DMN connectivity is associated with better WM performance (Pyka et al., 2009; Sala-Llonch et al., 2012; Zou et al., 2013) thus acting as a predictor of WM efficiency (Esposito et al., 2009). Evidently, DMN connectivity strength may have utility as a potential indicator of WM-related performance and cognitive behaviors. Previous report has demonstrated that higher resting-state connectivity in DMN nodes is related to increased attentional resources for WM task (Sala-Llonch et al., 2012). Further, WM performance has been implicated in real-world behavior such that higher WM performance is associated with better academic performance (Owens et al., 2008, 2012; Wu et al., 2017), and a higher adherence to interventions including substance-use treatment (Dean et al., 2009). Regarding the relevance of WM measures in terms of financial behavior, higher WM span predicted better task performance in a laboratory savings paradigm (Ballinger et al., 2011). Taking these
findings into consideration, understanding the role of WM performance measure as a predictor of real-world money-saving behavior could provide initial insights towards the development of interventions targeting savings behavior.

To this end, we aim to characterize rsFC of brain regions associated with WM among low-SES population. We further aim to examine the relationship between brain connectivity and laboratory performance in WM task, personality metrics, and real-world money-saving behavior. We hypothesize that the regions associated with WM (i.e., DMN) will be positively correlated with other regions in the task-negative network such as mPFC, posterior cingulate cortex, and inferior parietal lobe and negatively correlated with regions linked with the task-positive network such as the bilateral posterior parietal cortex and frontal cortex (Beaty et al., 2015). Taking previous findings into consideration (Owens et al., 2008, 2012), we hypothesize that WM performance will mediate the effect of resting-state DMN connectivity on real-world money-saving behavior. Enhanced understanding of DMN and CEN intrinsic connectivity and relationship with task performance and real-world financial behavior may provide a principled first step towards designing interventions for financial growth in the low-SES populations.

Methods

Participants. Participants (N=27) were enrolled in collaboration with Catalyst Miami, a not-for-profit organization whose mission is to improve health, education, and economic opportunities in the community. Catalyst connects low-SES families with financial services such as tax preparation, credit building, savings opportunities, and financial coaching through their community outreach programs. Participants were recruited from
different community outreach programs conducted by Catalyst Miami as well as via advertisement flyer. We collected fMRI and behavioral data, as well as survey questionnaire data from adult participants from low-socioeconomic households (<20,000$/yr household income). Additionally, participants also completed a savings program over a period of 6 months. All participants were drug free confirmed via breathalyzer testing (BACtrack S80 Breathalyzer) and urine toxicology (Drug Check Cup, NXStep). Participants has no presence or history of any medical, neurological, or psychiatric disorder. All participants signed a written informed consent approved by the Ethical Committee of Florida International University, FIU.

**Procedures.** This study consisted of a neuroimaging session (one visit approximately 4 hours) and a money-saving program (approximately 6 months). During the neuroimaging session, participants completed an 8-minute resting scan with eyes closed. After completion of the neuroimaging session, participants were enrolled in Catalysts’ savings program which involved saving $20 each month in their savings account for following 6 months.

**Savings program.** Following the neuroimaging session, all participants were instructed to achieve a monthly savings goal ($20/month), for 6 months. Participants received a $10 reward for meeting each month’s saving goal and an additional $60 reward for completing the 6-month savings program without any withdrawals. Real-life financial savings behavior data were collected for 24 participants who successfully opened and used savings accounts to complete a 6-month savings program via Catalyst’s community outreach
program. The total savings amount at the end of the savings program was considered as the main indicator of savings behavior.

**Neuroimaging data collection.** fMRI data were acquired with a 3T Siemens Prisma scanner. Participant had an opportunity to practice a brief session of resting scan in the mock scanner. In the MRI session, participants were prepped/loaded into the machine and neuroimaging data (8 mins) was collected during which participants were instructed to relax with their eyes closed and minimize movement. Participants also performed a risky-DM task and a WM task [not described further here]). Additionally, structural scans (T1-weighted scans) were also collected.

