INTERPERSONAL RELATIONS AND GROUP PROCESSES

Can an Unpredictable Childhood Environment Enhance Working Memory? Testing the Sensitized-Specialization Hypothesis

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Although growing up in an adverse childhood environment tends to impair cognitive functions, evolutionary-developmental theory suggests that this might be only one part of the story. A person's mind may instead become developmentally specialized and potentially enhanced for solving problems in the types of environments in which the person grew up. In the current research, we tested whether these specialized advantages in cognitive function might be sensitized to emerge in currently uncertain contexts. We refer to this as the sensitized-specialization hypothesis. We conducted experimental tests of this hypothesis in the domain of working memory, examining how growing up in unpredictable versus predictable environments affects different facets of working memory. Although growing up in an unpredictable environment is typically associated with impairments in working memory, we show that this type of environment is positively associated with those aspects of working memory that are useful in rapidly changing environments. Importantly, these effects emerged only when the current context was uncertain. These theoretically derived findings suggest that childhood environments shape, rather than uniformly impair, cognitive functions.

Keywords: evolutionary psychology, life history theory, social development, unpredictable environments, working memory

Supplemental materials: http://dx.doi.org/10.1037/pspi0000124.supp

Social environments are full of information. Imagine, for example, going to a professional conference containing a myriad of presentations, luncheons, and meetings. To successfully navigate the conference and interact well with others, an attendee must track some information from the presentations, remember meetings and meals with specific others, and actively update old information with new or more relevant information. These tasks rely on working memory, and some people are better at using it than others. In the current research, we investigate whether and how working memory is systematically influenced by a particular social-developmental factor: Growing up in a chaotic/unpredictable versus a stable/predictable childhood environment.

Psychologists have long been interested in working memory, documenting how it is affected by age (Salthouse, 1996; Salthouse & Babcock, 1991), disrupted by distractions and interference (Engle, Tuholski, Laughlin, & Conway, 1999), and how it correlates with intelligence and executive function (Kane & Engle, 2002; Miyake et al., 2000). In fact, much research has examined how working memory is affected by exposure to adverse childhood environments, such as experiencing poverty, family conflict, violence, or abuse. The findings thus far paint a bleak picture: Adverse childhoods typically impair working memory (Hackman, Farah, & Meaney, 2010; Karatsoreos & McEwen, 2013; McEwen, 1998, 2007).

Although these prior findings present a compelling story, we believe that this story is incomplete. We consider this topic within an evolutionary-developmental framework, which suggests that early life stress shapes, rather than impairs, cognitive functioning (Ellis & Del Giudice, 2014; Ellis, Bianchi, Griskevicius, & Frankenhuis, 2017; Frankenhuis & de Weerth, 2013; Mittal, Griskevicius, Simpson, Sung, & Young, 2015; Nederhof & Schmidt, 2012). According to this framework, individuals should develop cognitive functioning that is "specialized" for navigating the challenges and opportunities in the ecology within which they grew up. In the current research, we build on the idea of specialization by testing the sensitized-specialization hypothesis. This hypothesis posits that the specialized advantages in cognitive functioning among people who grow up in a specific type of environment might most likely manifest in current situations characterized by uncertainty.

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Journal of Personality and Social Psychology, 2018, Vol. 114, No. 6, 891–908
© 2018 American Psychological Association 0022-3514/18/$12.00 http://dx.doi.org/10.1037/pspi0000124

As such, the sensitized-specialization hypothesis predicts that while growing up in a chaotic and unpredictable environment may impair some cognitive functions, a chaotic and unpredictable early environment could specialize cognitive functions that are useful for living in such environments and sensitize them to be expressed under conditions of uncertainty.

We first discuss specialization within an evolutionary-developmental framework. Next, we present the sensitized-specialization hypothesis and derive predictions with regard to working memory. To do this, we consider different aspects of working memory and derive specific predictions about which aspects of it should be most useful for navigating unpredictable versus predictable environments. We then test the functioning of different aspects of working memory for people who grew up in unpredictable versus predictable environments. We find that growing up in an unpredictable environment has positive effects on precisely those aspects of working memory that should be useful in rapidly changing environments. Importantly, we also demonstrate that these effects emerge only when people are facing uncertain current contexts.

