Exploring the Neurodevelopmental Effects of Economic Scarcity on Learning and Memory

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To my mother and father.

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Abstract

The present study empirically investigated the effects of economic scarcity on cognitive processes that mediate reinforcement learning and memory in adolescents (13-18). Both low and high income participants (*n* = 80) were randomly assigned to evaluate and review hard or easy scarcity scenarios. Afterwards, each participant completed two cognitive tasks: one measuring working memory capacity and the other gauging fluid reasoning. Results found that participants (*N* = 104) did report hard financial scenarios are stressful compared to easy scenarios, yielding mixed results between participants and groups across each scenarios. Additionally, economic scarcity did appear to affect working memory in adolescents, and no statistical differences in fluid reasoning were detected. These findings suggest that economic scarcity can affect cognition in developmental populations, and may be a causal method to examine how poverty affects cognitive strategies necessary in flexible, complex learning behavior. Further studies should replicate these findings and investigate more intimately how poverty-related stressors affect learning and memory in adolescents.

Keywords: Scarcity, adolescence, socioeconomic status, learning, working memory

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Research highlighting the cognitive and neural systems that contribute to learning has proliferated in recent years (Doll et al., 2015; Collins & Frank, 2012), permitting a deeper understanding of how processes such as memory systems and executive function that aid in learning develop (Murty et al., 2016) as well as how these interactions between systems can differ across development (Nussenbaum & Hartley, 2019). This ability of using our accumulated knowledge from the past to guide actions in pursuit of a desired outcome is considered reinforcement learning (RL). Computational models—both simple and complex—based on this work have expanded conceptualizations of how experiences and environments modify competing valuation systems that govern decision-making. However, despite this progress in the neuroscience of RL and decision-making, it is worthwhile considering more intimately the factors that aid in optimal decision-making. Further advancing our understanding of these cognitive models can elucidate not just *how* we learn, but also how *well*—and under what circumstances.

For example, groups from low socioeconomic status (SES) backgrounds often experience persistent criticism for acting in ways that seem counterintuitive, such as increased likelihood of taking out a risky loan (Sheehy-Skeffington, 2020; Bertrand et al., 2004). This maladaptive behavior has also been highlighted among children and adolescents (McLaughlin et al., 2019; Spear, 2016) with some researchers positing that disruptions in reward processing could be early warning signs of disorders such as depression (Mehta et al., 2010; Guyer et al., 2006). Some research even suggest that RL approaches could serve as a potential intervention to prevent or ameliorate the development of certain psychopathological disorders (Sheridan et al., 2018).

However, while research has suggested baseline differences in reward processing and RL among developmental populations that experience early life adversity (ELA) such as poverty (Hanson et al., 2017), the causal mechanisms driving those behavioral differences remain unknown. Additionally, it is unclear whether these differences are symptomatic of impairment in reward processing or simply differences in computational learning algorithms as a result of one's environment and experiences.

Therefore, the central aim of this thesis is to begin addressing these gaps in the learning and memory literature by investigating how stressful experiences and environments associated with poverty affect RL and decision-making. To accomplish this broad research goal, this thesis will first review the literature outlining the current pervading theories regarding the role of particular memory and cognitive processes that facilitate learning. Afterwards, I will examine how stress affects the development of these pathways and propose a model that illustrates how stress may alter how these systems react to different learning environments (Figure 1). I will then highlight empirical research to lay the foundation for causal research exploring how poverty-related stress may affect learning.

The Neural Systems That Facilitate Reinforcement Learning

Classical RL paradigms are often composed of the following elements: an agent (i.e., learner), an action (a), a reward outcome (r), and the state (s). As an example, imagine an agent navigating a maze with the goal of finding the exit. To accomplish this goal, the agent must decide between one of two actions during each state: a right or left turn. With each choice the agent makes, they acquire feedback regarding their selections which provides information updating their current state (i.e., closer to the exit or not). This process continues until the agent reaches their desired goal of exiting the maze.

However, consider if the maze environment was increasingly more complicated: what if the maze was larger or physically stressful (e.g., shocks every minute)? How do these environmental factors affect how well an agent processes and incorporates feedback from their actions? And more importantly, what experiences *prior* to the task lead the developing neural systems that best prepare the agent to navigate through complicated experiences more rapidly and efficiently? For example, what if an agent has extensive experience navigating mazes or if another agent previously went through a maze that was physically stressful?

Considering these dimensions in a learning task is critical because it requires a statistical parameter to encompass that quality, which makes forging a computational model to predict behavior increasingly more sophisticated. Nevertheless, many individuals navigate society with such nuanced cognitive models that inform how they react from their actions and how these processes govern their future decision-making. Therefore, it is important to begin contextualizing these nuances to better understand how adverse experiences and environments influence the development of these models to better understand variation in behavior. To start, I will review two forms of learning algorithms that support common learning processes.

Model-Free Learning. Both neuroscience and psychology research has increasingly posited the application of multiple, flexible strategies to acquire and retrieve information necessary in response to various environmental conditions (Palminteri et al., 2016; Decker et al., 2016; Doll et al., 2011). This is complemented by a growing body of empirical literature highlighting integrated systems in the brain that support learning and goal-oriented behavior

(Master et al., 2020; Hazy et al., 2010; Shohamy et al., 2004). The relevant brain networks include hippocampal memory areas (HCM) that instantiate episodic, declarative memory systems to drive decision-making (Biderman et al., 2020; Bornstein & Norman, 2017; Wimmer et al., 2014; Bornstein & Daw, 2012) in conjunction with ventral striatal areas (STR) known to be involved in processing and updating reward information (Raab & Hartley, 2018; Davidow et al., 2016; Wimmer, et al., 2012).

To illustrate how the cognitive activities represented in an HCM-STR system can affect behavior, imagine someone going to a new restaurant and exploring the menu to select a dish. Despite being in a new environment, they select the burger because they were satisfied with that choice from prior memories in other restaurants. This behavior showcases a computational framework known as model-free (MF) learning: predicting the value of a decision based strictly on previous rewarding experiences with the same object (Johnson et al., 2007). In other words, MF learning strategies are often synonymous with habitual learning that favors repeated choices over new ones as a result of frequent, rewarding outcomes, a process considered to be facilitated by HCM-STR networks (Davidow et al., 2016).

Studies involving both animals and humans have emphasized the importance of HCM-STR connectivity by using repeated memories to forge associations: to enable learners to connect action A with outcome B to predict that action C may produce outcome B (Geerts et al., 2020; Biderman et al., 2020). Animal studies have revealed that this process of associative learning is disrupted with lesions to HCM-STR networks (Preston & Eichenbaum, 2012; Diana et al., 2007). This finding is convergent with evidence from patients who experienced damage within HCM areas (Blumfield & Ranganth, 2007) as well as animal studies that found lesions to STR areas impaired reward learning and resulted in more errors during a learning task (Costa et al., 2016). Hence, there is a dual necessity among HCM-STR systems to use prior experiences from memory alongside reward expectancies, to guide and modify behavior accordingly. In fact, this iterative learning process through an accumulation of experiences helps achieve desired outcomes even when faced with novel stimuli and/or environments (Wimmer & Shohamy, 2012). Such processes are integral to learning given that often selections must be made with little to no information to guide those decisions. Or perhaps new information may be obtained that requires shifting behaviors to accommodate those new details or contexts. This introduces an alternative, more complex computational strategy to guide these types of decisions—a process known as model-based (MB) decision-making.

Model-Based Learning. MB strategies in RL paradigms contrast with MF behavior since they posit that the learner forms various associations from their experiences that inform and influence their behavior depending on contextual information (Daw et al., 2011; Daw et al., 2005). For example, when choosing a burger, the learner may realize that it is not the "burger" in itself that is highly rewarding, but rather particular ingredients; learning that "beef" leads to a positive experience rather than the specific dish itself. This additional relation may then influence the learner to choose an object on the menu with an ingredient that lists beef rather than identifying the option that most closely resembles a burger (an action which would be more indicative of someone using MF strategies). However, while such cognitive learning models enable flexible behavior—which can be helpful during critical developmental periods—it is a more computationally complex endeavor. Therefore, contextualizing these learning algorithms and their neural correlates could provide details to discern between different populations and how these communities may adopt different strategies as a result of those particular experiences and environments.

Some research has hinted at the possibility that strategies employing MB decision-making are driven by dopaminergic projections in either STR or prefrontal cortical networks (Wunderlich et al., 2012). Doll et al. (2016) designed a study that delineated the role of dopamine in MB and MF learning strategies using a learning task that can differentiate between the two behaviors (Daw et al., 2005). Through a combination of genetic methodology and behavioral data, researchers found that striatal dopamine was most associated with habit-like behavior (MF) whereas increased dopaminergic activity within the prefrontal cortex (PFC) was more related with a cognitively flexible strategy (MB). This was subsequently confirmed in patients with Parkinson's disease that exhibit difficult in learning from rewards which can be ameliorated if taking dopamine agonists (Sharp et al., 2017).

These insights regarding the PFC have postulated the use of executive function (EF) behavior, such as working memory (WM), to mediate RL (Collins & Frank, 2012). Additionally, the connection between the PFC and HCM are becoming more understood, both among adult and developing populations (O'Doherty et al., 2016; Murty et al., 2016). Less understood, on the other hand, is how adverse experience during critical periods affect each of these networks— HCM, STR, and PFC— and its implications with learning.

Examining the Role of the Prefrontal Cortex in Learning and Memory

The PFC receives and projects numerous neural connections to facilitate a range of behaviors such as the attention (Knight, 1985), inhibition (Marek et al., 2018), as well cognitive actions that maximize MB learning behavior (Otto et al., 2013). Recent developmental research speculates that children and adolescents may rely more heavily on WM strategies—the ability to hold, store and manipulation information to help guide decision-making (Baddeley & Hitch, 1974)—to aid in learning compared to adults (Masters et al., 2020) due delayed maturation of the PFC compared to HCM or STR areas (Wierenga et al., 2014). This is supported structurally, as the HCM-STR and PFC regions are bridged by a white matter tract known as the uncinate fasciculus (UF), a structure that has been shown to play an integral role in associative learning (Simons & Spiers, 2003) based on observations that lesions to the UF can interfere with Pavlovian conditioning (a form of associative learning) in animals (Von Der Heide et al., 2013). Similarly, rodents that experienced lesions to PFC resulted in biases for habitual learning (Miyoshi et al., 2002). This evidence implies a structural and functional significance of an HCM-STR-PFC network in providing direct linkage and feedback of information. Therefore, it is likely that an interconnected HCM-STR-PFC network develops throughout childhood and into adulthood, becoming more efficient as these systems collaborate over time.

Indeed, the PFC has been suggested to be vital in updating memory representations alongside the hippocampus (Duarte et al., 2005; Winocur, 1991), but can be sensitive to disruption as a result of external influences. Elliott et al. (2008) found that intravenous drug infusion that promoted amygdala over PFC processes during memory retrieval biased a rat towards MF learning. This has been similarly posited in humans as well during events or environments that trigger competing neural systems, such as emotional areas like the amygdala. When initiated, these appear to take precedent by converting from a “top-down” to a “bottom-up” regulation. For example, in a learning study done with humans, participants were to learn memory associations between objects while subliminally (i.e., unconsciously) presented with fearful stimuli known to trigger emotional pathways. As a result, this led to impaired memory performance on non-fearful stimuli, but enhanced recollection of fearful or emotional stimuli (Lipp et al., 2014. Similar results have been found in animal studies (Giachero et al., 2013; Manzaneres et al., 2005), and has also been shown in children and adolescents as well (Thomas et al., 2001). In fact, even without the induction of external influences, children and adolescents appear to elicit a stronger emotional response to fearful stimuli compared to adults (Baird et al., 1999).

This evidence converges to suggests the importance of the PFC in not just collaborating with other neural systems, such as the HCM and STR to promote learning, but also competing against other mechanisms that may be triggered through stress-inducing events. Additionally, given its delayed maturation and sensitivity to environmental influences, it is highly subject to changes which could affect RL. In fact, research has shown a correlation between WM capacity (WMC) and income (Leonard et al., 2015; Finn et al., 2017) and this was further associated with differences in cognitive behavior (Rosen et al., 2018).

If such strategies are necessary in promoting optimal learning performance in a complex task, it seems reasonable to speculate that similar experiences throughout development would also affect RL behavior among in adolescents from low SES backgrounds. But research that examines this particular development of an integrated HCM-STR-PFC network with regards to RL and memory in low income populations is scarce. Nevertheless, examining the exogenous influences (such as prolonged environmental stressors) known to affect brain development in early childhood and adolescence may be a useful proxy to indirectly explore this system and lay the foundation for experimental paradigms to explore the causal mechanisms that drive this system.

The Effects of Stress on the Development of HCM-STR-PFC

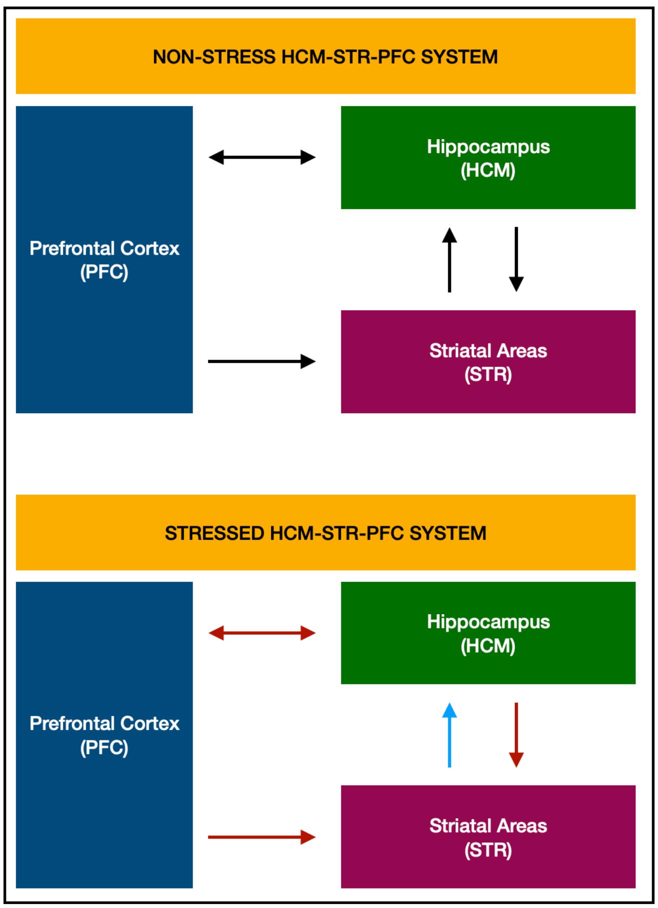
While stress induction and experience has resulted in notable behavioral and neural changes in adults (Lupien, 2007), developmental research has eluded that stress exposure during these windows may have different effects due to the brain's increased sensitivity and plastic nature during this period (for a review, see Tottenham & Sheridan, 2010; Tottenham and Galván, 2016). Tottenham and Galván (2016) postulate that these profuse impacts are driven as a result of two factors in particular. The first is that children and adolescents are more susceptible to stress hormones compared to adults as a result of having more stress receptors (Romeo, 2010; Avishai-Eliner et al., 1996). One of the neural systems implicated in the stress response is the hypothalamus-pituitary-adrenal (HPA) axis which, when activated, triggers a cascade of neural events leading to the production of glucocorticoids. This leads to a second unique consequence of stress during this window: brain development's hierarchical nature. Given the rapid changes that occur, and how experiences and environments influence this development, regions involved in the stress response are also hypersensitive to these experiences—and this includes each of the systems involved in the HCM-STR-PFC network that drives RL and decision-making.