**Self-report measures.** Participants completed a series of behavioral and self-report questionnaires. In this study, we focused on measures pertaining to self-reported cognitive failure and anxiety. We utilized the Cognitive Failure Questionnaire (CFQ), a 25-item questionnaire, to quantify participant’s experience of everyday cognitive failures. This questionnaire consists of three subscales namely forgetfulness, distractibility, and false triggering (Rast et al., 2009) and quantifies the lapses in perception, memory, and motor function (Broadbent et al., 1982). Similarly, given the widely reported association of low-SES and anxiety (Lemstra et al., 2008; Zhu et al., 2019), we examined state trait anxiety inventory (STAI) questionnaire to quantify anxiety (Ford et al., 2018; Spielberger et al., 1983). STAI is a 40-item questionnaire based on a 4-point Likert scale. The STAI measures two types of anxiety: (i) state anxiety and (ii) trait anxiety. Trait anxiety is how people feel across typical situations and on a daily basis or anxiety level as a personal characteristic.
and state anxiety is how a person is feeling at the time of a perceived threat and is considered temporary.

**Image data acquisition.** MRI scans were conducted in a 3T Siemens Scanner. A standard echo-planner imaging sequence was used to acquire BOLD fMRI resting-state data (TR = 800 ms, TE = 30 ms, FOV = 216 mm, slice thickness = 2.4 mm). Participants also underwent a high-resolution anatomical T1 sequence with the following parameters: repetition time = 9.9 ms; echo time = 4.6 ms; flip angle = 2 degrees; voxel size = 2.4 mm$^3$ (32 slices), slice thickness = 8 mm, FoV = 256 mm.

**Data-analysis:**

**Preprocessing.** MRI data were preprocessed using a standard Nipype-based tool called fMRIprep, (version 1.1.5) (Abraham et al., 2014; Esteban et al., 2019; Gorgolewski et al., 2011). Fieldmap images were utilized for distortion correction. T1-weighted structural volumes were skull-stripped (antsBrainExtraction.sh v2.1.0) and corrected for intensity non-uniformity (N4BiasFieldCorrection v2.1.0) (Tustison et al., 2010). We utilized nonlinear registration (ANTs v2.1.0) to spatially normalize structural volumes to the ICBM-152 asymmetrical template v2009c (Fonov et al., 2009). Motion correction of functional volume was implemented utilizing MCFLIRT (FSL v5.0.9) [95]. Additionally, we utilized 3dTshift for slice-time correction of functional frames to the middle of each TR (AFNI v16.2.07) (Cox, 1996). Distortion correction was implemented by co-registering functional images to corresponding anatomical volumes (Huntenburg et al., 2014; S. Wang et al., 2017) constrained by an average field map template (Treiber et al., 2016).
bbregister (FreeSurfer v6.0.1) that implements boundary-based registration was utilized to conduct co-registration of functional images to corresponding T1-weighted volumes (Greve & Fischl, 2009). The motion correction transformations, susceptibility distortion correction warp, functional-to-anatomical registration, and anatomical-to-template transformation were all concatenated and applied at once via Lanczos interpolation in a single step to minimize information loss (antsApplyTransforms ANTs v2.1.0).