Evolution, Development, and Specialization

Experiencing early life adversity such as poverty, family conflict, deprivation, or trauma is linked to a variety of cognitive deficits throughout life (Frankenhuis & de Weerth, 2013). For instance, early life stress tends to impair working memory (Bos, Fox, Zeanah, & Nelson Iii, 2009; Farah et al., 2006; Hackman et al., 2014; Noble, McCandliss, & Farah, 2007), executive functioning (Blair, Raver, Granger, Mills-Koonce, & Hibel, 2011; Hostinar, Stellern, Schaefer, Carlson, & Gunnar, 2012; Hughes, Ensor, Wilson, & Graham, 2010; Noble, Norman, & Farah, 2005), intelligence and standardized test scores (Bradley & Corwyn, 2002), and language, reading, and math skills (Farah et al., 2006; Noble et al., 2005). Adverse environments often contain higher levels of chronic stress, which can have long-term negative effects on physiology, as well as the structure and function of brain regions underpinning important cognitive abilities (Blair & Raver, 2012; Del Giudice, Ellis, & Shirtcliff, 2011; Karatsoreos & McEwen, 2013; McEwen, 2012). Growing up in a chaotic and unpredictable environment, therefore, should typically impair cognitive functioning.

Although the documented negative effects of childhood unpredictability on cognitive functioning are indisputable, an evolutionary-developmental framework suggests that adverse childhood environments might not universally impair cognition, but could instead shape it (Frankenhuis & de Weerth, 2013). This distinction is important because it suggests that adverse childhood environments may have some specific positive, rather than universally negative, effects on certain types of cognitive functioning. Given that humans and other animals encountered stressful and uncertain environments over the course of evolutionary history (Ellis, Figueredo, Brumbach, & Schlomer, 2009), individuals should have the potential to develop cognitive mechanisms for living in such environments (Ellis & Del Giudice, 2014; Frankenhuis & de Weerth, 2013; Mittal et al., 2015).

Central to understanding how unpredictable environments influence cognition is the evolutionary-developmental notion of specialization (Ellis et al., 2017). Specialization posits that a person's mind becomes developmentally adapted ("specialized") for solving problems that are ecologically relevant in the types of environments in which he or she grew up. Thus, instead of becoming impaired by adverse conditions, specialization argues that certain cognitive abilities become specialized during early childhood in ways that should have enhanced fitness in that environment (Del Giudice, Hinnant, Ellis, & El-Sheikh, 2012; Ellis et al., 2012; Nettle, 2010; Nettle, Frankenhuis, & Rickard, 2013).

The concept of specialization raises an important question: If early life adversity can enhance certain types of cognitive functioning, why have prior studies not found support for this idea? One reason is that very few prior studies have examined and differentiated the types of cognitive functions that should be enhanced by growing up in adverse environments. For example, there is little theoretical reason to believe that adverse childhood conditions should enhance performance on tests of general intelligence or college entrance exams. Instead, adverse environments should specialize the mind in ways that are useful specifically in the types of adverse environments in which a person grew up. If, for example, an individual grows up in a chaotic, unpredictable environment, this person's cognitive functioning should become specialized in ways that allow him or her to behave adaptively in environments that are chaotic and unpredictable.

When the cognitive function is directly aligned with the nature of early life environments, research with both animals and humans has found that adverse early life environments can indeed enhance specific cognitive functions (see Ellis et al., 2017). For example, birds raised in benign environments typically learn foraging strategies only from their parents. However, birds reared in unpredictable environments have an enhanced ability to learn foraging strategies from both biologically related as well as unrelated adults (Farine, Spencer, & Boogert, 2015). This learning flexibility enables birds raised in unpredictable environments to adapt to changing conditions, such as when parents are not available to teach their offspring important skills.

Similar types of specialization effects have been documented in rodents (Champagne et al., 2008; Oomen et al., 2010) and in humans (Frankenhuis & de Weerth, 2013). For example, although traumatized and maltreated children show cognitive deficits in a number of domains, they exhibit heightened attentional vigilance and memory for threatening information (e.g., Goodman, Quas, & Ogle, 2010). Physically maltreated children also recognize angry faces more quickly than children who were not maltreated (Pollak, 2008; Pollak, Messner, Kistler, & Cohn, 2009). These findings are consistent with the notion that it may be particularly useful for people who grow up in an environment of maltreatment to rapidly identify and remember individuals who might pose a threat. Viewed together, these findings in both human and nonhuman animals suggest that early life adversity does not invariably impair cognitive functioning; sometimes early life stress may hone the mind in particular ways so individuals can more successfully navigate the challenges associated with specific types of adverse environments.