However, stressful experiences—especially acute stressors—are not entirely troublesome. Some researchers found that exposure to acute stressors during development have positive implications (Goldfarb, 2019), but chronic stressors have been shown to affect brain and behavior in both animals and humans (for a review, see Lupien et al., 2009). The broad impacts of stress physiology on neural development have garnered much attention, but how the effects of poverty-induced developmental stressors (that may be difficult to evade due to environment factors) have only recently begun to get attention.

In the following sections, I will review research that illuminates behavioral differences between ELA and non-ELA populations. Afterwards, I will review his stress affects the HCM-STR-PFC network individually (a working model that summarizes these findings are illustrated in Figure 1).

Figure 1

Working Model of How Stress Affects Learning and Memory Systems



Note. Figure 1 shows a draft working model of an integrated learning system to support decision-making from experiences. (A) For non-stressed participants, There is bidirectional communication between PFC and STR with HCM areas, as well as unidirectional projection from PFC to STR. (B) For stressed participants, however, there is disrupted functional connectivity between PFC and HCM as well as PFC projections to STR. However, STR increases dopaminergic activity to HCM areas.

Behavioral studies. Perspectives on how stress affects learning and decision-making are mixed. One theory (Lighthall et al., 2013; Mather & Lighthall, 2012) suggests that stress *enhances* learning by promoting dopaminergic activity in reward-sensitive areas such as STR and PFC areas—but differently depending on the system (Petzold et al., 2010). Lighthall et al. (2013) employed the cold pressor test (CPT), in which participants submerged their hands in ice-cold water for as long as possible, an experimental manipulation that has been found to be an effective temporary inducer of stress (Lovallo, 1975). The results of this study found that stressed participants outperformed the non-stressed control group on an associative learning task, perhaps due to elevated dopamine levels within the striatum that facilitated the pursuit of goal-oriented behavior (Borsook et al., 2010). A separate study examined how stress during adolescence affected learning in adult rodents. Here, researchers similarly found that this did not affect learning performance with enhancements on particular components of the task; Chaby et al. (2015) reported that adult rats that endured stress during adolescence exhibited no differences in associative learning and even had better performance than non-stressed rats in a reversal task. So while Lighthall et al. (2013) lacked information regarding prior exposure to stress during development among their participants (such as stress severity and length), it is likely that this may not always manifest in learning differences during adulthood. However, an important caveat to consider with these studies is that it examined performance in *adults,* and prior studies done to compare behavior among adolescents and adults has suggested differences in reward sensitivity that influences learning performance (Davidow et al., 2016).

However, other neurobiological research investigating how chronic stress affects neural development and decision-making in rats did not find that similar patterns as noted by Chaby et al. (2015). Dias-Ferreira et al. (2009) exposed rats to chronic stress and found that this not only impaired their ability to shift behavior in favor of optimal decisions, but that this also blunted differentiating between reward values. This was also complemented with neurological associations, with researchers reporting atrophy within the PFC and hypertrophy within the STR. So while in some populations, the induction in stress may boost memory (Goldfarb et al., 2018) and learning (Lighthall et al., 2013), chronic exposure may impact developmental populations differently.

Indeed, research led by Hanson et al. (2017) recruited children from ELA backgrounds and found that their performance on an associative learning task was significantly lower compared to adolescents from non-ELA backgrounds. This pattern has been shown in subsequent studies (Harms et al., 2018; Birn et al., 2017) and is speculated to be associated with decreased connectivity found within the ventral striatum (Hanson et al., 2015). Similarly, Harms et al. (2018) highlighted similar baseline differences with regards to learning in ELA children but also that this group exhibited trouble on a reversal learning task. This is contrary to earlier research reported in this section that found that chronic stress during adolescence improved reversal abilities in adults, but this was replicated by McLaughlin et al. (2019). These researchers found differences in baseline learning accuracy and also disruption in using cognitive flexible strategies among ELA group. Children who were exposed to physical stressors during developmental periods showed impacts on their ability to update conceptual representations when new information was presented.

This research is indicative of how individuals process and incorporate feedback in different in ways that may diminish the use of optimal strategies to maximize outcomes. Such impairment may promote maladaptive behaviors even if feedback to suggest the consequences of such behavior is presented. Indeed, Ceccato et al. (2016) found that inducing acute stress in adults who experience chronic stress can lead to increased risk-taking behavior. Such findings suggest that habit-like behaviors biased by stress responses could explain why youth exposed to ELA may engage in more risk-taking behaviors than their less exposed peers, leading to difficulty in life outcomes (Balogh et al., 2013).

While the driving mechanisms behind behavioral differences among people experiencing different types of stress are still unknown, the possibility that stress could impact reward processing as a result of prior experiences—and hence learning—raised concerns. For example, children raised in affluent environments may have been able to defer rewards given the immediate availability of resources in the household; in contrast, children without immediate access to resources may have been unable to form similar associations and therefore their reward processing systems were altered by delayed reward expectations. This may indicate that that internalized rewarding information is purposely modified due to adaptation reasons which could lead to slower ability to forge associations.

Stress and the HCM. Reductions in hippocampal volume have been recently observed among children from economically impoverished backgrounds compared to their more affluent peers (Yu et al., 2018; Farah, 2017; Noble et al., 2012). However, other stressors do not appear to produce similar results. For example, children exposed to prolonged physical or sexual abuse did not show reductions in hippocampal volume until adulthood (Andersen & Teicher, 2008). A separate study found that retroactive reporting of chronic life stressors was predictive of grey matter volume in the hippocampus in postmenopausal women (Gianaros et al., 2007), but whether these structural differences were present in childhood or during adolescent periods is unclear. These findings could suggest a critical period whereby early, visible alterations of the hippocampus may only develop within the first few years, though brain atrophy may be accelerated throughout aging as a result of constant early exposure to particular stressors. Nevertheless, there currently exists scant neurobiological evidence in human adolescence sufficient enough to suggest that memory systems implicated in RL would result in HCM-driven learning differences between low and high SES populations during developmental periods.

Such implications could suggest that the use of episodic memory in RL may equally affect groups in response to stress. For example, the impacts of stress on episodic memory are well-documented (for a review, see Shields et al., 2017). Numerous studies have found that experiencing stress right before and during encoding (Schwabe & Wolf, 2010) and retrieval (Schwabe & Wolf, 2014) impaired memory. This could delay forging the necessary associations needed to optimize RL outcomes, thereby prohibiting the use of more sophisticated strategies by disrupting the encoding, retrieval, and integration of information necessary to drive optimal decision-making in complex learning environments.

Therefore, while HCM is integral to learning, these findings may suggest one of two theories. The first is that notably learning differences among adolescents from different SES backgrounds may be driven more as a result of STR-PFC circuitry. In other words, any disruption with memory encoding and retrieval integral to optimize RL may be buffered by reward processing within the STR or also the use of EF strategies. Indeed, such studies examining how stress impacted goal-directed behavior on a learning task found that stress enhances reward maximization (Byrne et al., 2019) and that impairment on a goal-directed learning task appeared to be driven by low WMC (Smittenaar et al., 2013). However, it is crucial to note that stress can enhance memory. This leads to a second, complementary theory that posits the context-dependent nature of the stressor and how this affects memory consolidation and retrieval.

Research has highlighted that adults that retroactively reported low stress exposure throughout development had reduced associative learning and memory performance compared to adults that experienced more stress (Goldfarb et al., 2017). In a separate study, researchers confirmed that pre-retrieval stress exposure affected associative memory formation, but did find that stress prior to an emotionally arousing pair was increased (Goldfarb et al., 2018). This is consistent with prior research that has found that memory formation was augmented if the stressor was directly associated with the information perceived (Jelici et al., 2004). As a result, such working theories lead to the idea that performance is more adaptive to the current environment and situation; such that there is not a deficit in performance, but a reaction to the current environment. This therefore insinuates a potential reasoning for why memory may not be a viable strategy during particular learning experiences among certain populations due to the incongruent nature of the stimuli being encoding in the context it is being acquired.

Stress and the STR. The previous section of this thesis reviewed research highlighting the reward-sensitive nature of the STR by receiving dopamine from ventral tegmentum areas

(VTA; Lammel et al., 2012). This dopaminergic activity appears to be amplified in response to stress (Scott et al., 2006). Neurobiological research using rodents has demonstrated this augmented dopaminergic activity occurs both as a result of stress during development as well as heightened dopaminergic inputs in response to a stress inducer (Schwabe, 2013; Ungless et al., 2010). Similarly, this increased dopamine response pattern seems to occur in humans as well (Pruessner et al., 2004). Scott et al. (2006) induced stress in adult participants and using positron emission tomography (PET) demonstrated that this resulted in elevated levels of dopamine.

However, while *experiencing* stress seems to increase dopamine in towards striatal areas, this does not seem to be the case in adolescents that experience adversity during development. Mehta et al. (2010) had adolescents take a reward learning task and found that those with a history of institutionalization were unable to dissociate between rewards of varying levels, a finding that was similarly found in chronically stressed rodents (Dias-Ferreira et al., 2009). Specifically, exposure to either medium or high rewards resulted in increased dopaminergic activities within the STR compared to low rewards, but this pattern did not manifest in ELA participants.

Prior studies have suggested that the increase in reward processing within STR and the slow maturation of the PFC promoted risk-taking in adolescence (Telzer et al., 2015). This has also been shown in groups in which dopamine signaling was increased via stress such that risk-taking was increased in the stress group. However, this does not appear to be the case for participants with a history of adversity (Loman et al., 2014). Several studies have highlighted that chronic exposure to stress blunted STR responses to dopamine which diminished risk seeking behavior (Silvers et al., 2016; Humphreys et al., 2015). This provides the possibilities that chronic stress during sensitive developmental windows may result to blunted reward processing which then diminishes the ability to differentiate between values. However, an antecedent to this consequence could be that constant exposure to chronic exposure *amplifies* risk-seeking behavior (Ceccato et al., 2016) due to constant elevated dopaminergic levels (Pruessner et al., 2004). For example, the former theory could be symptomatic of additional neurological disorders such a depression. In fact, in studies that showed a lack of risk-taking, this was specifically done in groups with clinical depression (Mannie et al., 2015) which has been correlated with both decreased reward sensitivity and risk-taking behavior (Morris et al., 2015).

Stress and the PFC. Relative to HCM and STR regions regarding how stress affects behavior, the impacts of stress on PFC regions and associated behaviors are well-documented (for a review, see Arnsten, 2009). In animal studies, it has been demonstrated that both chronic and acute exposure to stress during development results in visible neurological differences within the PFC along with profound behavioral disruptions seen in tasks tapping into PFC activations.

Structurally, research suggest that both acute and chronic stress results in visible changes in dendritic morphology (Dias-Ferreira et al., 2009). Namely, chronic stress appeared to result in reductions in dendritic branching (Brown et al., 2005; Cook et al., 2004), length (Izquierdo et al., 2006), and spine density (Radley et al., 2008), which later demonstrated changes in behavior as well. One study found that chronically stressed rats were unable to perform tasks measuring inhibition and WM (Mika et al., 2012), a finding that has been repeatedly shown (Peay et al., 2020; Ortiz & Conrad, 2018; Holmes & Wellman, 2009). This performance change is thought to be associated with decreased dopaminergic signaling to the PFC. Mizoguchi et al. (2000) replicated memory impairments in chronically stressed rats that were ameliorated by dopamine receptor antagonists. More recently, Piggott et al. (2019) found that even single prolonged stressors were sufficient to impair PFC, and also demonstrated stress-related reductions in striatal connectivity. Prolonged exposure to stress is also known to have significant effects on the dendritic arborization and spine density of neurons in medial PFC (mPFC; Cook & Wellman, 2003), an area associated with error monitoring (Zarr & Brown, 2016).

Studies in humans have similarly highlighted behavioral deficits in PFC-dependent tasks as a result of stress. One such task demonstrated that temporary induction of a psychosocial stressor prior to an attention-demanding experiment manifested behavioral impairments thought to be the result of disrupted connectivity with other cortical areas. (Liston et al., 2009) These findings demonstrated that the effects of non-experimentally driven stress were cascading, in that they affected performance during the task as a result of pronounced exogenous chronic stressors outside the task. The effect was shown to be reversible, suggesting that there could be intrinsic mechanisms in the brain that work to remedy deficits upon cessation of environmental stressors among adults. Such findings, however, may not hold for participants in whom exposure to stress has been more severe, prolonged, and during different developmental windows in which they brain had already reorganized in anticipation of future stress exposures.

Indeed, WMC—with no experimentally-induced stress—has been shown to be negatively correlated with income (Leonard et al., 2015; Evans & Shamberg, 2009; Hackman & Farah, 2009), people with schizophrenia (Glahn et al., 2005; Abi-Dargham et al., 2002; Fleming et al., 1997), and people with other disorders that affect cognition (Gilbert et al., 2005; Yetkin et al., 2006; Döhnel et al., 2008). Such observations suggest that baseline performance on PFC-mediated tasks may be affected in these populations without the incorporation of any additional stressors. If this is the case, the result of stress induction prior to a PFC-related task in people from low SES or ELA backgrounds may either have no difference or some—whether it is to affect performance such as tasks prior or perhaps even promote behavior.

In fact, researchers have shown that baseline WMC affects learning performance (Radenbach et al., 2015). Otto et al. (2013) measured individual differences in WMC and compared how stress affected performance on a two-step probabilistic RL task. They found that participants with high WMC mitigated any deleterious impacts of stress on performance, which indicates that stress may indeed be influencing the development of an HCM-STR-PFC system as well as producing opposing effects in the face of acute stressors. What remains uncertain, however, is how individuals who have endured chronic stress will fare on a task that relies heavily on both mechanisms *without* inducing stress.