Further preprocessing was conducted in AFNI version 17.3.06 (Cox, 1996). Spontaneous nonneuronal physiological signals were mitigated by regressing out nuisance signals. The first three principal components derived from the time courses of white matter (WM) voxels and that from cerebrospinal fluid (CSF) voxels were regressed out. In addition to the motion correction during preprocessing, we implemented motion censoring for mitigating motion. Functional volumes were censored with motion thresholded at > 0.35mm Euclidean norm mean displacement. Additionally, immediately adjacent time frames with less than 3 contiguous uncensored neighbors were also excluded. Individual scan sessions with less than 5 minutes of the functional data were excluded. Two participants were excluded from further analysis after motion censoring in addition to the 3 individuals who did not have access to the bank account. The time series underwent de-trending and band-pass filtering (0.01-0.1 Hz). Nuisance regression, motion censoring, and bandpass filtering were conducted utilizing 3dTproject (Gonzalez-Castillo et al., 2014; Steel et al., 2019). The functional data were further spatially blurred to 6-mm FWHM using 3dBlurTOFWHM [AFNI 17.3.06] (Cox, 1996).
**Seed-based Functional connectivity.** Seeds were defined based on the results from a WM task effect from the same participant pool. We defined regions of interest (ROIs) informed by WM task main effect revealed by ANOVA. A total of 4 ROIs from the main effect of n-back task were utilized which included clusters from: (1) dorsolateral prefrontal cortex (dLPFC) [249 voxels], (2) parietal cortex [1024 voxels] (regions showing significant activation during n-back task), (3) precuneus [210 voxels], and (4) mPFC [554 voxels] (regions showing significant deactivation during n-back task).

**Regional effects.** Mean reference time series from each of the ROIs from the preprocessed data were extracted in a GLM utilizing 3dDeconvolve. To further control for physiological noise, global signal that is considered to encompass the combination of cardiac and respiratory fluctuations was included as a covariate in the GLM. Correlation coefficient images were calculated by correlating each voxel’s time course with the time series from the predefined seed regions. Resulting correlation images were Fisher r-to-z transformed resulting in a subject-level Z-images for each subject. The Z-images were then submitted to group-level one-sample t-tests, to delineate the average rsFC map for each region.

**Brain Behavior relationship.** To explore the functional relevance of intrinsic brain connectivity with behavior, we examined the correlation between whole-brain connectivity and self-report measures as well as real-world behavior. We utilized 3dRegAna to conduct whole-brain linear regression analyses for connectivity z-maps generated during first level analyses and its association with self-reported measures (i.e., cognitive failure and anxiety) and real-world money-saving behavior. To correct for multiple comparisons, we utilized
AFNI's 3dClustSim with spatial autocorrelation correction function to perform a cluster-based thresholding (Cox et al., 2017).

**Mediation analysis.** We conducted mediation analysis using SPSS PROCESS V3.4 to examine whether the relationship between rsFC values in brain circuit (X) and real-world money-saving behavior (i.e., savings outcome at the end of 6 months) (Y) was explained by laboratory performance in a WM task (i.e., dprime) (M) [**MODEL:** intrinsic brain connectivity values (X) \(\rightarrow\) laboratory performance/dprime (M) \(\rightarrow\) real world behavior/ savings (Y)]. Theoretically, path “c” in the model refers to the total effect of brain activity on savings. Path “a” is the impact of brain connectivity on dprime (i.e., laboratory WM performance) and path “b” refers to the effect of laboratory performance on real-world behavior (i.e., savings outcome at the end of 6 months). The total effect of intrinsic brain connectivity on savings (path “c”) is decomposed into, i) direct effect (path “c’”) and ii) indirect effects (path “ab”, i.e., c=c’ + ab). WM performance is considered to mediate the relationship between brain connectivity and savings if the indirect path “ab” is significant. The “ab” indirect path is significant if the bias-corrected 95% confidence interval (95% CI), computed via a bootstrapping method, rejects the null hypothesis (A. Hayes, 2012; A. F. Hayes, 2017).

**Results**

**fMRI results (regional effects).** Consistent with previous findings, we observed that the ROIs showing significant activation during n-back task (dLPFC and parietal cortex) demonstrated positive functional connectivity with regions associated with the CEN such
as bilateral middle frontal gyrus and bilateral parietal cortex regions associated with task positive network [Figure 1 A, B]. Similarly, ROIs showing significant deactivation during n-back task (i.e., precuneus and mPFC) demonstrated positive functional connectivity with regions associated with the DMN including posterior cingulate, precuneus, and mPFC, regions linked with task negative network [Figure 1 D, E]. These findings are consistent with previous reports probing rsFC in the similar regions (Basten et al., 2012; Hemington et al., 2016; Smallwood et al., 2016; Venkatesan & Hillary, 2019).