The Sensitized-Specialization Hypothesis

Most past studies have not found that early life adversity is associated with enhanced cognitive functioning because they have not examined the types of cognitive abilities that should be enhanced by growing up in adverse environments. However, there is a second reason why earlier research has failed to find such effects: Some cognitive abilities specialized by early life may be witnessed only under particular conditions in adulthood (Ellis et al., 2017). This process is known as sensitization (Ellis et al., 2017) and is defined as a special case of specialization. Here, we refer to this as the *sensitized-specialization hypothesis*, which posits that the hypothesized advantages in cognitive functioning among people who grow up in particular conditions should be manifested primarily when they experience similar conditions later in life—that is, early life experiences adaptively sensitize later responses to similar conditions (Griskevicius et al., 2013; Griskevicius, Tybur, Delton, & Robertson, 2011; Mittal & Griskevicius, 2014).

Uncertainty is believed to serve as a cue to potential threats and challenges in the current environment, which then triggers psychological responses specialized by adverse childhood environments (Mittal & Griskevicius, 2016). The sensitized-specialization hypothesis predicts that specialized abilities shaped by adverse early life conditions may not be detectable in benign, nonthreatening circumstances. Instead, the specialized abilities shaped by adverse early life conditions may be activated when one encounters uncertain situations later in life.

The sensitized-specialization hypothesis has received support in work with rodents. When tested under benign laboratory conditions, rats reared in adverse environments tend to perform worse on learning and memory tasks than rats reared in nurturing environments. However, when tested in threatening conditions—such as when a threat is experimentally induced in the laboratory—rats reared in adverse environments show *improved* performance on learning and foraging tasks (Bagot et al., 2009; Chaby et al., 2015).

Recent experimental findings with humans are also consistent with the sensitized-specialization hypothesis. For instance, Mittal and colleagues (2015) investigated how growing up in an unpredictable versus predictable environment influences the executive function of shifting—efficiently switching between goals or tasks. Based on the logic of specialization, Mittal and colleagues predicted that growing up in an unpredictable environment should enhance shifting. Because opportunities are fleeting in unpredictable environments, being adept at shifting should be particularly useful, especially when rapidly shifting between tasks facilitates responding to constantly changing threats and opportunities (Nederhof & Schmidt, 2012). Importantly, Mittal and colleagues predicted that these effects should most clearly emerge when current conditions in adulthood are uncertain, consistent with the idea of sensitized-specialization. To test this possibility, they experimentally manipulated the current context by having participants view a news story about economic uncertainty or a control condition story. They found that people who experienced an unpredictable early life environment exhibited enhanced shifting, but *only* when they were exposed to the economic uncertainty condition.

Although these findings provide support for the sensitized-specialization hypothesis, they also raise important questions: Is there something unique about shifting? Might shifting be a "special case"? According to the sensitized-specialization hypothesis, adverse childhood environments ought to enhance a variety of ecologically relevant cognitive functions. The current research was designed to investigate this possibility by examining how growing up in unpredictable versus predictable environments impacts working memory.

Working Memory and Environmental Unpredictability

Working memory is a multifaceted cognitive system designed for interacting with information over relatively short time-periods (Baddeley, 1992, 2012). It is central to tracking, temporarily storing, manipulating, associating/binding, integrating, and retrieving information to complete a task (Baddeley, 2000, 2003; Unsworth & Engle, 2007a). Consider a server who takes orders at a restaurant without writing them down. The server must use working memory to take orders from multiple customers, associate those orders with the spatial location of individuals at different tables, track changes or specific requests to orders, and correctly convey the appropriate information to the kitchen. Working memory not only tracks and retains relevant information; it also protects information from interference, or distracting information. Moreover, even though it operates across relatively short time-periods, working memory encompasses more than what has historically been termed "short-term memory" because it includes a variety of different processes, such as manipulating or processing information (see Baddeley, 1992, 2000, 2003, 2012; Unsworth & Engle, 2007a).

In developing our hypotheses, we considered which aspects of working memory should be particularly useful in unpredictable environments. Unpredictability is one of the fundamental dimensions of environmental stress (Ellis et al., 2009). It is characterized by unforeseeable fluctuations of events across space and time. Living in such an edgy, inconsistent environment makes it difficult to predict what will happen on a daily basis. To assess the unpredictability of people's childhood environment, Mittal and colleagues (2015) asked people to think back to when they were younger than 10 years old and report the extent to which events in their home were chaotic, people moved in and out of their home on a fairly random basis, and they had difficulty knowing what their parent(s) or other people in the home were going to say or do from day-to-day. These retrospective measures of environmental unpredictability align closely with longitudinal measures of environmental unpredictability that assess similar events during childhood (e.g., Belsky, Schlomer, & Ellis, 2012; Simpson, Griskevicius, Kuo, Sung, & Collins, 2012).