One theory is that chronic stress promotes a system that attenuates to “bottom-up” sensory processes. For example, while the research highlighted in this section suggest both reductions in neural architecture and dopamine processes, as well as impairment in “top-down” regulation, stress exposure had an opposite effect on amygdala neural circuitry. Specifically, it has been shown to *promote* dendritic branching in the amygdala due to chronic stress (Vyas et al., 2002). Such changes could suggest neural systems that rely more heavily on rapid “top down” cognitive regulation strategies are competing against systems that prioritize emotional stimuli. This was previously exemplified experimentally in the study done by Liston et al. (2009) and could explain the reversal upon cessation of stress. However, for developmental populations that experience more chronic stressors without knowledge on when they will cease, the brain may become more accustomed to bottom-up processes, which results in slower, emotional processes driven by amygdala cortices known to favor habit learning (Lingawi & Balleine, 2012). This therefore suggests that, by default, populations that experience ELA, such as low income populations, engage in habit learning due to this system dominating baseline processes but either requires strategic modifications to bias towards “top-down” regulation or the use of system-relevant stimuli (e.g., fear).

Research challenges

A significant caveat with analyzing and interpreting the effects of stress on brain development and behavior is with regards to two things: the timing and duration of stress.

There are 4 main stages of development prior to adulthood (prenatal, post-natal/infancy, childhood, and adolescence), with some research suggesting that the timing of particular events may result in different effects later in the lifespan (Lupien et al., 2009). This poses a challenge for stress developmental research in human populations. Take for example the first four cases highlighted in Figure 2, where each person experiences acute stress during only one stage of their pre-adult development. This can become even more complicated: in addition to a case where one only experiences stressors during a particular stage of development, equally likely is an individual that experiences chronic stress throughout all stages of development; in another case, it is likely that stress appeared in several stages but with brief interruptions in between; another example can be a combination of chronic and acute stressors appearing in different periods but with breaks.

Figure 2

Challenges Measuring Developmental Stress in Behavioral and Neural Research

	Prenatal	Infancy	Childhood	Adolescence
Person 1	STRESS			
Person 2		STRESS		
Person 3			STRESS	
Person 4				STRESS
Person 5	CHRONIC STRESS			
Person 6		STRESS		STRESS
Person 7		CHRONIC STRESS		
Person 8	CHRONIC STRESS			STRESS

Note. Figure 2 highlights an experimental complexity regarding how stress during developmental periods affects behavior. Each row represents a different person and each column represents a period of development (prenatal, postnatal/infancy, childhood, and adolescence). Person 1-4 represent individuals that endure acute stress during each of the four stages of development. Person 5 and 7 exhibit chronic stress for longer or brief periods of time, respectively. Person 6 highlights acute stress during two separate developmental windows. Person 8 has a history of chronic stress with a break prior to the onset of acute stress in later period. As a result, this highlights a potential scenario where the unique experience, onset, and duration of one's stressor could have on development and how this could manifest behaviorally.

These complexities represent an experimental challenge for this line of stress research: narrowing down the exact timing of when stressors occurred, what they were, and whether the timing could be a root cause of behavioral factors. Even with retroactive reporting, recollections are imprecise and informants may misremember components of the stressor. Additionally, it is also practically difficult to engage enough participants to perform such investigations longitudinally with a sufficient sample size.

This poses a secondary challenge: the *type* of stressor. While various stressors affect HCM-STR-PFC networks, different environmental stressors do not affect behaviors in the same way. This was most salient in recent work by Dennison et al. (2019), in a study designed to contextualize how different forms of ELA affect reward processing. Participants who had experienced different forms of adversity (such as food deprivation, physical abuse, etc.) carried out a variety of cognitive tasks, revealing that chronic food deprivation impaired reward processing behavior compared to other kinds of stress. Such research indicate that the kind of adversity matters—meaning that different experiences will affect learning pathways differently—thus meriting attempts to tease apart the nature of the different possible stressors affecting development. So in addition to how stress as a result of one's environment affects these kinds of systems, their development, and their interactions, which kind of stressor is also noteworthy.

Such concerns about the difficulty of stress research do not indicate that current and future evidence is pointless, but rather emphasize the urgency for continuing this line of inquiry given that the aforementioned challenges represent gaps in the understanding of how stress affects development and behavior. Despite the progress made throughout the years, a significant amount of work still remains—particularly with regards to disentangling the causal mechanism by how stress exactly modifies these learning procedures. The research reported in this thesis was designed to utilize the promise of randomized controlled trials for investigations of specific stress inducers, and in part to address some of these caveats.

Economic Scarcity and Financial Stress

Given that prior work has highlighted behavioral differences among populations that endure ELA (Hanson et al., 2017; Hanson et al., 2015; McLaughlin et al., 2019) and the aforementioned research challenges with examining the causal ways that stress affects the development of an HCM-STR-PFC network, a potential approach to examine the causal link between these behavioral differences as a result of adverse experiences is by employing a scarcity framework.

In a study led by Mani et al. (2013), researchers asked participants to review a series of hypothetical scenarios that were either financially hard or easy. For example, one hard scenario was for adults to imagine that they received a 15% reduction in their salary, but in the easy condition that reduction was 5%. Afterwards, all participants completed cognitive tasks aimed to measure EF and fluid reasoning. What they found was that low SES participants in the hard condition had reduced performance compared to all other groups, suggesting that a scarcity induction affected cognitive capacity to optimize their progress on the tasks.

However, while other studies have since found similar behavioral results (Huijsmans et al., 2019), this does not always materialize in real-world settings (Carvalho et al., 2016). Also, some scarcity frameworks have found that inducing scarcity in adults actually improved performance (Dang et al., 2016). One task asked participants to review the same scenarios from Mani et al. (2013) and then had them do a procedural learning task. In this study, participants in the hard condition who were from low SES backgrounds actually outperformed other groups.

This was specifically to distinguish between how scarcity affected the cognitive processes separately: the effect of scarcity is not always unidirectional in how it impacts behavior, and may be dependent on the systems that are activated as a result of the scarcity effect.

Such findings provide a unique perspective on the mechanisms whereby poverty-related stressors may affect decision-making in a population. However, to the best of my knowledge, a scarcity experimental design has not been tested on RL or memory tasks. Additionally, the effects of scarcity on cognition in adolescents has not yet been investigated. Therefore, this thesis will attempt to use a scarcity framework as an opportunity to investigate if exposure to financially difficult situations will trigger competing neural systems that will interfere with utilizing strategies integral in complex learning environments.

Research Questions

This thesis aims to address the following questions:

1. Is it possible to induce economic scarcity in low SES adolescents by affecting cognitive performance on tasks that mediate RL?
2. Can economic scarcity disrupt the use of more complex computational strategies to optimize learning outcomes?
3. Does exposure to economic scarcity affect memory formation and reward associations?

Hypotheses and Predictions

If scarcity has previously shown to uniquely impact cognition in individuals that endure financial deprivation (Mani et al., 2013), then I first hypothesize that similar behavior exists in an adolescent population. Specifically, I predict that exposing low SES adolescents to financially difficult scenarios will serve as a form of cognitive distraction that will affect performance on tasks similar to the cognitive studies done by Mani et al. (2013) and which have been thought to mediate RL (Nussenbaum et al., 2020).

Additionally, assuming that inducing economic scarcity in a developmental population is possible, I also theorize that such a distraction will make it harder to integrate rewarding information and therefore exacerbate the ability to use prior knowledge to update behavior to optimize learning outcomes. Given this, I hypothesize that economic scarcity will result in slower learning acquisition behavior among adolescents and that this will manifest with recalling less information that was associated with highly-rewarding outcomes.

If both these hypotheses are realized, then I hypothesize that economic scarcity could also interfere with neural mechanisms that support the use of more complex learning strategies such as model-based decision-making. Specifically, I suspect that inducing scarcity to low SES adolescents could prohibit them from relying on systems that enable MB strategies to help optimize their decision-making which forces the use of autonomous, habit-like behavior.

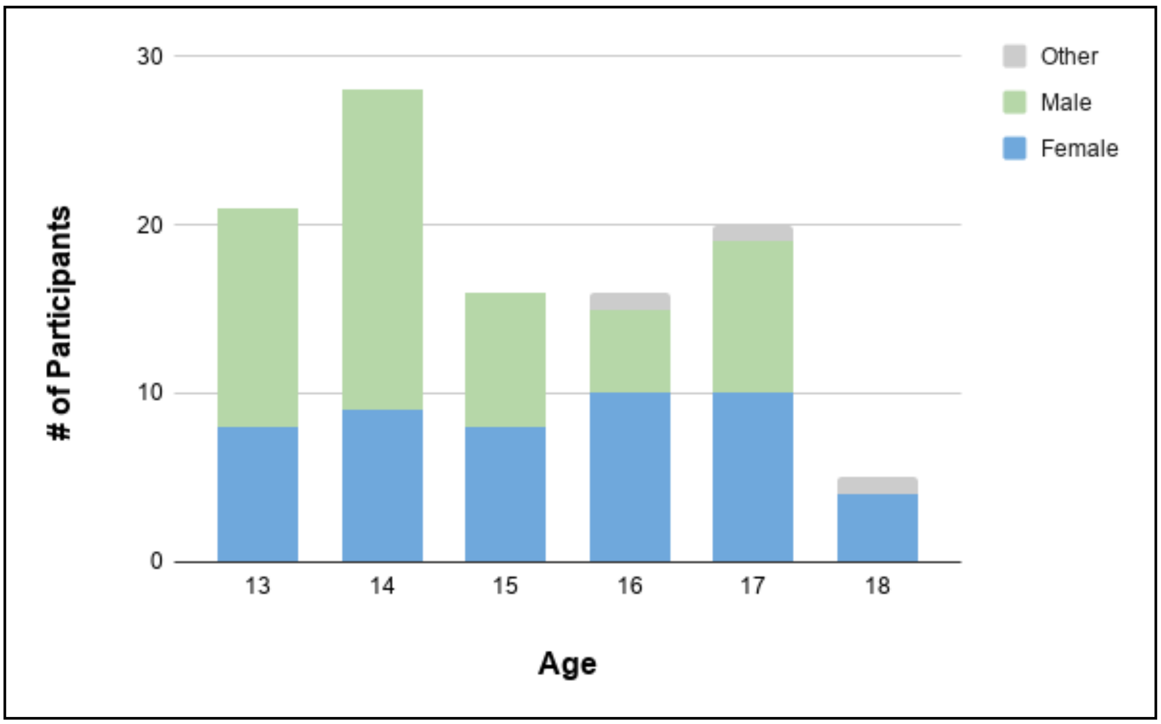
Method

Participants

The data presented here were collected from 104 participants between the ages of 13 - 18 (M = 15.1, SD = 1.55, F = 50) who completed some part of the study. In total, 343 parents consented for their child to take part. Of those, 264 participants were invited to participate in the study based on eligibility. 144 participants completed the scarcity trials, 133 participants completed the working memory experiment, and another 115 completed the fluid reasoning task. Participants were excluded if they did not fully complete the experiments, failed the comprehension check more than 3 times, performed at chance levels in any of the cognitive experiments, or if they submitted duplicated responses. Additionally, if participants did complete all tasks but reported being unable to complete the tasks without interruptions or encountered any technical difficulties while taking the task as self-reported on an optional post-experiment survey, their data was excluded. The final data presented here includes 104 participants that provided data on the scarcity scenarios, and 80 participants that complete each part of the study. Demographic breakdown of the participants are shown in Figure 3, Figure 4, and Table 1.

Figure 3

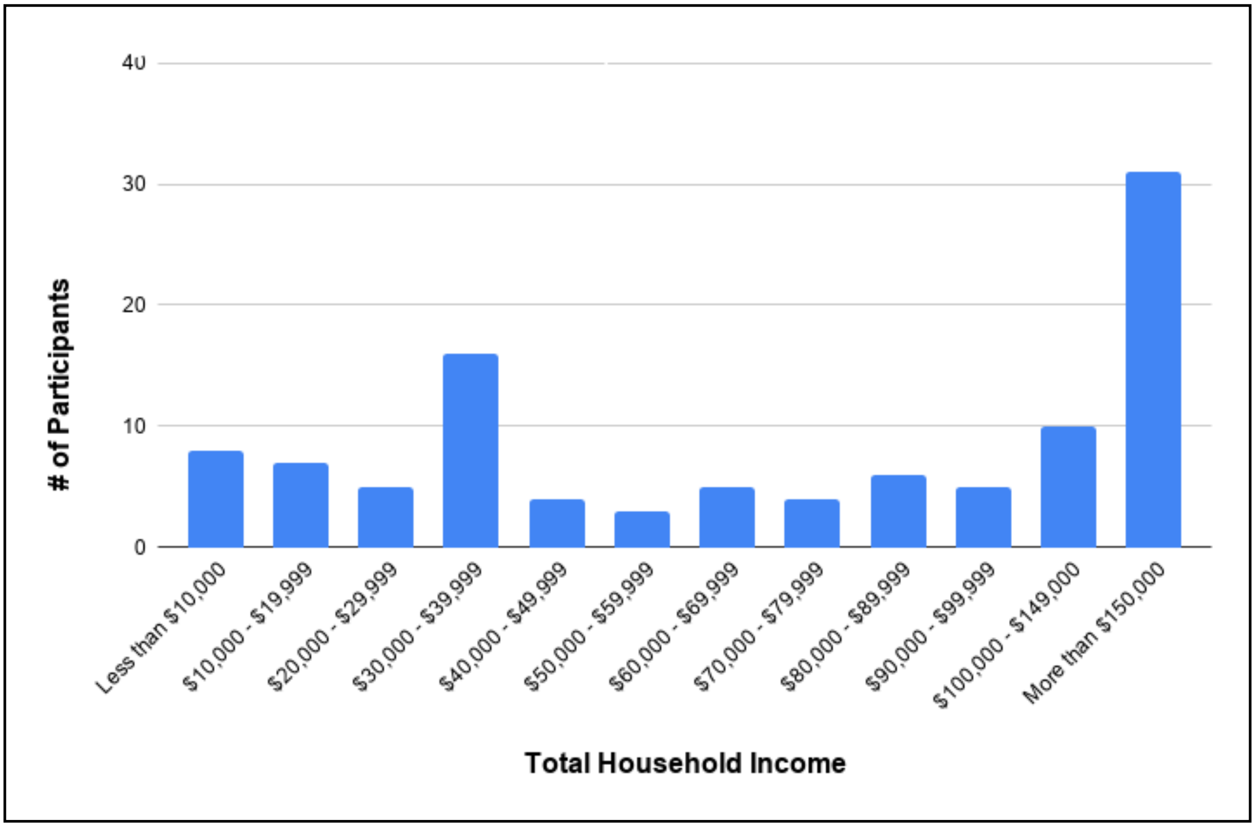
Demographic Breakdown by Gender and Age



Note. Total break down of all participants reported in this study (males in green, females in blue, and non-binary or gender nonconforming participants in grey). Further details are provided in Table 1.

Figure 4

Socioeconomic Breakdown of Participants



Note. Total breakdown of participant's socioeconomic income as reported by their parent(s) and/or legal guardian(s). Participants were divided into low and high SES based on this information provided and total number of family members in the household based on U.S. Federal Poverty Guidelines.