**Brain-behavioral relationship.** We utilized 3dRegAna to identify relationship between whole-brain intrinsic connectivity and self-report measures as well as savings outcome ($p_{FWE\text{-corrected}}<0.05$; $p_{\text{voxel-wise}}<0.001$, cluster extent: 42 voxels). We found that precuneus-mPFC circuit was significantly positively correlated with subscale of cognitive failure (i.e., distractibility) (x=-9.6, y=50.4, z=27.6; voxels=78) [Fig 2A] such that as the coupling in this circuit increases, distractibility increases. The dlPFC-PCC circuit was significantly negatively correlated with subjective measure of cognitive failure (x=-7.2, y=-57.6, z=66; voxels=48) [Fig 2B] such that as the coupling in this circuit increases, subjective cognitive failure decreases. Similarly, the parietal cortex-insula circuit was significantly positively correlated with self-report measure of trait anxiety (x=43.2, y=12, z=-3.6; voxels=104) [Fig 2C] such that as the coupling in this circuit increases, anxiety score increases. Further, regarding the relationship between brain function and real-world savings behavior, the mPFC-thalamus circuit was significantly negatively correlated with money-saving behavior (x=-7.2, y=-26.4, z=10.8, voxels=48) [Fig 3A] such that as the coupling in this circuit increases, savings decreases. Similarly, the mPFC-dorsolateral prefrontal gyrus
(dlPFC) circuit was significantly positively (x=52.8, y=7.2, z=27.6; voxels: 65) [Fig 3B] correlated with real-world money-saving behavior such that as the coupling in this circuit increases, savings increases.

**Mediation Analysis.** As real-world money-saving behavior was correlated with both rsFC values in mPFC-thalamus and mPFC-dlPFC circuit as well as performance in WM task (i.e., dprime) that preceded the resting-state scan, we subsequently conducted a mediation analysis to test the hypothesis that functional connectivity in brain circuitry (i.e., mPFC-thalamus circuit and mPFC-dlPFC circuit) (X) on real-world financial behavior (Y) was mediated by n-back task performance (i.e., dprime) (M). The dprime partially mediated the influence of brain connectivity on real-world financial behavior. Specifically, when including dprime as a mediator in the model, brain connectivity’s direct effect on real-world financial behavior was significant (i.e., mPFC-thalamus: c’ path: β=-337.41, p =0.0007; mPFC-dlPFC: c’ path: β=-337.95, p=0.0002) as well as the indirect effect was significant (mPFC-thalamus: ab path: β= -80.73, 95% CI= -181.61, -5.27; mPFC-dlPFC: ab path: β= -72.90, 95% CI= 7.68, 220.12) [Fig 3 C, D].

**Discussion**

In the current study, we examined the intrinsic connectivity of brain regions associated with WM task performance probed by utilizing letter n-back task in the same participant pool. Precuneus and mPFC showed positive functional connectivity with regions associated with the task negative network. Frontal and parietal cortices showed positive functional connectivity with regions associated with the task positive network.
Further, considering the relationship between brain function, laboratory performance, and real-world money-saving behavior, we found that the WM task performance partially mediated the effect of the brain’s intrinsic connectivity on real-world money-saving behavior such that higher frontal-limbic connectivity predicted worsened task performance, and, in turn, worsened task performance predicted reduced savings outcome (potentially modulated by appetitive nature of the frontal-limbic circuitry). Additionally, higher intra-regional frontal connectivity predicted better task performance during the n-back task, and, in turn, better task performance predicted improved savings outcome (potentially modulated by regulatory nature of the frontal circuitry). Overall, our findings suggest that either lower frontal-limbic intrinsic connectivity or higher fronto-frontal intrinsic connectivity is associated with success related to money-saving behavior.