One specific component of working memory that should be particularly adaptive for navigating unpredictable environments is *working memory updating*. Updating refers to tracking changing information and replacing older information that is no longer relevant with new, updated information (Ecker, Lewandowsky, & Oberauer, 2014; Ecker, Lewandowsky, Oberauer, & Chee, 2010; Ecker, Oberauer, & Lewandowsky, 2014; Friedman et al., 2008; Kessler & Meiran, 2008). Updating is the process by which individuals select and maintain information that is relevant to what is currently occurring in their environment. Working memory updating is akin to situational awareness because it involves focusing attention on changes while simultaneously forgetting past information that is no longer relevant (Ecker et al., 2010).

In unpredictable environments, information about potential threats and opportunities is subject to rapid fluctuations. In such environments, therefore, it should be advantageous to track and rapidly update information about the immediate environment. Such enhanced awareness and efficient updating should facilitate the detection of changing opportunities and threats, enabling individuals to adapt to rapidly changing circumstances more quickly by incorporating novel information into awareness. In unpredictable ancestral environments, effective updating typically should have enhanced fitness because novel information would have had more fitness consequences than old information, such as new information regarding the best food locations or which people are currently trustworthy or untrustworthy. Thus, the sensitized-specialization hypothesis predicts that growing up in an unpredictable environment should specialize the mind toward detecting and processing novel information and removing old, irrelevant information, as reflected in the updating component of working memory.

In contrast to working memory updating, unpredictable environments are unlikely to enhance other kinds of working memory abilities. This includes *working memory retrieval*—the ability to remember and retrieve information after a time delay, and *working memory capacity*—the ability to hold information in mind while concurrently performing secondary tasks (Unsworth & Spillers, 2010; Unsworth, Spillers, & Brewer, 2010; Unsworth, Fukuda, Awh, & Vogel, 2014; Wilhelm, Hildebrandt, & Oberauer, 2013). Both retrieval and capacity enable individuals to control their attention, suppress interference from distractions, and facilitate the storage of old information outside of conscious awareness (Unsworth & Engle, 2007a). Because relying too much on *old* information may have carried serious consequences in unpredictable environments (e.g., trusting someone who is no longer trustworthy), unpredictable environments are unlikely to hone working retrieval and capacity. Instead, retrieval and capacity are more likely to be adaptive in *predictable* environments, since it would be beneficial to maintain and recall older information in a consistent environment where the same information is likely to be valid and advantageous over longer periods of time.

Although working memory updating, retrieval, and capacity are all important components of working memory, they are distinct (Ecker et al., 2014; Unsworth et al., 2014; Wilhelm et al., 2013). Whereas updating involves focusing on novel information that replaces older memory representations, both retrieval and capacity involve maintaining older information and retrieving it for later use. Because unpredictable environments are characterized by constantly changing conditions, growing up in an unpredictable environment should specialize working memory by enhancing updating, but not necessarily enhancing retrieval and capacity. Importantly, we predicted that these effects should emerge only under conditions of current uncertainty, consistent with the sensitized-specialization hypothesis.

Experiment 1: Working Memory Updating

Experiment 1 was designed to test how experiencing an unpredictable childhood environment affects working memory updating under uncertainty. Working memory updating was assessed using two well-established tasks: the keep track task (Friedman et al., 2008; Yntema, 1963) and the continuous counters task (Unsworth & Engle, 2008; Unsworth et al., 2015). Both of these tasks measure working memory updating (Friedman et al., 2008; Unsworth et al., 2015; Wilhelm et al., 2013). We also measured childhood unpredictability and childhood socioeconomic status.

Consistent with past research, we expected that people who grew up in unpredictable environments would generally perform worse than those who grew up in predictable environments. However, based on the sensitized-specialization hypothesis, we predicted that early exposure to an unpredictable environment would be associated with working memory updating in a positive way when people were tested in an uncertain versus control context.

To increase confidence in the results, participants ($N = 372$) for Experiment 1 were drawn from two populations. About half of the participants were drawn from Amazon's Mechanical Turk (MTurk) online subject pool ($N = 176$), and the other half were drawn from a university sample of students and staff ($N = 196$). The experimental procedures were identical for both samples. Although we tested for differences between the two samples, we had no reason to expect that our results would differ between them. Because of the novelty of the prediction in Experiment 1, we combined the two samples to achieve adequate power (0.87) to detect our hypothesized effect.[1]

Method

Participants. Three-hundred seventy-two people participated in the study. This included 154 males, 217 females, and 1 participant who did not provide gender information. The mean age was 33.41 ($SD = 13.5$).