Recruiting Protocol

Participants were recruited through various methods including Facebook ads (*n* = 22), students in the Upward Bound program (*n* = 17), Prolific (*n* = 54), a website that hosts behavioral studies, and finally from ChildrenHelpingScience.com (*n* = 6), a website that hosts developmental studies, and through word of mouth. All potential participants needed to have parental consent provided by a parent or legal guardian; participants who were aged 18 were redirected to a separate informed consent form on the condition that they were currently high school students who had not yet received a high school diploma or equivalent.

Both parent and adult consent forms were completed on Qualtrics and supplied information regarding the child's age, the total income for the household, highest levels of education attained by parent(s) and/or legal guardian(s), race/ethnicity, and any history of a learning disability or a neurological disorder. Participants were instructed that they would receive a $5.00 Amazon Gift card plus a potential $2.50 based on performance; however, in actuality, all participants received the full $7.50 regardless of performance. All experimental procedures were carried out with approval from the Teachers College, Columbia University Institutional Review Board (protocol #21-086).

When submissions were received and it was confirmed that the participant met the criteria for inclusion, an email was sent with links to the experiments along with a unique participant ID. Participants had to first access the informed assent form to have a full understanding of what their participation entailed. Once they had reviewed this and provided their assent, they were immediately sent to Cognition to begin the first part of the experiment, and this link automatically took them to each part of the experiment. However, participants were also provided individual links for each part in their email in the event that any experienced technical issues while taking the tasks. Additionally, participants were notified that the study could only be completed on a computer and that it was not compatible with a tablet or smartphone. All tasks were completed in fullscreen to reduce browser interactions and could only be completed on laptops that were at least 12 inches (in order to prohibit the use of tablets for each of the tasks). If participants attempted to launch the tasks without meeting each of these criteria, they were unable to proceed to the instructions. Furthermore, while difficult to ascertain, participants were instructed to complete each study without interruptions or any assistance, in a quiet area.

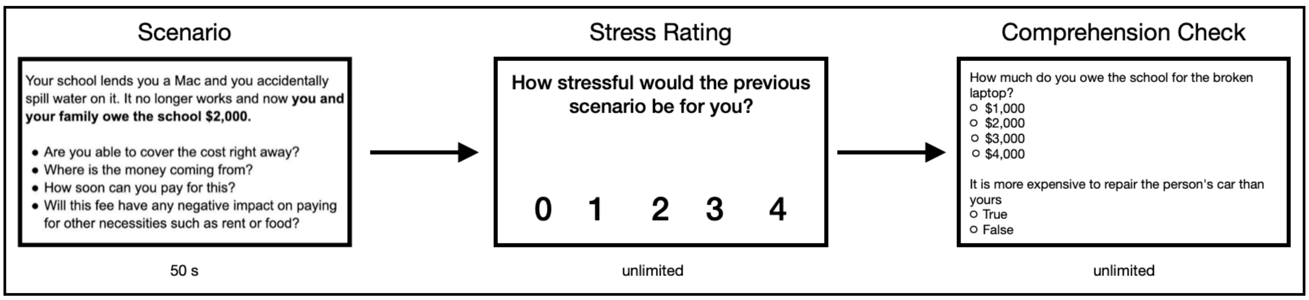
Procedure

Scarcity Scenarios

Figure 5 provides an overview of a scarcity trial. Participants were randomly assigned to either hard or easy conditions. Four novel scenarios targeting high school students and modeled after the original scenarios from Mani et al. (2013) were created using jsPsych (De Leeuw, 2015) and hosted on Cognition (www.cognition.run). Participants were first shown a screen outlining the informed assent, and once consented they were provided with instructions and told to think about each scenario. The order of scenarios presented was randomly generated for each participant, and each participant had to review each one for a total of 50 s. After reviewing each scenario, they were asked to provide a rating on a Likert scale of how stressful the scenario would be if they found themselves in it (Not stressful at all, Kind of stressful, Stressful, Very stressful, Extremely stressful). To ensure that all participants reviewed the scenarios and internalized the financial component of each situation, a comprehension check was administered that asked simple questions to verify that they actually read them and to serve as a check against spam bots. Participants were given advance notice during the instructions regarding this check, and told that in order to proceed to the following experiment that they must score 100% on the comprehension check. In the event that a participant missed a question, they were instructed to review each of the 4 scenarios for as long as they wanted and allowed to redo the comprehension check until a perfect score was achieved. When a participant answered each question correctly, they were asked to provide a final subjective stress rating on a similar scale described earlier. Once this was complete, participants were immediately sent to the next task—either a digit span working memory task or a matrix puzzle task.

Figure 5

Example Scarcity Trial



Note. Figure 6 shows an example of a scarcity trial. First, after reviewing instructions, participants will randomly review one of 4 scenarios for 50 s. Afterwards, they would automatically be taken to the next screen and provide a stress rating of the scenario (0 = not stressful at all; 1 = kind of stressful; 2 = stressful; 3 = very stressful; 4 = extremely stressful). After reviewing 4 scenarios, participants then completed a brief 4-question comprehension test based on each of the scenarios. Participants were instructed that they must score a 100% before proceeding to the next part of the study. Table 2 below provides the scenarios that they reviewed (values in parenthesis represent values that were shown to participants in the easy condition) along with their respective comprehension check question.

Digit Span Working Memory Task

The forward digit-span task was used a proxy for WMC. Participants were shown a sequence of digits one at a time each for 1.5 s. They were instructed to memorize the order in which the numbers were shown and to recall them in the order they appeared (forward task). First, participants did 3 practice trials to orient them to the task. During the actual experimental trials, participants first saw a screen that informed them of the number of digits that would be shown. Then digits were presented one at a time.

Each participant began with three-digit sequences and carried out three trials before proceeding to a block with a one-digit increase in sequence. For trials of 10 digits or more, participants completed two trials. After the set of numbers was presented, participants were presented with a screen asking them to recall the numbers. As soon as participants entered their response, they were provided with feedback as to whether or not the response was correct (Figure 6). WMC was determined by the highest sequence of digits that a participant answered 2/3 trials correctly or each of the two trials for sequences of 10 or more digits.

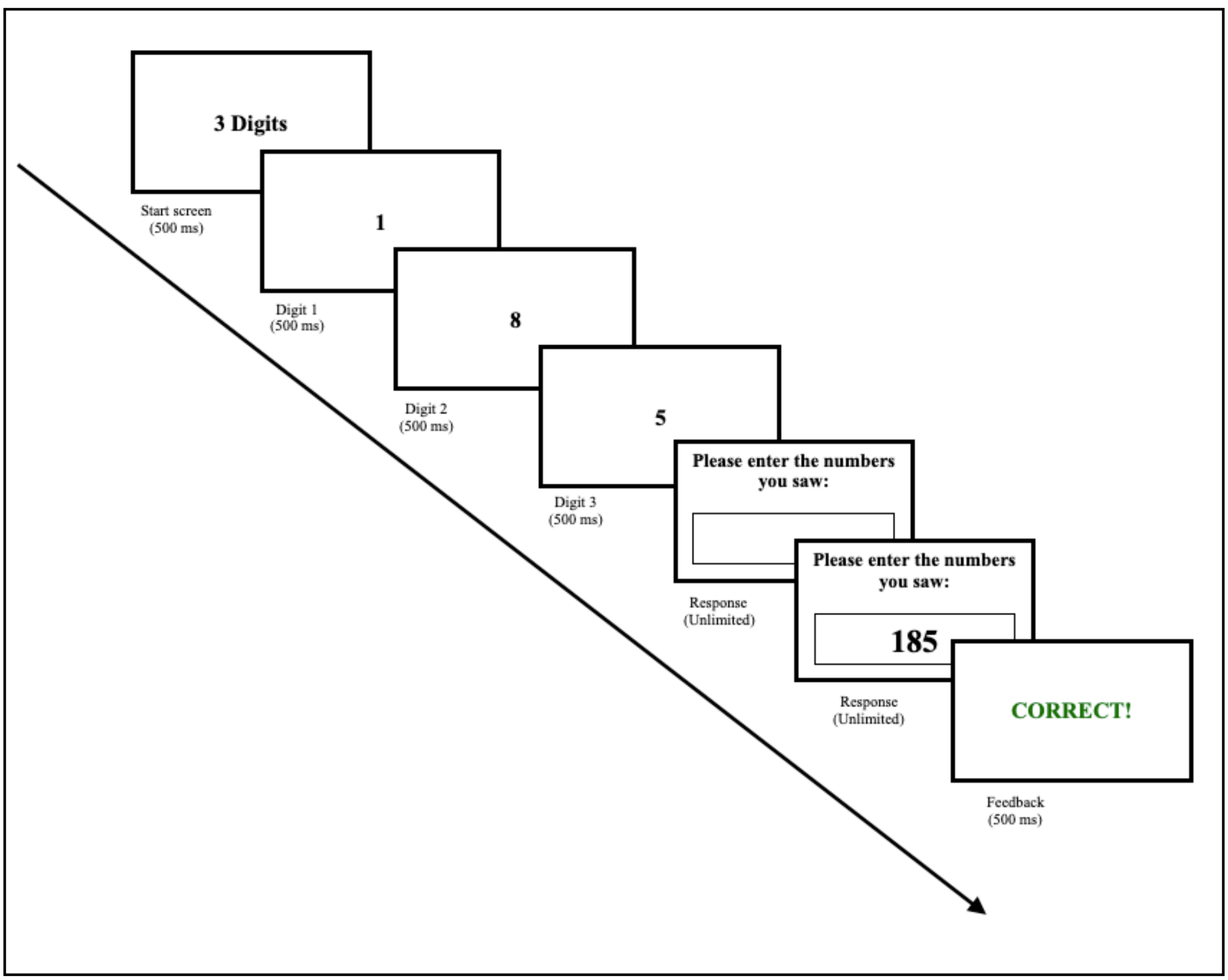
Matrix Reasoning Item Bank (MaRs-IB)

After either completing 4 scarcity trials or completing the digit span task, participants were directed to Gorilla (www.gorilla.sc; Anwyl-Irvine et al., 2020) to complete the Matrix Reasoning Item Bank (MaRs-IB). This is an open-source task that measures fluid reasoning, how children reason through problems to solve them (Wright et al., 2008), and is specifically adopted for adolescents (Chierchia et al., 2019). This task has been previously shown to be effective at gauging fluid reasoning in developmental populations through online methods (Nussenbaum et al., 2020).

In this task, participants were shown a 3x3 grid of various abstract shapes, with one missing in the bottom right corner. Participants were asked to determine which of 4 options would best fit the last grid based on the pattern, within 30 s. Once 25 s had passed, a timer appeared on screen to countdown the remaining 5 s. Upon making a selection, they were provided with feedback as to whether or not their selection was correct (Figure 7). A total of 80 puzzles were possible, with 3 difficulty levels (easy, medium, and hard). Participants either completed all 80 puzzles or 8-minutes worth of trials—whichever came first. In the event that participants completed all puzzles, the study simply ended. All puzzles were randomly presented.

Figure 6

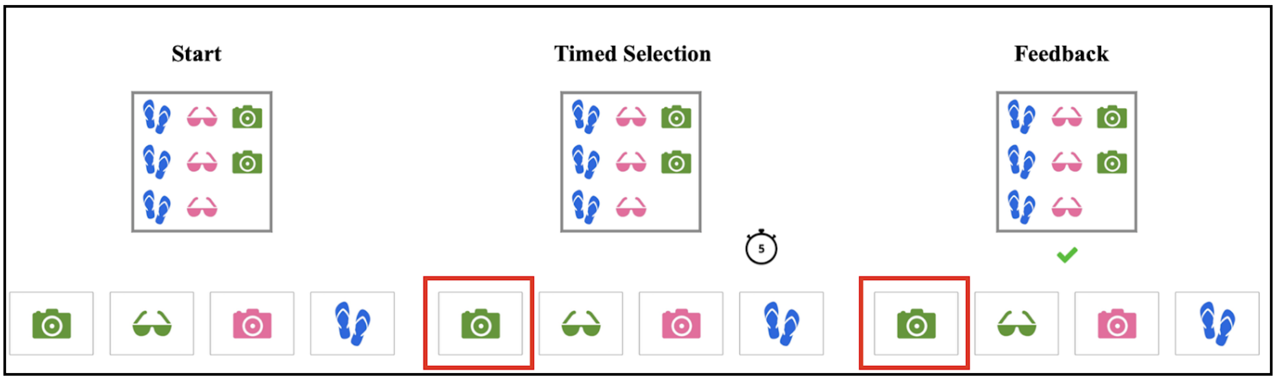
Example Digit Span Forward Trial



Note. Figure 6 shows an example of a digit trial. First, participants were given a cue as to how many digits were about to be presented on the screen. Then each digit was presented one at a time for 500 ms. After all digits had been shown, participants were given an unlimited time to input the digits and receive immediate feedback once they submitted their answer. They then proceeded to the next trial.

Figure 7

Example MaRs-IB Trial



Note. Participants are first shown a 3x3 grid with each of the abstract images and the four options to determine which best fits the image missing in the bottom right panel. After 25 s have passed, a 5 second countdown timer will commence to alert them of the remaining time. Once participants have made a selection, they are given immediate feedback whether their choice was correct or incorrect before proceeding to the next trial. All participants completed either 8 minutes-worth of puzzles or 80 puzzles, whichever came first.

Counterbalancing Check

To ensure that order of presentation did not influence any results, participants were first randomly grouped into either hard or easy conditions. Additionally, all scenarios were presented in a random order. However, while all participants first reviewed the scenarios, participants were also randomly assigned to the next task—either to complete the digit span task or complete the

MaRs-IB. This was to account for potential ordering effects given that the MaRs-IB task was shorter (eight minutes max for each participant) whereas the digit span task was longer and more stress-inducing since participants had to complete all blocks regardless of performance. Therefore, it is possible that experience from the digit-span task could provide an additional cognitive tax impact on the MaRs-IB.

Measures

Socioeconomic Status (SES)

Participants all provided total household income made by parent(s) and/or legal guardian(s) in the primary household along with information regarding the total number of individuals living in the household. I used federal poverty guidelines in order to classify individuals into either low or high SES groups. Specifically, any participant who was at or below federal poverty guidelines were considered low SES; all other participants were considered high SES.

Working Memory Capacity (WMC)

For the forward digit span task, WMC was calculated based on the highest digit a participant was able to accurately recall in two out of the three trials (except for trials with 10 digits or higher, in which they had to get all trials correct given that participants were only given two trials on those digits; more details in the preceding section). WMC scores were then averaged between scarcity conditions and SES groups.

To aid with additional analyses described in this thesis, participants were also classified with either low or high WM capacity. This was calculated if they performed two standard deviations below or above the overall average, respectively (i.e., regardless of scarcity condition or SES).