**Appetitive role of frontal-thalamic circuitry.** Our results suggest that higher intrinsic connectivity in the mPFC-thalamus (i.e., frontal-limbic) circuit predicted reduced savings mediated by n-back task performance. Thalamus, a critical component of mesocorticolimbic circuitry, is widely implicated in appetitive behavior that regulates motivation for food and drug (George et al., 2001; Hill-Bowen et al., 2020; Millan et al., 2017; Tang et al., 2012). Specifically, the thalamus is theorized to interact with mPFC in animal studies (Yang et al., 2020) such that stimulation of thalamic neurons that projects to mPFC reinforce behaviors by activating dopaminergic neurons, thus creating a positive-feedback loop reorganization that regulates motivation reinforcement for cues (Yang et al., 2020). Corticolimbic circuitries including prefrontal-thalamic circuitry are known to regulate reward-related signaling such that higher functional connectivity in these regions can impact the top-down control over limbic and forebrain leading to maladaptive
behaviors such as drug abuse (Verdejo-Garcia et al., 2014). In addition to the appetitive behaviors such as drug craving and seeking, the frontal-limbic circuitry has been previously implicated in cognition, reading, arithmetic, and IQ (Gu et al., 2010; Koyama et al., 2020; M. Zhang et al., 2021). Functional connectivity in these circuits predicts self-reported information processing indicating the potential role of these circuits as a biomarker of cognitive impairment (M. Zhang et al., 2021), with implications on WM performance as observed in our result. Further, both structural and functional aspects of the thalamus have been shown to be significantly impacted by hyperresponsivity of the HPA axis as a result of stress exposure, a characteristic feature of low-SES (Bhatnagar et al., 2000; Brito & Noble, 2014; Hackman et al., 2010; Reinelt et al., 2019). Consistent with our finding, a recent study demonstrated that the thalamus showed reduced functional connectivity particularly with frontal regions (specifically, mPFC and left ACC) in relation to a recent stressful life event such as earthquake (Yin et al., 2011) and early life stress (Philip et al., 2016). Although examination of mPFC-thalamic circuitry among high-SES population and comparison of the result we observed in low-SES individuals and its relation to savings behavior is out of scope for this study, the negative association between mPFC-thalamic circuitry and savings observed in this study might be associated with stress-related disruption in cognitive functioning that may result in maladaptive financial decisions.

**Regulatory role of frontal circuitry.** Our results further suggested that the intraregional connectivity within the prefrontal cortex between mPFC and dLPFC is associated with better money-saving behavior. Frontal regions including the ventrolateral prefrontal cortex (vLPFC) and dLPFC have been shown to be engaged in craving related to food cues as well as drug cues suggesting the potential regulatory role of this circuitry in the modulation of
different kinds of cues (Kober et al., 2010). The prefrontal system is also known to regulate both positive and negative emotions (Hare et al., 2009; S. H. Kim & Hamann, 2007; Ochsner & Gross, 2008) suggesting a common prefrontal dynamic responsible for regulating responses to various kinds of stimuli (i.e., emotion and drug cues). Additionally, PFC activity associated with executive control and self-regulation is established as a critical contributor to the alteration and maintenance of health-related behaviors (Kelley et al., 2019; Lowe et al., 2019; Wagner et al., 2011). Specifically, the cue reactivity in frontal regions regulates eating and thus influencing behaviors in the context of interventions related to weight loss and obesity management (Szabo-Reed et al., 2020). Extending the regulatory role of frontal regions in real-world behavior, increased PFC volume is associated with sustained engagement in exercise training (Best et al., 2017; Buckley et al., 2014) thus promoting healthy behavior. Previous evidence suggested that activity in prefrontal subregions (i.e., mPFC and ACC) predicted adherence to the 3-month-long course therapy in drug dependence, pointing to the heuristic value of self-regulatory brain regions in tailoring and optimizing therapeutic interventions (A.-L. Wang et al., 2015). In conjunction with previous evidence, our results suggest that nodes in PFC circuitry in addition to regulating different appetitive cue is potentially associated with regulating monetary cues thus boosting positive outcome.