The online sample consisted of an initial sample of 204 participants recruited via MTurk. Participants completed the study in exchange for a small monetary reward. We applied a set of predetermined exclusion criteria that had to be met in order for participants to be included in the final analysis sample. These criteria included passing an attention check and reporting being fluent in English. These exclusion criteria resulted in an analysis sample of $N = 176$. These participants included 62 males, 113 females, and 1 individual who did not identify his or her gender. The mean age for this sample was 41.2, ($SD = 12.72$).

Regarding education, sample participants reported 1% completed some high school or less, 10% obtained a high school diploma or equivalent, 35% completed some college/university, 33% obtained a college/university diploma, 5% completed some graduate school, and 18% obtained a graduate degree. Regarding ethnicity, participants reported 3% were Asian/Asian American, 7% were Black/African American, 9% were Hispanic/Latino, 77% were White, 2% were of mixed descent, and 2% indicated Other. We also collected information on each participant's current annual household income: 14% made $15,000 or less, 13% made $15,001-$25,000, 10% made $25,001– $35,000, 21% made $35,001–$50,000, 22% made $50,001–$75,000, 12% made $75,001–$100,000, 6% made $100,001–$150,000, and 2% made $150,000 or more.

The other half of the participants were university undergraduate and graduate students, as well as staff, who completed the study in the lab in exchange for $8. We sought to recruit 200 participants for this sample and obtained 201. The same exclusion criteria were applied to this sample as the online sample; we dropped participants who did not pass an attention check and reported low fluency in English. This resulted in a final analysis sample of $N = 196$. This sample included 92 males and 104 females (mean age 26.42, $SD = 9.88$).

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[1] To determine the sample size, we conducted a power analysis based on previous work in this area. Specifically, we drew from a study that examined the interaction between early life unpredictability and an uncertainty manipulation predicting performance on an executive function task (Mittal et al., 2015). Mittal et al. (2015) reported an interaction effect size of $r = .16$ for the executive function of shifting (the cognitive ability hypothesized to be enhanced by early life unpredictability and current uncertainty). With an effect size of $r = .16$, an alpha level of 0.05, and a sample size of 372, we had 0.87 power to detect our hypothesized effect.

Regarding education, participants in this sample reported 6% obtained a high school diploma or equivalent, 40% completed some college/university, 22% obtained a college/university diploma, 15% completed some graduate school, and 17% obtained a graduate degree. Regarding ethnicity: 34% were Asian/Asian American, 5% were Black/African American, 3% were Hispanic/Latino, 53% were White, 1% were Native American, 3% were of mixed descent, and 2% indicated Other. Regarding annual income, participants reported 40% made $15,000 or less, 8% made $15,001-$25,000, 7% made $25,001– $35,000, 13% made $35,001–$50,000, 8% made $50,001–$75,000, 11% made $75,001–$100,000, 9% made $100,001–$150,000, and 4% made $150,000 or more. A majority of the university sample completed some college/university, so the large portion of the sample making $15,000 or less was because many participants were students (38 of 79 of participants who made $15,000 or less also indicated they had completed some college/university).

Procedure. Consistent with previous research using similar experimental manipulations (Griskevicius et al., 2013, e.g., 2011; Hill, Rodeheffer, Griskevicius, Durante, & White, 2012; Mittal & Griskevicius, 2014; Mittal et al., 2015; White, Li, Griskevicius, Neuberg, & Kenrick, 2013), a cover story was used to minimize suspicion. Participants were told we were interested in studying two different phenomena in the session: cognitive abilities and how people process information. To give participants a sense of the cognitive tasks they would be working on later in the session, participants first practiced and familiarized themselves with the two working memory updating tasks. Following this, they were told that we were ready to start the information processing part of the study, which would assess how different people process information from the news. Everyone would first watch a news slideshow, which served as the experimental manipulation. Then, later in the session after allowing some time to elapse, participants would be asked to complete a writing task regarding the news slideshow. Directly following the news slideshow, participants were told they would work on the first cognitive task to allow some time to elapse for memory decay of the news slideshow. After finishing the first updating task, participants were asked to recall the news slideshow they viewed earlier and describe in writing its most important and vivid aspects. This served as the manipulation "booster shot" to ensure that participants were still experiencing an uncertain context (e.g., Mittal et al., 2015). Participants then completed the remaining updating tasks and provided information about their childhood background and demographics. The results for all tasks and all measures assessed in the study are reported below.