MaRs-IB Accuracy

Experimental Accuracy. Participants were instructed to complete as many puzzles as possible within an 8-minute timeframe. Here, accuracy was determined based on the number of puzzles correctly completed out of the total number attempted.

True Accuracy. Given that 80 puzzles were possible, an additional score was provided based on each participant's total number correct out of a potential 80 puzzles.

Results

Analysis Plan

All analyses were done using statistical packages provided by R (R Core Team, 2013). To compare between condition and SES on the scarcity ratings and for both cognitive tasks, I performed a two-way analysis of variance (ANOVA) using the ggpubr package in R (Kassambara & Kassambara, 2020). Data from participants were included in the analyses only if they completed the comprehension check during the scarcity trials. Additionally, if participants were detected to perform the MaRs-IB experiment at chance level (~25%), they were excluded from analysis. For participants who completed the digit span task, they were included only if they acquired a 100% accuracy on practice trials.

Scarcity Results

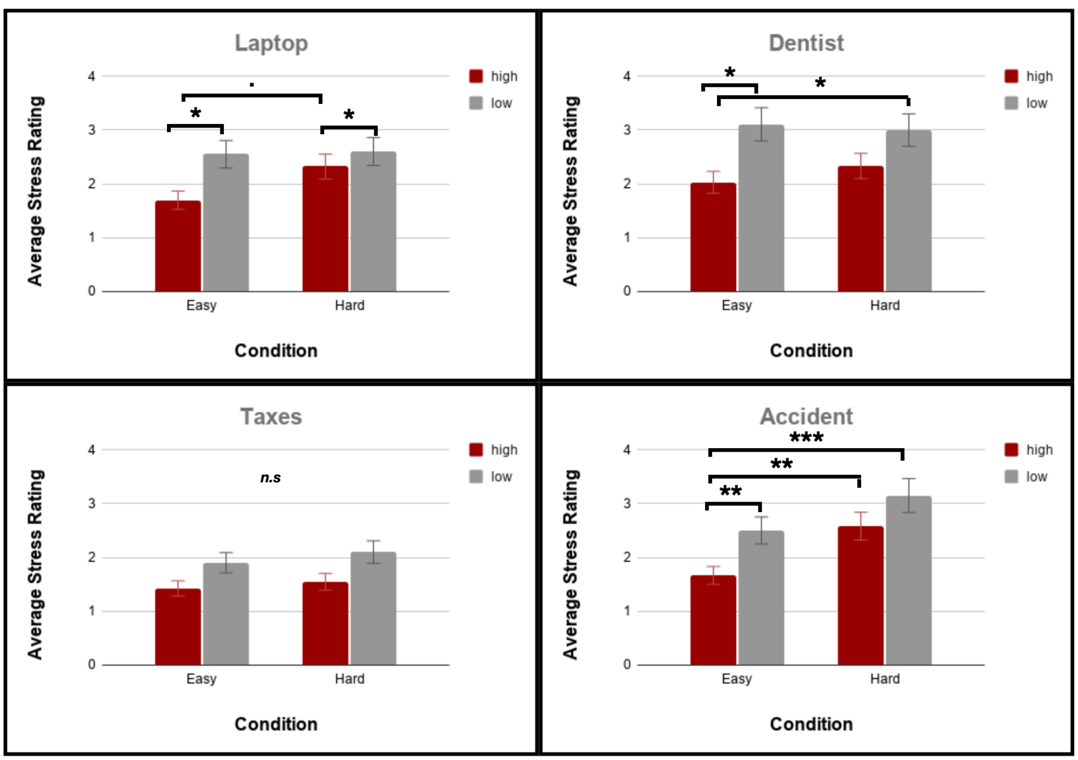
Individual Scenario Results

By condition and SES. A two-way ANOVA was run on an unbalanced sample of 102 participants to test the effects of condition and SES on scarcity ratings. There was no significant interaction between the effects of condition and SES on scarcity ratings for any of the four scenarios [Laptop, $F(1, 98) = 2.56$, $p = .113$; Dentist, $F(1, 98) = .658$, $p = .419$; Taxes, $F(1, 98) = .083$, $p = .774$; Accident, $F(1, 98) = .614$, $p = .435$]. On the other hand, my analysis did show that an effect of SES was significant for all scenarios [Laptop, $F(1, 98) = 8.29$, $p = .005$; Dentist, $F(1, 98) = 12.0$, $p < .001$; Taxes, $F(1, 98) = 5.67$, $p = .019$; Accident, $F(1, 98) = 12.6$, $p < .001$]. Additionally, one scenario indicated an effect on condition with regards to scarcity ratings [Accident, $F(1, 98) = 15.4$, $p < .001$], and another scenario was found to be marginally significant [Laptop, $F(1, 98) = 3.92$, $p = .051$]. The Dentist and Taxes scenario did not exhibit any statistical significance between conditions, $F(1, 98) = .523$, $p = .471$ and $F(1, 98) = .434$, $p = .512$, respectively. Post hoc comparisons using a Tukey Honest Significance Difference (HSD) test were carried out to test for specific pair-wise differences among each of the conditions.

With regards to the Laptop scenario, the Tukey HSD analysis indicated that scarcity scores for were significantly different for all groups compared to high SES participants in the easy condition. Specifically, a marginal difference was detected between high SES participants in the easy condition and high SES participants in the hard condition ($p = .072$), a significant difference was detected among low SES participants in the easy condition compared to high SES participants in the easy condition ($p = .011$), and finally a significant difference was highlighted between low SES participates in the hard condition compared to high SES participants in the easy condition ($p = .013$). For the Dentist scenario, my analysis revealed that low SES participants in the easy conditions differed significantly in their scarcity ratings compared to high SES participants in the easy condition ($p = .016$). Additionally, and low SES participants in the hard condition had a significant difference compared to high SES participants in the easy condition (p = .033). Finally, with regards to scarcity ratings in the Accident scenario, there was a significant difference between high SES participants in both conditions (p = .002), between low and high SES participants in the easy condition (p = .004), a significant difference between low SES participants in the easy condition compared to high SES participants in the easy condition (p = .014), and between low SES participants in the hard condition compared to high SES participants in the easy condition ($p < .001$). Post hoc analysis did not reveal any pairwise significant differences in the Taxes scenario.

Figure 8

Scarcity Scenario Stress Results



Note. Figure 8 provides average stress ratings and effects for each scenario by condition and SES. Error bars represented standard error of the mean (SEM).

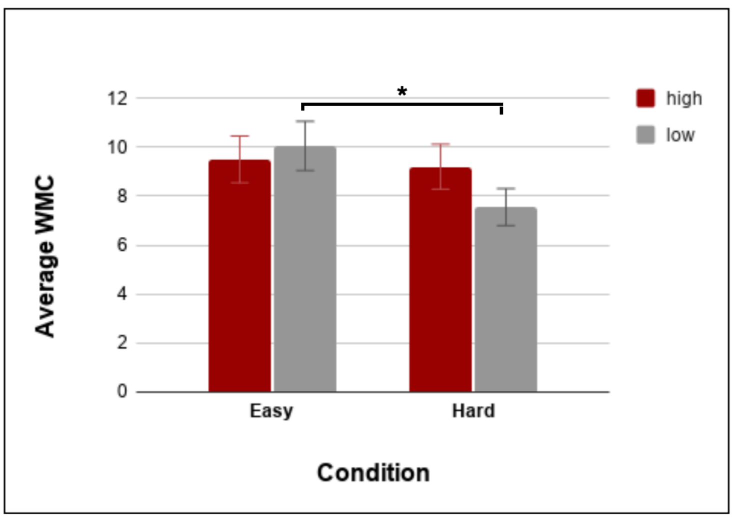
*p < .05 **p < .01 ***p < .001

Digit Span Results

By condition and SES. Performance for the forward digit-span working memory task is plotted in Figure #. A two-way ANOVA revealed a main effect on average WMC between condition, $F(1, 76) = 4.99$, $p = .029$), but not for SES, $F(1, 76) = .764$, $p = .385$. Additionally, there was a marginal interaction effect between condition and SES, $F(1, 76) = 3.06$, $p = .0855$. These results suggest that the differences found between conditions depend on income. I also used a Tukey HSD test to further examine pairwise comparisons between groups and conditions. This analysis suggested that a significant difference between low SES in the hard and easy conditions ($p = .031$), which highlights that low SES participants in the hard condition had, on average, lower WMC compared to low SES participants in the easy condition.

Figure 9

Digit Span Results by Condition and Socioeconomic Status



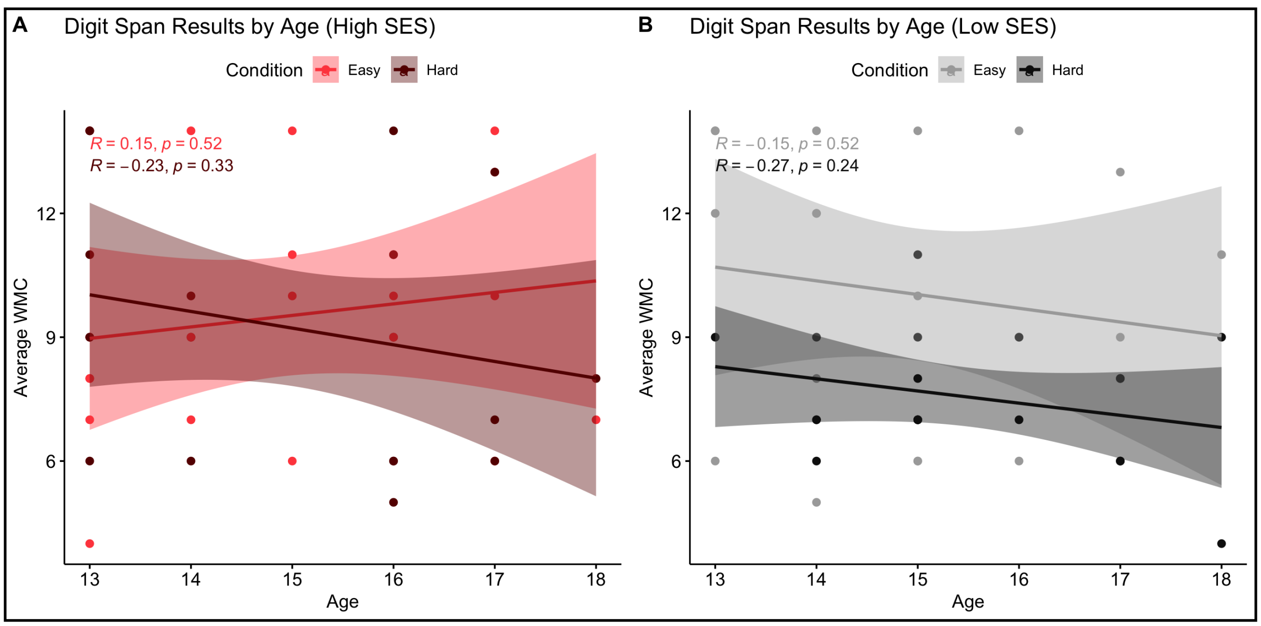
Note. Figure 9 highlights average working memory capacity by condition and SES on the digit span task. Error bars represented SEM.

*p < .05

By age. Figure 10a and 10b show changes in WMC by age and condition for low SES (*n* = 40) and high SES participants (*n* = 40), respectively. Two linear regression models were used to examine if age and condition was predictive of WMC performance for both income groups separately. First, for high SES participants, regression analysis did not indicate that the model was significantly predictive of WMC, $F(3, 36) = .509$, $p = .678$. On the other hand, while neither condition nor age was significantly predictive of WMC for low SES participants ($p = .744$ and $p = .403$, respectively), the overall regression model was significant, $F(3, 36) = 3.408$, $p = .028$. While there was not a

Figure 10

Working Memory Capacity Differences by Age, Condition, and SES



Note. Figure 10 shows changes in WMC by age. (A) Shows differences in mean WMC between conditions for high SES participants as a function of age (n = 40). (B) Shows the differences in average WMC for low SES participants by condition as a function of age. No significant differences were found. Shaded area represents confidence intervals.

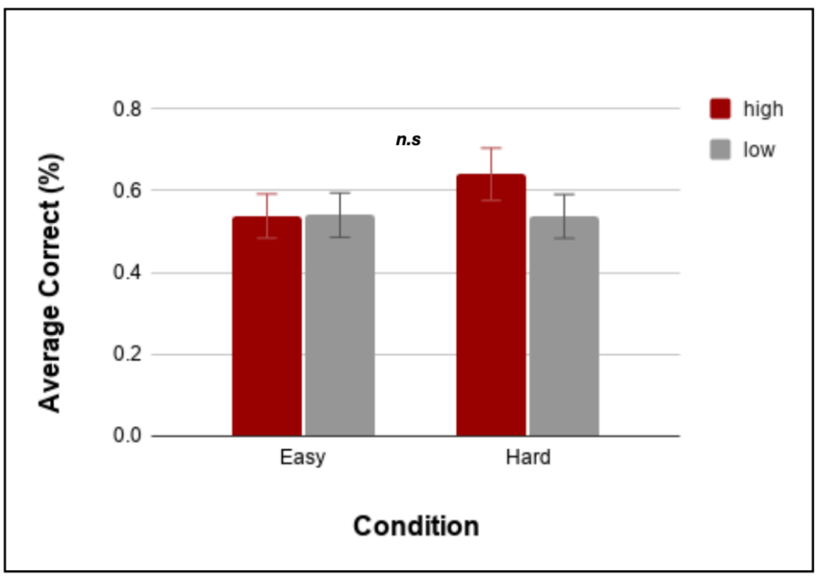
MaRs-IB Results

Experimental Accuracy

By condition and SES. A two-way ANOVA to test if condition and SES had effect on experimental performance on the MaRs-IB was conducted. Results from this analysis indicated that there were no differences based on condition, $F(1, 76) = 1.86$, $p = .177$, and SES, $F(1, 76) = 1.91$, $p = .171$. This indicates that economic scarcity did not cause any changes in problem solving abilities among any of the participants. These results are illustrated in Figure 11.

Figure 11

MaRs-IB Experimental Accuracy Results by Condition and SES



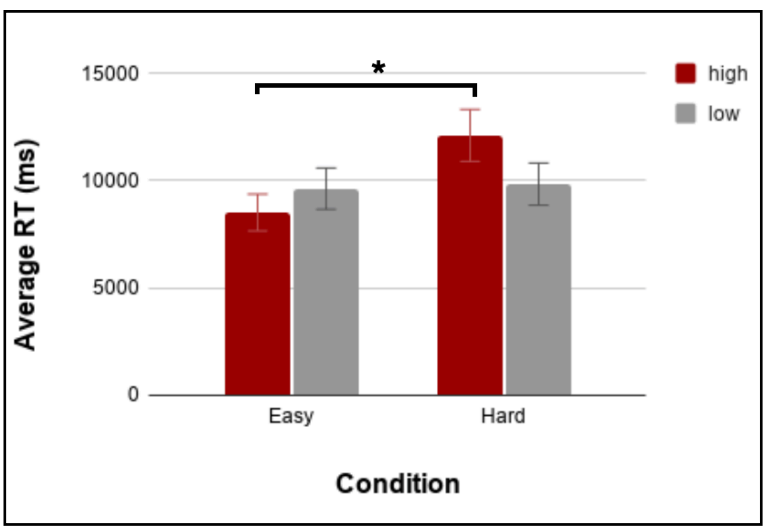
Note. Figure 11 shows the results on the matrix reasoning item bank puzzles by condition and SES. There were no signifiant differences detected between groups. Error bars represented SEM.