**Working memory performance and real-world behavior.** Previous study has demonstrated that intrinsic resting-state functional connectivity predicted WM-related activation during subsequent task performance and measure of behavioral performance (Zou et al., 2013). WM performance is related to increased activity in CEN and decreased activity in DMN (Hu et al., 2013). Altered brain connectivity associated with DMN nodes
have been previously reported to be associated with risky behaviors such as increased craving and usage of addictive substances (Li et al., 2016; Sutherland et al., 2012; Wetherill et al., 2015), and increased behavioral disorders (Hong et al., 2018; Jung et al., 2014; Lee et al., 2017). Similarly, perturbed DMN connectivity is also associated with poorer academic performance (X. Shen et al., 2018) and perturbed ECN connectivity has been associated with substance and behavioral addiction (Dong et al., 2015; McHugh et al., 2017; Wilcox et al., 2017). Our results suggested that the WM performance (i.e., dprime) mediated the effect of brain functional connectivity on real-world money-saving behavior. Consistent with our findings, previous study has demonstrated the role of WM behavioral measure on improved savings in a savings paradigm (Ballinger et al., 2011). These findings demonstrate the utility of WM task performance measures to identify individuals who may need intervention for improving financial behaviors. WM training has been shown to be highly associated with improved academic performance and therapeutic adherence (Dehn, 2011; Insel et al., 2006). In addition to identifying individuals who might need intervention to modify savings behaviors, WM training have been implemented to modify maladaptive behaviors such as alcohol abuse (Bickel et al., 2014; Brooks et al., 2020; Houben et al., 2011b; Stanger et al., 2020), anxiety, depression (Beloe & Derakshan, 2020; Jopling et al., 2020; X. Zhao et al., 2020), ADHD (Dotare et al., 2020), and learning disabilities (Brooks et al., 2020; Rahimipour et al., 2018). Based on prior evidence in terms of adherence to behavioral modification and our findings suggesting the role of WM performance in improved savings behavior, we speculate that WM training could be a potential therapeutic tool in terms of interventions related to better money-saving behavior.
**Limitations.** The current results should be considered in light of several limitations. First, the absence of a comparison group in the current study inherently limits the examination of the differential neurocognitive mechanisms associated with money-saving behavior. Second, we have utilized three factors (income, education, and the number of dependents) to operationalize SES, however SES has been operationalized using multiple constructs (social prestige, neighborhood quality, parental interaction, childhood adversity, occupation, and urbanicity) in the existing literature. Similarly, we have utilized a mediation model to demonstrate the underlying role of WM performance by which brain function affects money-saving behavior. Previously methodological work has cautioned against utilizing mediation in cross-sectional data with no experimental manipulation (A. F. Hayes, 2017). We argue that the impact of low-SES on neurocognitive function measured at future timepoint might alter with changes in SES level, as extended period of stress related to low-SES might aggravate the neurocognitive mechanism at a later time-point (Duval et al., 2017; Gonzalez et al., 2016; P. Kim et al., 2013).