Uncertain context manipulation. Participants were randomly assigned to either a control or an economic uncertainty condition. Both conditions involved viewing a news article slideshow ostensibly from the *New York Times*. The article was formatted to appear like a web-article featuring the newspaper's logo, font, and style. The slideshows were based on previous research that used these manipulations to induce a sense of economic uncertainty experimentally (Griskevicius et al., 2013; Hill et al., 2012; Mittal & Griskevicius, 2014; Mittal et al., 2015, Study 4). Both the control and uncertainty slideshows contained five images accompanied by a one-sentence caption with each image. Each slide was displayed one at a time for 10 seconds. The content of the economic uncertainty slideshow featured a worsening and unpredictable economic climate. The control slideshow contained images and text describing issues of modern computer technology. Although the slideshows in both conditions were negative in their content, the economic uncertainty manipulation was intended to elicit a higher degree of uncertainty, especially pertaining to resources (see the Supplement for slideshow stimuli).

Pretest. To test whether the two slideshows elicited different levels of uncertainty, the manipulations were pretested on a separate sample drawn from MTurk ($N = 253$). One participant was excluded because s/he reported being 13 years of age. A final sample size of 252 participants was used in the following analyses (141 females; 111 males). The mean age for this sample was 35.94 ($SD = 11.38$; range = 19–69). Participants were randomly assigned to view either the control or the uncertainty slideshow. After viewing the slideshow, all participants responded to the following four items: (a) How uncertain is the world?; (b) How uncertain is the economy?; (c) How unpredictable is the world?; and (d) How unpredictable is the economy? Responses to each item were provided on a 7-point scale anchored at 1 = *not at all* and 7 = *extremely*. The four items were averaged to create an uncertainty index ($M = 4.89$, $SD = 1.61$, $\alpha = .91$).

After completing the uncertainty items, respondents also indicated the extent to which the manipulation made them feel 20 different emotions on the Positive and Negative Affect Scale (PANAS; Watson, Clark, & Tellegen, 1988), for which all items are anchored on a 5-point scale from 1 (*not at all*) to 5 (*very much*). Participants rated 10 positive emotions ($M = 2.31$, $SD = 0.89$, $\alpha = .91$; enthusiastic, interested, determined, excited, inspired, alert, active, strong, proud, attentive), and 10 negative emotions ($M = 1.96$, $SD = 0.86$, $\alpha = .93$; scared, afraid, upset, distressed, jittery, nervous, ashamed, guilty, irritable, hostile). This enabled us to measure how the manipulation influenced a variety of positive and negative emotions.

The results confirmed that the uncertainty slideshow elicited significantly more feelings of uncertainty than the control slideshow ($M_{control} = 4.07$, $SD = 1.63$; $M_{uncertainty} = 5.72$, $SD = 1.09$; $t(250) = -9.40$, $p < .001$, Cohen's $d = -1.18$). Findings also revealed a main effect of participants' childhood unpredictability [$B = 0.15$, $t(246) = 2.75$, $p = .006$], which indicates that, on average, more childhood unpredictability was associated with more perceived uncertainty. There was no main effect of participants' childhood SES [$B = -0.06$, $t(246) = -1.19$, $p = .24$], and there was no interaction between SES and condition [$B = -0.01$, $t(246) = -0.10$, $p = .92$]. However, there was an interaction between unpredictability and condition [$B = -0.12$, $t(246) = -2.21$, $p = .028$].

To probe this interaction, we performed a simple slopes analysis at high (+1 SD) and low (−1 SD) levels of unpredictability. This analysis indicated that individuals exposed to higher levels of childhood unpredictability felt significantly more uncertain in the uncertain condition than in the control condition [$b = 0.60$, $t(246) = 4.93$, $p < .001$]. Similarly, individuals exposed to lower levels of unpredictability felt significantly more uncertain when viewing the uncertainty slideshow than the control slideshow [$b = 0.99$, $t(246) = 8.09$, $p < .001$]. Viewed another way, in the control condition, individuals exposed to an unpredictable childhood felt significantly more uncertain than people from predictable backgrounds [$b = 0.43$, $t(246) = 3.43$, $p < .001$]. However, in the uncertain condition, there were no differences in feelings of uncertainty between individuals exposed to different levels of unpredictability [$b = 0.05$, $t(246) = 0.38$, $p = .70$].