Age differences. Figure 15 shows the average experimental accuracy as a function of age for each group. I ran a linear regression analysis to determine if age had an effect on performance when controlling for other variables such as SES and condition. No interaction effects were detected in this model, but it did indicate that there was a significant effect on age when controlling for all other variables [*t(*87) = 2.23, *p* = .028]. The regression model was marginally significant, *F(*7, 72) = 1.92, *p* = .080 with 15.7% of the variance accounts for by this model (R^2 = .157). This results of my regression analysis confirmed no differences as a result condition or SES, and suggests that as age increase per 1 unit, the average experimental accuracy increases by 4.8%.

Reaction Time. The next analysis I conducted was to examine if there were differences in reaction time between participants. A two-way ANOVA revealed that there was a marginal interaction effect between condition and SES, *F*(1, 76) = 3.49, *p* = .066, and that there was a main effect by condition, *F*(1, 76) = 4.41, *p* = .039. Post hoc comparisons revealed that there were significant differences between high SES participants in the hard and easy conditions, such that high SES participants in the hard condition spent, on average, more time per puzzle that high SES participants in the easy condition (*p* = .032). No other significant effects were identified with my Tukey HSD test.

Figure 12

MaRs-IB Reaction Time (RT) Results



Note. Figure 12 shows differences in reaction time (RT) by condition and SES. Error bars represented SEM.

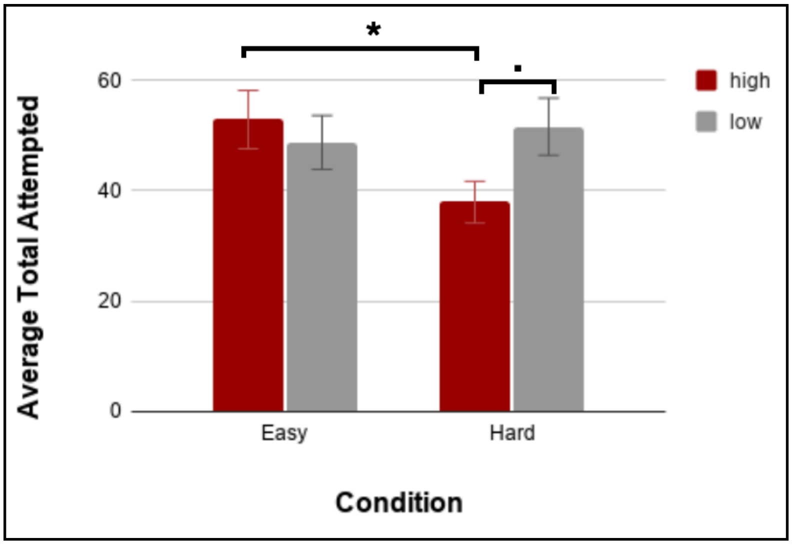
*$p < .05$

True Accuracy

By total attempted puzzles. Since participants each did a range of puzzles per experiment (Easy: $M = 50.9$, $SD = 18.4$; Hard: $M = 44.8$, $SD = 16.2$), I ran a two-way ANOVA to test if condition and SES had effect on the number of overall puzzles attempted on the MaRs-IB. While there were no main effects detected for condition or SES, there was a significant interaction between condition and SES, $F(1, 76) = 5.59$, $p = .021$. Using a Tukey HSD test, it was later determined that a significant difference emerged between high SES participants in the hard condition versus the easy condition ($p = .031$), and similarly a marginal significant effect was identified between low SES participants in the easy condition against high SES participants in the hard condition ($p = .058$). There was also not a significant effect found between high SES and low SES participants in the hard condition ($p = .863$) nor was there an effect between low SES participants in hard and easy conditions ($p = .950$). This suggests that while overall experiment accuracy was not affected by scarcity, it appears that high SES participants in the easy condition on average completed more puzzles than both low and high SES participants in the hard condition.

Figure 13

MaRs-IB Total Attempted Puzzles by Group



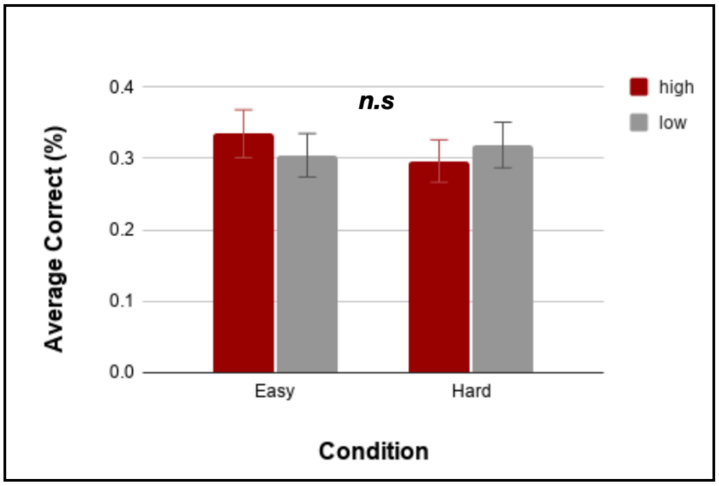
Note. Figure 13 shows different in total number of puzzles attempted by condition and SES. Error bars represented SEM.

*p < .05

By condition and SES. Next, I examined if total attempted puzzles resulted in differences in true accuracy (total attempted correct / total attempts possible, 80). Using a two-way ANOVA, it was determined that no differences between condition or SES were significant [Condition: $F(1, 76) = .319$, $p = .560$; SES: $F(1, 76) = .038$, $p = .840$]. These results suggest that while high SES participants attempted more puzzles, there were no significant differences among overall performance.

Figure 14

MaRs-IB True Accuracy Results by Condition and SES

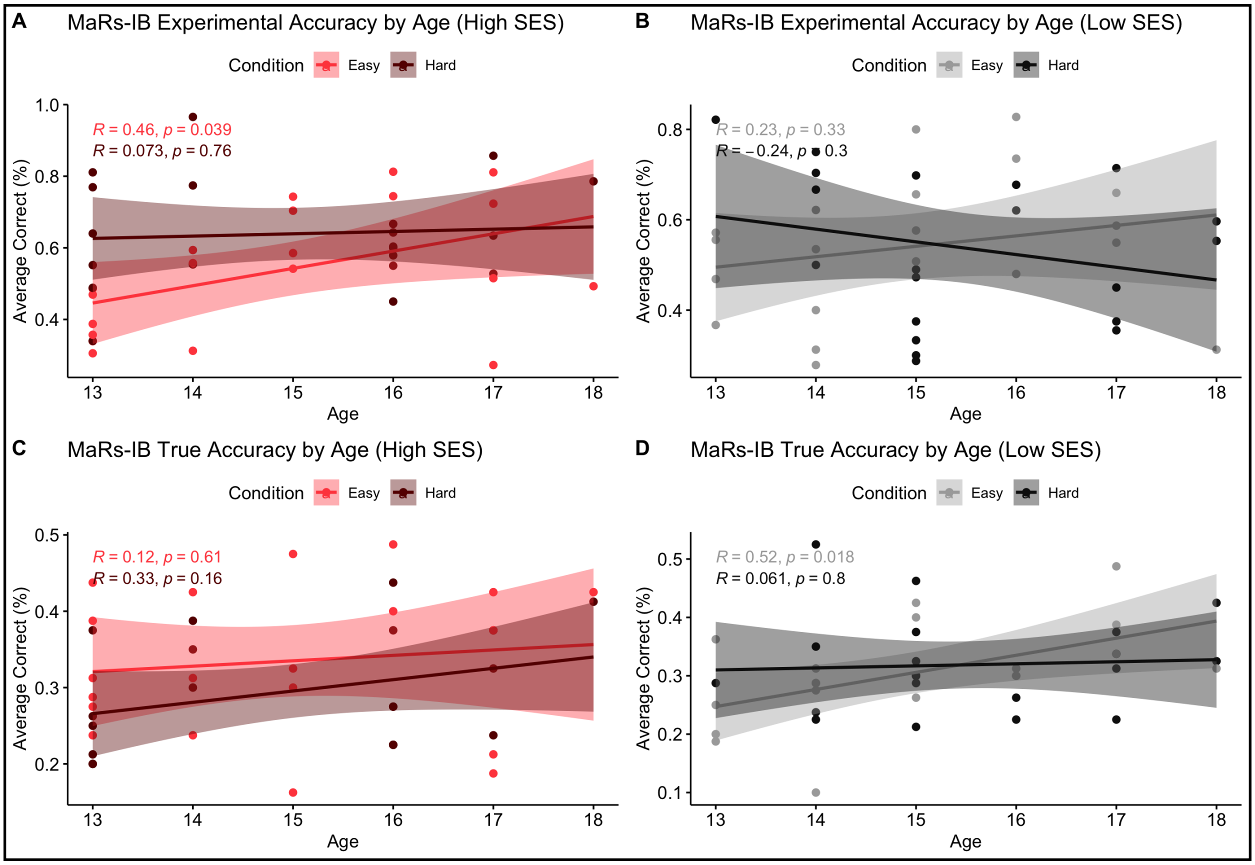


Note. Figure 14 shows the accuracy of participants calculated by correct puzzles / possible puzzles (80). No significant differences were identified between condition or SES. Error bars represented SEM.

By age. Similar to experimental accuracy, the final analysis examined if age was predictive of true accuracy. Unlike with experimental accuracy, a simple linear regression analysis revealed that age was not a significant predictive of true accuracy performance, and this regression model was not statistically significant, $F(7, 72) = 1.42$, $p = .210$. Overall these findings similar reveal that despite high SES participants having more trials during the MaRs-IB experiment, there were no differences regarding performance between participants of different ages.

Figure 15

MaRs-IB Experimental and True Accuracy Results by Age and SES



Note. Figure 15 shows experimental and true performance on MaRs-IB by age between SES and condition. (A) and (C) show the results of high SES participants for experimental and true accuracy, respectively. (B) and (D) show the results for low participants for experimental and true accuracy, respectively. Shaded areas represent confidence intervals.

Discussion

The results from this experiment provide several insights that offer a possibility for researchers to causally investigate the effects of poverty on learning and memory. Since, to the best of my knowledge, inducing scarcity in adolescents had not previously been shown, I first had to evaluate whether there were distinctions between how the novel scenarios were perceived by adolescents from different socioeconomic backgrounds. By analyzing the stress ratings provided by the participants, my results did suggest that most of the hard scarcity scenarios are significantly more stressful than the easy scenarios. However, this finding was not exclusive to low SES participants; unexpectedly, some high SES participants in hard conditions, and low SES participants in easy conditions, did rate scenarios as stressful. This provides two critical implications: the first is the possibility of inducing economic scarcity in a developmental population—but perhaps not exclusive to a particular socioeconomic group. This leads to a second implication: that adults and adolescents foster different socioeconomic identities which influences how they perceive financial stress.

Consider the results from the Accident scenario as an example. Despite my initial hypothesis, it seems that this hypothetical situation was equally stressful to both high and low SES participants in the hard condition, given that both groups did not differ significantly from each other—but both did score significantly higher than high SES groups in the easy condition. Additionally, in each of the scenarios (besides the Taxes scenario—which had no significant differences between the groups), low SES participants rated each one as more stressful than high SES participants in the easy condition. Similarly, data from the Dentist scenario produced similar results where low SES participants in both easy and hard condition provided significantly higher stress ratings than high SES participants in the easy condition. These findings suggest that how adolescents react to financial situations may not be focused entirely on the *total* cost of the scenario, but in consideration of the entire situation. This could imply one potential theory to examine further.

First, low SES participants may not compartmentalize value into stressful and non-stressful categories given the nature of their financial circumstances (e.g., $200 in an easy condition is still a considerable amount for an adolescent compared to adults with income). This could also explain why some high SES participants differed significantly in their rating between conditions, such as a marginally significant difference between conditions for high SES participants that reviewed the laptop scenario. As a result, one way to further examine this possibility is to incorporate non-financial components in the easy condition for adolescents. In fact, Mani et al. (2013) led a second experiment to examine if similar non-financial scenarios would produce similar effects on cognition as financial situations. The results from their second experiment highlighted that there were no differences in performance among any of the participants, meaning that adults were able to distinguish between the values and their respective contexts, which may be a possibility for adolescents as well. If so, and if adolescents from low SES backgrounds are stressed regardless of financial value, then a more ideal control group would be a non-financial scenario for adolescents.

Despite the mixed findings of the scarcity ratings, the results from the digit span working memory experiment are indicative of a scarcity effect in low SES participants. Namely, my pilot data does appear to suggest that low SES participants that reviewed difficult financial scenarios had lower performance compared to low SES participants in the easy condition. However, it is important to note that this difference was not present for any other comparison (low SES in hard versus high SES in hard or low SES in hard versus high SES in easy). This could be because of a relatively small sample size ($n = 20$), and therefore with increasing sample size could increase statistical power.

Indeed, results from age differences between SES groups and conditions provide promising insights as to the effects by increasing sample sizes. This analysis paralleled previous findings that showed negative associations between SES and WMC (Finn et al., 2017); however, my results did suggest that this association was stronger for low SES participants in the hard condition (albeit not a significant correlation, $p = .240$). Additionally, while also not significant ($p = .330$) there did appear to be a negative association between age and WMC for high SES participants in the hard condition, and a positive association for high SES participants in the easy condition, suggesting that scarcity was having an effect on their performance on the digit span task. While neither of these correlations or regression analysis were significant with age, condition, and/or SES, this may be amplified with the incorporation of myriad participants per group.

Nevertheless, if future research does emerge to suggest a scarcity effect on WMC, this could mean that inducing scarcity can be a mechanism to examine how it affects learning algorithms in low, or even high, SES participants. Previously, Otto et al. (2013) found that WMC buffered the deleterious effects of stress on incorporating complex procedures on a learning task but it is unclear if patterns between participants SES backgrounds with low WMC would produce similar findings. And even if so, this still would not offer a causal explanation for how poverty impacts learning. Therefore, if scarcity does affect WMC and this is a cognitive strategy needed to maximize MB learning, then inducing economic scarcity can be an experimental component to examine the effects of financial stress on learning.