**Conclusions.** Our results demonstrate that reduced mPFC-thalamic and increased intraregional frontal connectivity is associated with improved money-saving behavior. Given the widely accepted role of frontal-limbic circuitry in appetitive behavior (George et al., 2001; Millan et al., 2017) and frontal circuitry in regulation of reward and motivational cues (Kober et al., 2010), we suggest that the improved savings behavior is a result of enhanced regulation of motivation and emotional processes. Further the mediating role of WM performance in real-world financial savings behavior suggests its potential utility in development of intervention focused on improving financial behavior.
Tables and Figures

Regional effects:

**Fig 1.** Brain intrinsic functional connectivity associated with regions linked to working memory. (A, B) ROIs showing activation during n-back task (frontal and parietal regions) demonstrate positive functional connectivity with wide range of brain regions related to task-positive network including bilateral middle frontal gyrus, bilateral thalamus, bilateral temporal gyrus, bilateral cingulate gyrus, bilateral inferior frontal gyrus, left medial frontal gyrus, right caudate ($p_{FWE\text{-corrected}} < 0.05$). (C, D) ROIs showing deactivation during n-back task (mPFC and precuneus) demonstrate positive functional connectivity with wide range of brain regions related to task-negative network including precuneus, bilateral angular gyrus, bilateral parahippocampal gyrus. Green dot represents the approximate seed regions. Abbreviations: CEN; central executive network, DMN; Default mode network.
Brain-Behavior relationship:

Fig 2. Brain-behavioral relationship. Whole-brain correlation of brain connectivity maps of ROIs associated with n-back deactivation and activation with self-reported cognitive failure and anxiety ($p_{FWE-corrected}$<0.05; $p_{voxel-wise}$<0.001, cluster extent: 42 voxels). To demonstrate the task-induced activation and deactivation, brain activities associated with 3-back level are illustrated. (A) The precuneus-mPFC ($x=-9.6$, $y=50.4$, $z=27.6$; voxels=78) circuit was found to be significantly positively correlated with subscale of cognitive failure (i.e., Distractibility). (B) The frontal-left PCC ($x=-7.2$, $y=-57.6$, $z=66$; voxels=48) is significantly correlated with cognitive failure total score. (C) The parietal-insula circuit ($x=43.2$, $y=12$, $z=-3.6$; voxels=104) is significantly associated with measure of trait anxiety. Abbreviations: rsFC; resting-state functional connectivity, mPFC; medial prefrontal cortex, cog failure; cognitive failure, PCC; posterior cingulate cortex.
Brain-Behavior relationship:

Fig 3. Brain-behavior relationship. (A) The resting-state functional connectivity (rsFC) in mPFC-thalamus (x=-7.2, y=-26.4, z=10.8, voxels=48) circuit is significantly negatively associated with money-saving behavior ($p_{FWE-corrected}<0.05; p_{voxel-wise}<0.001$, cluster extent: 42 voxels). (B) The resting-state functional connectivity in mPFC-dlPFC (x=52.8, y=7.2, z=27.6; voxels=65) circuit is significantly positively associated with real-world money-saving behavior ($p_{FWE-corrected}<0.05; p_{voxel-wise}<0.001$, cluster extent: 42 voxels). As money-saving behavior was correlated with both rsFC values in mPFC-thalamus and mPFC-dlPFC brain circuits and working memory (WM) task performance (i.e., dprime), we subsequently conducted a mediation analysis to test the hypothesis that the effect of brain function (X) on real-world savings behavior (Y) was mediated by WM task performance (M). The dprime partially mediated the influence of mPFC-thalamus and mPFC-dlPFC connectivity on real-world savings behavior. (C) Specifically, when including dprime as a mediator in the model, mPFC-thalamus circuits’ direct effect on real-world financial behavior ($c'$ path: $\beta=-337.41$, $p=0.0007$), as well as the indirect effect (ab path: $\beta=-80.73$, CI= -181.61, -5.27) was significant. (D) Similarly, the mPFC-dlPFC circuits’ direct effect on real-world savings behavior ($c'$ path: $\beta=337.95$, $p=0.0002$), as well as the indirect effect (ab path: $\beta=72.90$, CI= 7.68, 220.12) was significant. Abbreviations; mPFC: medial prefrontal cortex, dlPFC; dorsolateral prefrontal cortex.
CONCLUSION