The pretest also revealed that the uncertainty slideshow generated slightly higher positive emotions ($M_{control} = 2.19$, $SD = 0.85$; $M_{uncertainty} = 2.43$, $SD = 0.91$; $t(250) = -2.13$, $p = .034$, $d = -0.27$) and higher negative emotions ($M_{control} = 1.76$, $SD = 0.81$; $M_{uncertainty} = 2.16$, $SD = 0.87$; $t(250) = -3.82$, $p < .001$, $d = -0.48$). As shown in the Supplement, the specific positive emotions driving the main effect of condition on the positive emotion composite were determined, strong, and proud. For the negative emotions, the uncertainty manipulation made participants feel significantly more afraid, distressed, hostile, nervous, scared, and upset. However, the manipulation did not significantly influence feeling ashamed, guilty, irritable, or jittery (see the Supplement).

In sum, the pretest indicates that the experimental manipulation significantly increases the sense of uncertainty for people from both unpredictable and predictable backgrounds. In addition, the uncertainty manipulation significantly increases feelings of being distressed and scared for people from both unpredictable and predictable backgrounds.

Manipulation booster shot. After completing the first half of the updating tasks, participants completed a manipulation "booster shot" to ensure they remained in an uncertain or a control state of mind (Mittal et al., 2015). Consistent with the cover story, participants were asked to: "Please think back to the slideshow you viewed earlier and write about the most important and vivid aspects of the slideshow in detail." Participants were given up to two minutes to recall and describe in writing the news story presented in the slideshow.

Working memory updating. All participants completed two working memory updating tasks: the keep track task (Friedman et al., 2008; Yntema, 1963) and the continuous counters task (Unsworth & Engle, 2008). In both tasks, participants had to track information that changed over the course of each round and update their memory as these changes occurred. Both tasks are depicted in Figure 1.

In the first updating task (keep track), participants tracked a sequence of words that belong to different categories. The categories included relatives, countries, colors, animals, and tools. Each category contained a pool of eight words that were randomly selected from each round. The goal of the task was to remember the last word that was displayed from each target category.

At the beginning of each round, three to five categories (randomly determined in each round) were displayed on the screen. For example, if a participant saw the categories "animals, relatives, and tools," this indicated that s/he would be tracking animals, relatives, and tools for that round (see Figure 1). When the participant was ready, s/he clicked the mouse button to begin the round. Once the round began, 15 words belonging to the target categories were displayed in a sequence one word at a time for 1.5 seconds. The target category names remained on the bottom of the screen for the entire sequence (see Figure 1).

At the end of the sequence, participants were asked to select the last word they saw from each category from a list of all possible exemplars. For example, if the categories in the last round were animals, relatives, and tools, participants were asked to select the last animal, the last relative, and the last tool they saw in the sequence of 15 words presented to them (see Figure 1). There were 6 rounds total: 2 rounds with 3 categories, 2 rounds with 4 categories, and 2 rounds with 5 categories. Thus, participants received scores based on a maximum of 24 possible correct answers ($M = 19.34$, $SD = 2.98$). Participants completed the first half of the task after