Furthermore, the preliminary results from my MaRs-IB task does not provide evidence to suggest that such performance in learning behavior is a result of disrupting problem-solving abilities. While my initial hypothesis was that scarcity would affect fluid reasoning based on prior findings in adults that did show scarcity affecting performance on a similar matrix reasoning tasks (Mani et al., 2013), this did not appear to manifest in my data. In the original study, participants did not complete as many puzzles as adolescents did; adults in the Mani et al. (2013) design completed 8 puzzles whereas adolescents completed up to 80 puzzles and on average completed more than adults did (M = 47.8, SD = 17.5). The additional opportunities to complete a larger set of puzzles could have mitigated any effects of scarcity. However, similar age analysis were conducted on accuracy performance on the MaRs-IB task, and while all groups showed mostly positive associations, there was indication that low SES participants in the hard condition had a negative correlation between age and performance (but this was not significant). This offers the possibility that by incorporating more adolescents in follow up analyses scarcity may affect fluid reasoning abilities, but it might also be driven by external factors.

My analysis did reveal that there was a marginal effect detected in total number of puzzles attempted between high and low SES participants in the hard condition such that low SES participants, on average, completed more puzzles than high SES participants in the hard condition. Additionally, high SES participants in the easy condition attempted more than high SES participants in the easy condition, and no effects were statistically significant between other groups. Furthermore, high SES participants in the hard condition spent significantly more time per puzzle than high SES participants in the easy condition. These analyses could suggest that scarcity has other effects on behavior than just problem-solving such as affecting motivation ad speed processing. As a result, this could indicate that restricting the number of puzzles completed versus restricting the time to complete may amplify results in a manner that highlights a more salient scarcity effect. However, overall performance on the experiment do not offer statistical evidence to suggest that, nor was an additional analysis looking at true accuracy. So even though some participants were able to complete more puzzles, there was no evidence to suggest that this had a major effect on performance.

The Value of Scarcity in Learning and Memory Studies

Simply comparing the learning performance between high and low SES participants could highlight baseline differences, but provides marginal insights into the reasons why those differences exist given the correlative nature of the experiment. However, the use of a scarcity framework could highlight a unique form of stressor and also determine which population variables render individuals more susceptible to the effects of that stressor. Furthermore, these kinds of experimental approaches can draw attention to how both environmental and experiential factors influence complex decision-making. The scarcity studies highlighted in this experiment can be useful in providing a causal experimental approach without endangering adolescents or relying on actual financially precarious situations, while still yielding some fruitful insights that could explain not only differences in learning behaviors, but how these differences may account for divergent life outcomes.

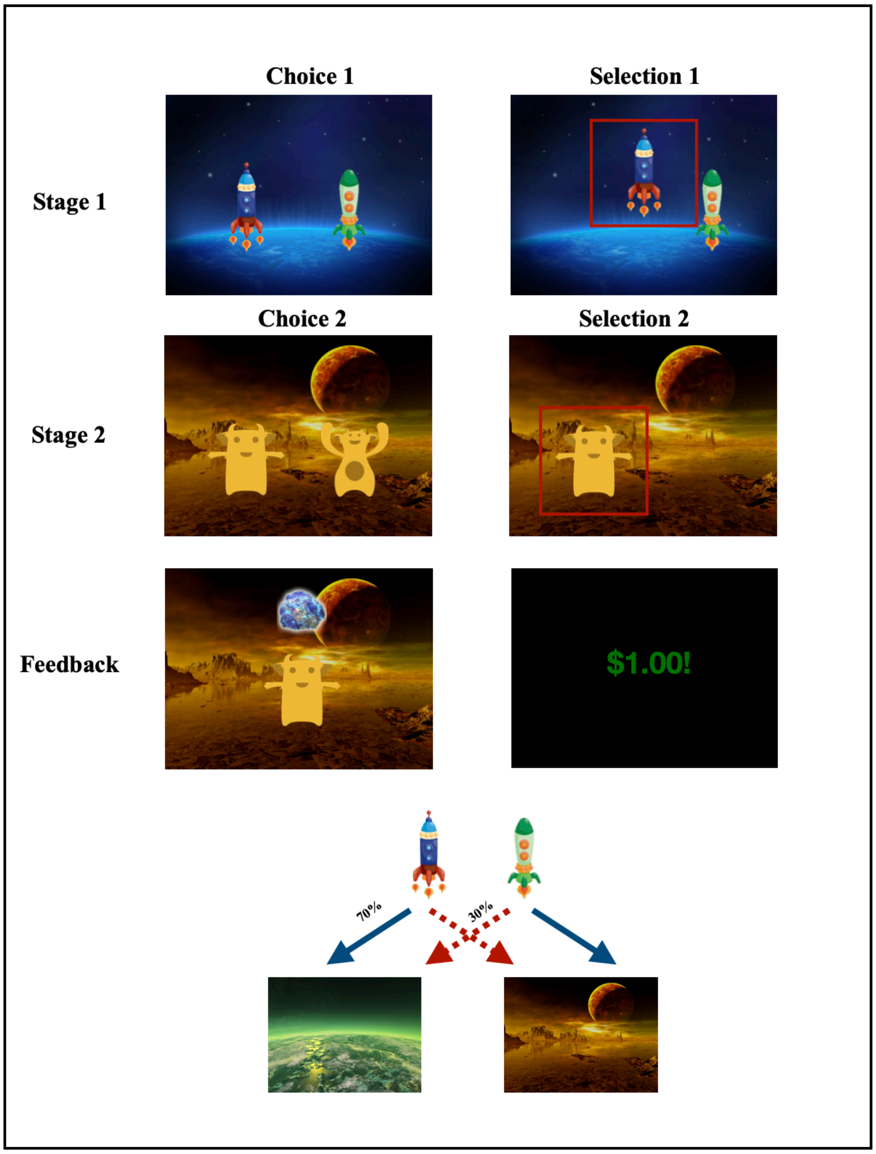
However, while utilizing a scarcity framework is usually with the assumption that it will *impair* performance, these insights may also offer opportunities to investigate what *helps* with learning. For example, if scarcity is affecting learning performance by disrupting the recruitment of PFC mechanisms by triggering amygdala-driven bottom-up processes, then perhaps experimental interventions can examine how to influence performance in the alternate direction: by activating PFC strategies. Or, this can also offer opportunities to critically examine stimuli that is favored by emotional systems: if scarcity disrupts performance on tasks mediated by executive function, then perhaps it will also affect tasks that are mediated by emotionally rich stimuli (such as fearful stimuli) but in the opposite direction—by facilitating the acquisition of that information. This offers investigators an opportunity to utilize scarcity as a way to delineate between various neural systems that incorporates stimuli differently.

This suggests a working theory that complements an adaptation framework in research with ELA populations (Raver & Blair, 2020). Specifically, it does not argue that the learning differences found between low SES participants are a result of deficient neural processes—nor is it to insinuate that adolescents are “adapting” to their environment. Rather, it argues the direction by which particular events influence competing learning systems and how repeated experiences may strengthen these connections. This may result in biasing an individual to default to a system for decision-making, but not to imply that others are defective or unable to be utilized.

For example, Figure 16 illustrates a trial in a two-step decision-making task aimed to differentiate between MB and MF learning patterns. First, participants are shown one of two rocket ships that will take them to different planets (Stage 1). Each rocket has a particular probability of going to either planet, with one more likely to go to a particular planet than the other and vice versa. Once the selection has been made and the rockets lands on the planet, they are then presented with one of two aliens (Stage 2). The participant must then choose one of those aliens to get a reward or nothing. Each of the aliens also has a certain probability of providing a high reward—but this will depend on the planet they are on.

Figure 16

Two Step Decision-Making Task



Note. Example of a two-step decision-making trial. First participants are presented with one of two rockets ships. The participants selects one of the rockets which takes them to one of two planets (green or yellow) with different probabilities of sending them to one of the planets (the blue rocket has a 70% change of sending the participant to the green rocket and a 30% of sending them to the yellow rocket; the green rocket has a 70% change of sending the participants to the yellow rocket but only a 30% chance of sending them to the green planet). Once participants arrive at the planet (Stage 2) they must make a second choice by deciding between one of two aliens to acquire either a reward of drifting value or no reward. The probability of alien granting a rewarding outcome depends on the planet. Participants must learn to either make choices based on prior rewarding outcomes or to learn the probabilistic nature of the rockets and aliens to guide their decisions.

The setup of the aforementioned task is engineered such that it can illuminate whether someone makes decisions based on past rewarding outcomes (MF) or by learning these probabilities and making selections that are most optimal and advantageous depending on the rockets and aliens presented in each of the stages (MB). For example, imagine if someone chooses a rocket and alien pair that provides them with a reward. An individual using MF strategies will likely repeat the same sequence of actions based on the results of the prior trial. On the other hand, someone using MB strategies will choose the rocket and alien that is most likely to send them to a rewarding planet *and* choose the alien that is statistically more likely to provide a reward—regardless of whether or not the prior trial gave a reward. The latter requires numerous trials and integrating various pieces of information from each of those trials to learn these statistical probabilities to a sufficient degree, which suggests the importance of components such as high WMC to facilitate this process.

As a result, this task design and prior studies suggest that people with low WMC may rely on MF behavior to make decisions (Otto et al., 2013). Which means that using scarcity in such a task could bias low SES participants towards habit-like learning patterns. Or this may suggest that low SES participants may already be biased towards MF strategies given studies have suggested that there is a negative association between WMC and income (Finn et al., 2017). However, even if the latter were to materialize in a study design, or if scarcity did prohibit someone's ability to use more optimal, complex strategies, neither suggest deficiency or adaptation. Instead, it suggests which system a participant is initially accustomed to making decisions—but that theses systems are susceptible to influences. Because even if low SES participants utilized MF strategies at baseline or through a scarcity induction, this could mean that low SES participants can be supported in the other direction through guidance and feedback. For example, the two-step decision-making task outlined above does not explicitly inform participants of the statistical differences between each of their decisions. Therefore, it would be worthwhile to first highlight default approaches to such learning and decision-making tasks among low SES participants but even more insightful to examine how to encourage MB learning if scarcity does impact networks integral to complex learning environments.

Limitations

Though preliminary pilot data seem to suggest the possibilities of a scarcity effect on cognitive performance, there are a few concerns worth addressing. The most salient concern is the online nature of the study; it was difficult to control environmental conditions to ensure that the quality of submissions is equal among all participants. In fact, a subset of participants did provide additional context regarding their circumstances. A few mentioned in an optional post-survey that they were either unable to complete the study alone (n = 23) or that they were unable to complete each of the tasks without experiencing some form of interruptions (n = 18). Though prior studies have advocated for the use of online data collection with experiments regarding learning (Lefever et al., 2007) and also within a developmental population (Nussenbaum et al., 2020), it is still worth highlighting the challenges faced in low income households with such tasks, such as having the space to complete tasks independently with no interference or accessing technological resources to complete tasks without technological difficulties (Cooper et al., 2000). In itself this is a reminder of the inequities encountered in low SES situations with respect to needed learning resources and environments.

This leads to important considerations regarding the sample size of the participants presented in this study. First, it was determined *a priori* to have at least 300 participants, but due to the challenges described previously, acquiring a sufficient sample size was not achieved. Of course, while despite our small sample size, some meaningful effects did emerge, it is still critical to recognize that such effects may not be replicated in future studies. Indeed, much of the data collected online was done during the COVID-19 pandemic (Pfefferbaum & North, 2020; Daniel, 2020), a period of significant economic and mental stress—especially for low SES populations (Jay et al., 2020). It is of course entirely possible that much of the effects in this thesis are also a response to the current climate. And while it is still unclear the extent by which recent events affect marginalized populations, residual effects post-pandemic may or may not support my hypothesis.

Additionally, another caveat with administering these tasks remotely is the inability to confirm the participants. A subset of participants was recruited through Prolific (n = 20), and while it was instructed that children between the ages of 13-18 only were permitted to complete the task, there were no checks to guarantee that the recruited age group were the individuals who actually completed the tasks. Future studies using online developmental data should incorporate more robust screening measures to ensure that all data submissions are done by adolescents, as it is possible that results in these tasks would different between adults and adolescents.

With regards to the scarcity design, a fundamental challenge in utilizing a psychosocial framework—particularly with a developmental population—is the reliability and validity of the tasks. Directly examining the construct of poverty, and how it shapes learning, memory, and the neural systems that support these functions, is a difficult endeavor. It may not be adequately addressed through the application of hypothetical financial scenarios because they are, by definition, not real; it is therefore relatively easy to mentally abstract away from the situations described. There is also the possibility that participants may not fully comprehend the nature of the scarcity descriptions, given that how adolescents engage with finances varies drastically, especially compared with adults who may be more reliable and tethered to finances. Therefore, the possibility exists that experimentally employing scarcity in a psychosocial manner in a developmental population may not be possible with the current methods. To dissociate the two, future research should incorporate physiological measures to confirm a lack or presence of stress induction. This can be accomplished by taking cortisol measures either via saliva (responsive to acute stressors) or through hair samples (an index of chronic stress). Another tool to capture acute stress could be galvanic skin response, which can determine whether there are subtle changes in skin conductance associated with stress states.

Nevertheless, the experimental methods trialled in this study offer a means to investigate how poverty affects learning and could usefully be extended by refining scarcity scenarios and recruiting more diversely. With additional data, the insights provided could further elucidate if a scarcity effect in a developmental population is possible, if this can be narrowed down to low SES participants, and continue to examine how it impacts cognitive processes that mediate RL.

Future Directions

Pilot results from this experiment highlighted that individual ratings for most of the scenarios varied greatly within and between conditions such that some scenarios. A subset of participants (*n* = 13) engaged in a post-study workshop to provide feedback on the experimental design and highlighted additional external scarcity stressors. This session revealed important insights regarding differentiation between how adults and adolescents process financial value. Future studies should further disentangle how these are processed prior to incorporating them in modified scarcity scenarios.