In this series of studies, we utilized fMRI data associated with decision-making (DM), working memory (WM), and resting-state to interrogate the neurocognitive mechanisms associated with real-world money-saving behavior among the low-SES population. We further utilized a battery of standardized questionnaires to examine the effect of self-reported personality measures on real-world financial behavior. The results suggest that brain activity associated with higher-order cognitive functions such as DM and WM are associated with real-world money-saving behavior influenced by cognitive performance. For example, in study 1 we found that increased risky-DM related amygdala activity was associated with better real-world savings outcomes and is mediated by BART performance. Similarly, in study 2, our findings showed that WM task performance mediated the effect of WM-related DMN deactivation (i.e., precuneus and mPFC deactivation) on real-world savings. The results of study 3 suggested that reduced mPFC-thalamic and increased mPFC-IFG coupling is associated with improved money-saving behavior mediated by WM performance.

Our findings from an exploratory analysis on study 1 suggested the role of clinically relevant personality trait (i.e., alexithymia) on money-saving behavior. We found that individuals with low alexithymia (versus higher alexithymia) had better strategic-DM (i.e., BART performance) with higher real-world savings outcome. Alexithymia has been widely associated with increased propensity of risky behaviors such as substance abuse and gambling (Marchetti et al., 2019; Stasiewicz et al., 2012; Sutherland et al., 2013) which may hinder goal-directed behavior such as savings thus impacting financial behaviors. Further research interrogating the impact of alexithymia on real-world savings behavior is
warranted to identify the utility of alexithymia as a treatment substrate for improving savings behavior.

Our findings further suggest that individual differences in WM performance and/or WM-related DMN deactivation and connectivity may be relevant aspects associated with successful money-saving behavior. DMN suppression is indicative of increased attention towards the external task, goal-directed behaviors such as money-saving are impacted by the inability to direct attention to relevant external stimuli (Hu et al., 2013). The deteriorating effect of mind wandering on money management and risk tolerance behavior suggests the importance of attentional processes in successful financial behaviors (Elma & Baydaş, 2020). Specifically, individuals who have excessive mind wandering prefer to avoid risks in their financial plans, impulsively spend money, and eventually fail to efficiently manage money (Elma & Baydaş, 2020). Prior literature suggests the role of cognitive training and mindfulness training to reduce mind wandering, enhance task performance, and increase DMN deactivation during task performance (Iordan et al., 2020; Mikos et al., 2021; Morrison et al., 2014; Morrison & Chein, 2011) indicating the utility of WM training and mindfulness as potential interventions for financial growth.

The findings from this study bridge the gap between brain function, underlying personality, laboratory task performance, and real-world financial behavior among low-SES population. Results may provide insights for initial development and improvement of tailored interventions aimed towards financial growth and facilitate adaptive behavioral change for financial success focused on minimizing SES-related inequities. Further, these findings could provide evidence-based insights to policymakers for the development of sustainable approaches geared towards long-term planning and financial growth among vulnerable population that will address socioeconomic disparity.
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VITA

RANJITA POUDEL

DEC 2021
DOCTOR OF PHILOSOPHY IN COGNITIVE NEUROSCIENCE
Florida International University
Miami, Florida

AUG 2018
MASTERS OF SCIENCE IN PSYCHOLOGY
Florida International University
Miami, Florida

2012-2014
MASTERS OF SCIENCE IN SYSTEM NEUROSCIENCE
Norwegian University of Science and Technology
Trondheim, Norway

2007-2011
BACHELORS OF SCIENCE IN HUMAN BIOLOGY
Kathmandu University
Dhulikhel, Nepal

2015-2016
TEACHING ASSISTANT
Department of Psychology
Florida International University
Lab Instructor, Research Method
Florida International University

2017-2021
GRADUATE RESEARCH ASSISTANT
Neuroinformatics and brain connectivity laboratory
Florida International University

PUBLICATIONS AND PRESENTATIONS