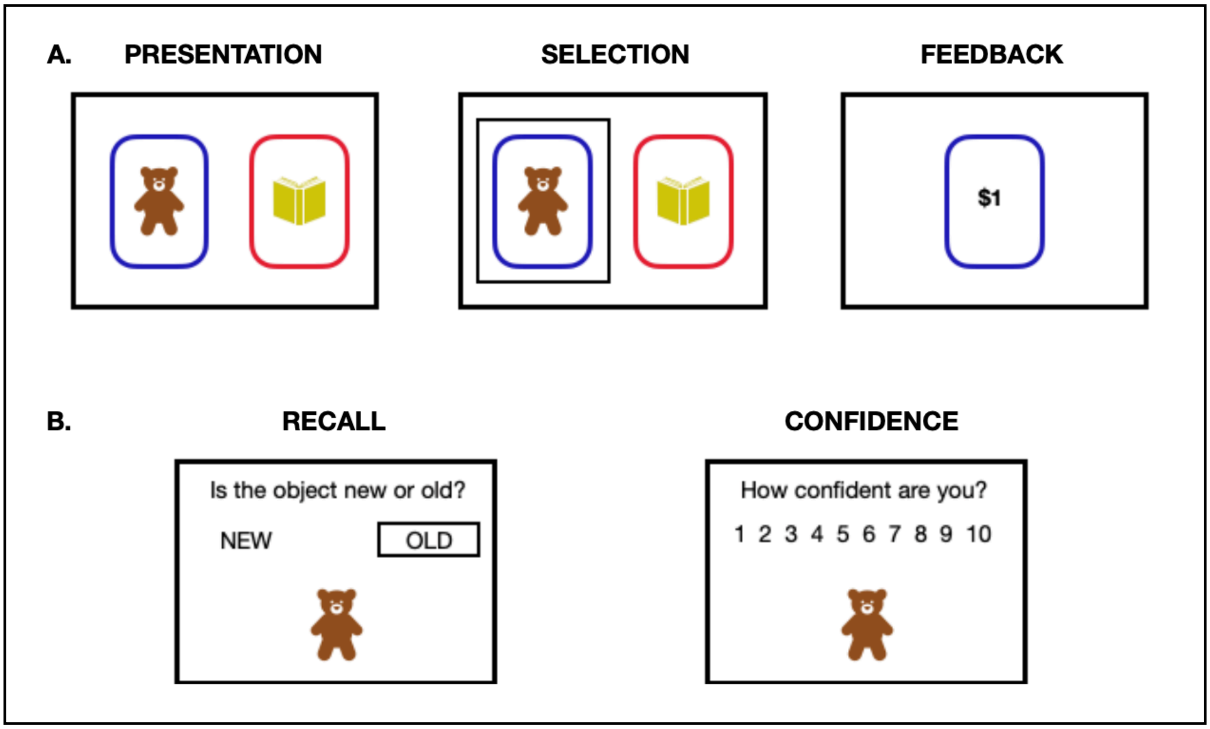
Additionally, it was identified that distinctions between the MaRs-IB task and the Digit Span task induced more stress with regards to the timing than the task difficulty. For the former, participants were only given 30 seconds to complete each puzzle compared to the digit span task that permitted an infinite amount of time. This scarcity of time simulated a similar stressful experience to academic settings that were suggested to be simulated across experiments (e.g., force participants to recall digit sequences in a constrained period of time). Additionally, several participants noted that the “test anxiety” of the digit span task provided an additional stress factor: the feeling that it was an examination of their intellectual abilities that provided an additional cognitive load. As a result, incorporating more “real-world” test examples (such as math problems) within the study could be explored, as a way to increase task difficulty and stress levels more effectively. This can be achieved using a complex digit span task (Chain & Morrison, 2010), which requires participants to complete and answer correctly simple mathematical operations in between digit presentations. This can also improve online data by using these mathematical operations in between stimuli as frequent attentional checks (as opposed to brief fixation screens).

Finally, while future studies should explore differences in MF and MB performance between low and high SES adolescents (Figure 16), studies should also more closely examine how scarcity affects memory systems from reward information. Prior studies have shown that reward processing is blunted in ELA populations (Tottenham & Galván, 2016), such that participants are unable to distinguish between high, mid, and low rewarding stimuli. However, it remains unclear how such differences in reward processing affect implicit memory associations from rewarding experiences.

Davidow et al. (2016) used a probabilisitic learning task that required participants to learn predetermined paired associations between two stimuli. If a participant made a correct choice during a trial, a random image was presented during the feedback stage. The results from this task found that adolescents were much better at learning from reward-salient experiences which led to increased recollection of stimuli simultaneously presented during these events. This was supplemented with neuroimaging correlations between HCM-STR connectivity in adolescents during these experiences, which might suggest that this activity mediated the associations of those stimuli into memory due to increased dopaminergic activity from the STR. Such insights can be further examined by examining how low SES participants learn from rewards and if scarcity affects this process by using a similar task design (Figure 17). Results can explore if (a) low SES and high SES participants learn from rewarding experiences differently and (b) if scarcity affects learning and memory on this task.

Figure 17

Reinforcement Learning and Memory Task



Note. An example trial of a reward learning and episodic memory task. (A) First, participants are presented with one of two objects on a color-bordered deck that has a drifting probability of providing a high reward (70/30). Participants make a timed selection and then immediately acquire feedback based no their choice. (B). Surprise memory test. After completing several blocks in the previous learning task, participants will see a series of stimuli and asked whether the object is new (not shown during the experiment) or old (shown during the experiment) followed by a confidence rating of their choice.

Based on the results presented in this thesis, it is possible that scarcity may affect learning rates on this task due to affecting PFC functions; however, this thesis did not provide any evidence to suggest alternations in HCM-STR connectivity, or evidence to suggest that scarcity would augment or diminish dopaminergic activity from ventral tegmentum areas to STR. As previously stated, however, increased dopaminergic activity has been found in ELA populations, which may suggest that low SES participants may either subliminally recall more stimuli from feedback trials or exhibit no differences, a process that could be confirmed by comparing HCM-STR connectivity between adolescents from different SES backgrounds. Additionally, by incorporating a scarcity effect, this can exemplify if such a method disrupts this process as well and even examine if it affects memory consolidation from rewarding experiences. If such results do manifest, this may also be confirmed by examining decreased connectivity between HCM and STR regions, and perhaps even by examining connectivity between the HCM-STR-PFC network.

Conclusion

This thesis aimed to address whether economic scarcity could be a helpful framework to understand the causal mechanisms of stress among low SES populations and its effects on learning and memory systems. The results outlined in this thesis appear to suggest, for the first time, that such experimental measures are possible in developmental studies. Additionally, this also hinted at distinctions between adult and adolescent processing of financial events, such that low and high SES adolescents do not dissociate financial value similarly compared to working-class professionals. This provides an opportunity to investigate how poverty affects cognitive processes vital to learning and memory during developmental periods, and even to identify critical windows for when such events have longer-lasting effects. Future research should attempt to replicate the findings presented in this thesis, and if realized, extend to other learning tasks. Thus, the insights generated through this experiment merit future investigations.

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Table 1

Scarcity Scenarios and Comprehension Check Questions

Scenarios	Text	Comprehension Questions
Laptop	Your school lends you a Mac and you accidentally spill water on it. It no longer works and now you and your family owe the school $2,000 ($200). Are you able to cover the cost right away? Where is the money coming from? How soon can you pay for this? Will this fee have any negative impact on paying for other necessities such as rent or food?	How much do you owe the school for the broken laptop?
Dentist	You go to the dentist and find out you urgently need a root canal which will cost $5,500 ($550). If you do not have the procedure, you will have severe tooth pain. Is this cost an issue for your parents? If your dentist wanted to perform the procedure the next day, can they pay for it that soon? If you need time to save money, are you worried about the pain?	What dental procedure will cost you $5,500 ($550)?
Taxes	It turns out that your family miscalculated their tax returns and they owe the government a total of $1,500 ($150). If they do not pay soon, they can face felony charges and additional fees to pay. Is this something your family will be able to afford? Can they borrow money from a family member or friend to help? Do they have access to an attorney to help review their taxes? How soon could they pay this off?	Your family was fined more than $1,000 ($100) from the IRS (true or false):
Accident	You cause a major car accident and must pay the person you hit a total of $1,000 ($100) plus $2,000 ($200) to fix your car. Is this financially feasible for you? If not, are you able to borrow money from anyone? How quickly are you able to pay this off? Are you and your family able to continue without a car until you can pay for the repairs?	It is more expensive to repair the person's car than yours (true or false):

Note. Table 1 shows each of the 4 scenarios showed randomly during the scarcity trials. All participants were randomly shown one of these scenarios (with values in the easy condition shown in parentheses). All participants were also asked to answer the 4 comprehension and score a 100% in order to proceed to the next task. Feedback was no provided, and if a participant missed any question, they were automatically redirected to view each scenario again and allowed to retake the questionnaire as many times until they got all questions correct. Any participant that did not achieve a perfect score on the comprehension test was unable to proceed to the second part of the study.

Table 2

Participant Demographics

Factor	Total	High SES Easy (%)	High SES Hard (%)	Low SES Easy (%)	Low SES Hard (%)
Age					
N	104	33 (30.84%)	31 (28.97%)	20 (18.69%)	20 (18.69%)
13	21	9 (8.41%)	7 (6.54%)	4 (3.74%)	1 (0.93%)
14	25	9 (8.41%)	7 (6.54%)	5 (4.67%)	4 (3.74%)
15	18	5 (4.67%)	2 (1.87%)	4 (3.74%)	7 (6.54%)
16	16	2 (1.87%)	9 (8.41%)	3 (2.80%)	2 (1.87%)
17	19	7 (6.54%)	5 (4.67%)	3 (2.80%)	4 (3.74%)
18	5	1 (0.93%)	1 (0.93%)	1 (0.93%)	2 (1.87%)
Gender					
N	104	33 (31.73%)	31 (29.81%)	20 (19.23%)	20 (19.23%)
Male	50	15 (14.42%)	14 (13.46%)	13 (12.50%)	8 (7.69%)
Female	52	17 (16.35%)	17 (16.35%)	7 (6.73%)	11 (10.58%)
Other	2	1 (0.96%)	-	-	1 (0.96%)
Race					
N	0	33 (31.73%)	31 (29.81%)	20 (19.23%)	20 (19.23%)
Asian	9	4 (3.85%)	3 (2.88%)	1 (0.96%)	1 (0.96%)
Black or African American	15	4 (3.85%)	2 (1.92%)	5 (4.81%)	4 (3.85%)
Hispanic/Latinx	14	3 (2.88%)	5 (4.81%)	3 (2.88%)	3 (2.88%)
Other	2	-	1 (0.96%)	-	1 (0.96%)
White	57	21 (20.19%)	18 (17.31%)	8 (7.69%)	10 (9.62%)
Multi-Racial	7	1 (0.96%)	2 (1.92%)	3 (2.88%)	1 (0.96%)
Income					
N	104	32 (30.77%)	29 (27.88%)	21 (20.19%)	22 (21.15%)

Less than $10,000	8	-	-	3 (2.88%)	4 (3.85%)
$10,000 - $19,999	7	-	-	4 (3.85%)	6 (5.77%)
$20,000 - $29,999	5	-	-	2 (1.92%)	3 (2.88%)
$30,000 - $39,999	16	-	-	11 (10.58%)	5 (4.81%)
$40,000 - $49,999	4	-	-	-	4 (3.85%)
$50,000 - $59,999	3	2 (1.92%)	1 (0.96%)	-	-
$60,000 - $69,999	5	3 (2.88%)	1 (0.96%)	1 (0.96%)	-
$70,000 - $79,999	4	3 (2.88%)	1 (0.96%)	-	-
$80,000 - $89,999	6	3 (2.88%)	3 (2.88%)	-	-
$90,000 - $99,999	5	1 (0.96%)	4 (3.85%)	-	-
$100,000 - $149,000	10	3 (2.88%)	4 (3.85%)	-	-
More than $150,000	31	17 (16.35%)	15 (14.42%)	-	-
Education - Parent 1					
N	104	33 (31.73%)	31 (29.81%)	20 (19.23%)	20 (19.23%)
Less than high school	9	3 (2.88%)	2 (1.92%)	2 (1.92%)	2 (1.92%)
High school graduate	12	1 (0.96%)	-	6 (5.77%)	5 (4.81%)
Some college	21	3 (2.88%)	3 (2.88%)	8 (7.69%)	7 (6.73%)
2 year degree	7	1 (0.96%)	-	2 (1.92%)	4 (3.85%)
4 year degree	20	9 (8.65%)	8 (7.69%)	1 (0.96%)	2 (1.92%)
Professional degree	28	14 (13.46%)	13 (12.50%)	1 (0.96%)	-
Doctorate	7	2 (1.92%)	5 (4.81%)	-	-
Education - Parent 2					
N	104	33 (31.73%)	31 (29.81%)	20 (19.23%)	20 (19.23%)
N/A	3	-	-	-	3 (2.88%)
Less than high school	18	5 (4.81%)	2 (1.92%)	7 (6.73%)	4 (3.85%)
High school graduate	19	1 (0.96%)	3 (2.88%)	6 (5.77%)	9 (8.65%)
Some college	15	3 (2.88%)	4 (3.85%)	6 (5.77%)	2 (1.92%)
2 year degree	5	-	2 (1.92%)	1 (0.96%)	2 (1.92%)

4 year degree	15	8 (7.69%)	7 (6.73%)	-	-
Professional degree	24	14 (13.46%)	10 (9.62%)	-	-
Doctorate	5	2 (1.92%)	3 (2.88%)	-	-

Table 3

Scarcity ANOVA Tables

Scenario	Variable	df	Sum Sq	Mean Sq	F	P-Value
Laptop	Condition	1	4.11	4.11	3.92	0.051
	SES	1	8.7	8.7	8.29	0.005
	Condition x SES	1	2.68	2.68	2.56	0.113
	Error	98	102.9	1.05	-	-
Dentist	Condition	1	0.8	0.798	0.523	0.471
	SES	1	18.3	18.3	12	0.001
	Condition x SES	1	1	1.003	0.658	0.419
	Error	98	149.43	1.525	-	-
Taxes	Condition	1	0.53	0.527	0.434	0.512
	SES	1	6.89	6.89	5.67	0.019
	Condition x SES	1	0.1	0.101	0.083	0.774
	Error	98	119.2	1.22	-	-
Accident	Condition	1	16.3	16.31	15.4	0.0002
	SES	1	13.5	13.5	12.7	0.0006
	Condition x SES	1	0.65	0.651	0.614	0.435
	Error	98	103.8	1.06	-	-

Table 4

Digit Span ANOVA Tables

Variable	df	Sum Sq	Mean Sq	F	P-Value
Condition	1	39.2	39.2	4.95	.029
SES	1	6.10	6.05	.764	.385
Condition x SES	1	24.2	24.2	3.06	.085
Error	76	602.1	7.92	-	-

Table 5

MaRs-IB ANOVA Tables

Model	Variable	df	Sum Sq	Mean Sq	F	P-Value
Experimental Accuracy	Condition	1	.049	.049	1.86	.177
	SES	1	.050	.050	1.91	.171
	Condition x SES	1	.056	.055	2.10	.151
	Error	76	1.99	.026	-	-
MaRs-IB Reaction Time	Condition	1	7.231e+07	72313800	4.41	.039
	SES	1	6.753e+06	6753426	.412	.523
	Condition x SES	1	5.719e+07	57185128	3.49	.066
	Error	76	1.246e+09	16398192	-	-
Total Puzzles Completed	Condition	1	732	732.1	2.58	.112
	SES	1	451	451.2	1.59	.211
	Condition x SES	1	1584	1584.2	5.59	.021
	Error	76	21527	283.3	-	-
True Accuracy	Condition	1	.003	.003	.379	.540
	SES	1	.000	.000	.038	.846
	Condition x SES	1	.014	.014	1.85	.178
	Error	76	.566	.007	-	-