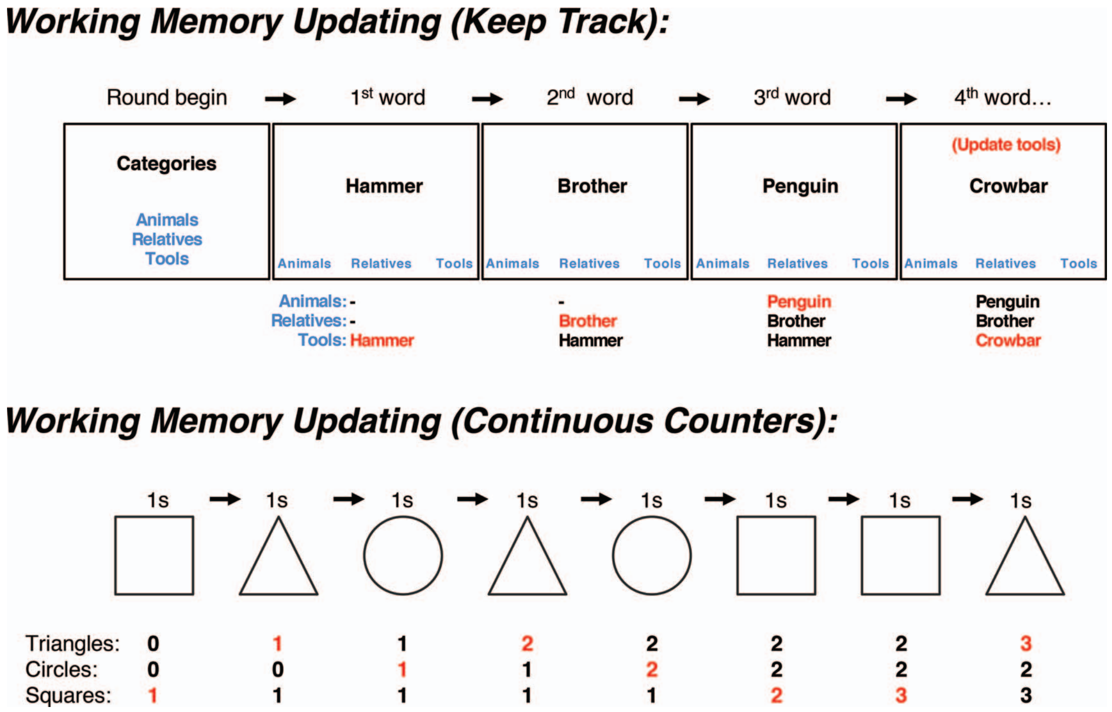

Figure 1. Working memory updating tasks. See the online article for the color version of this figure.

the initial experimental manipulation, and the second half following the manipulation booster shot.

In the second working memory updating task (continuous counters; Unsworth & Engle, 2008; Unsworth et al., 2015), participants were assessed on how well they kept a mental count of the number of shapes they saw in a sequence. Participants were presented with a sequence of squares, circles, and triangles that were displayed for one second, one at a time (see Figure 1). Participants were told to keep a mental running count of each shape they saw in the sequence. For example, consider the following sequence: square, triangle, circle, triangle, circle, square, square, triangle. In this sequence, a participant must keep track of how many squares, triangles, and circles s/he saw. Each time a new shape appeared, the mental count for that shape had to be updated. At the end of each sequence, participants were asked to report the number of squares, circles, and triangles that appeared in that round. The number of shapes displayed in each sequence varied from 12 to 14. For each round, there were 3 possible correct answers. In total, there were 6 rounds: 2 rounds with 12 shapes, 2 rounds with 13 shapes, and 2 rounds with 14 shapes. Thus, participants received scores based on a maximum of 18 possible correct answers (M = 14.10, M = 3.75). They completed first half of the task after the experimental manipulation, and the second half following the experimental manipulation booster shot.

Both of these tasks underpin a latent working memory updating variable (Friedman et al., 2008; Unsworth et al., 2015; Wilhelm et al., 2013). They both reflect the updating aspect of working memory because they require immediate attentional focus along with the ability to update memory with new information. In the keep track task, for instance, the last word from each category must be maintained in the focus of attention; it is disadvantageous to remember all of the words from the sequence because only the last word from each category is relevant. When new words from a particular category are presented, one must quickly dispose the old word from that category and update it with the new word. Similarly, in the continuous counters task, one must actively maintain running counts of each shape and update them with new information as quickly as possible.

Because both tasks measure the same underlying construct (Friedman et al., 2008; Unsworth et al., 2015; Wilhelm et al., 2013) and were moderately correlated (r = .39) in Experiment 1, we combined the scores of both tasks to create a global measure of working memory updating. To do so, we first computed the proportion of correct responses in the keep track task (M = 0.81, SD = 0.12) and the continuous counters task (M = 0.78, M = 0.21). We then averaged the two proportion scores, giving each task equal weight in the total updating score (M = 0.79, M = 0.14). (See the Supplement for the findings for each task separately by each subsample in Experiment 1).

Childhood unpredictability. After completing the updating tasks, participants reported the level of exposure to unpredictability in their childhood environments. Participants were instructed to: "Think back to your life when you were younger than 10. This time includes preschool, kindergarten, and the first few years of elementary school." Participants then answered 8 items that assessed their level of exposure to unpredictability in childhood (M = 1.96, SD = 1.23, α = 0.92). These items were: (a) "My family life was generally inconsistent and unpredictable from day-to-day"; (b) "My parent(s) frequently had arguments or fights with each other or other people in my childhood"; (c) "My parents had a difficult divorce or separation during this time"; (d) "People often moved in and out of my house on a pretty random basis"; (e) "When I woke up, I often didn't know what could happen in my house that day"; (f) "My family environment was often tense and on edge"; (g) "Things were often chaotic in my house"; and (h) "I had a hard time knowing what my parent(s) or other people in my house were going to say." The 8 items included the original 3 items developed for previous research (Mittal et al., 2015) plus five additional items, which were included to better and more reliably measure the underlying construct on an unpredictable childhood environment. Each item was scored on a scale anchored at 1 = *not at all* to 7 = *extremely*. Principal axis factor analysis (using an oblimin rotation) indicated that all 8 items loaded on a single factor (only one of the factors had an eigenvalue above one; factor loadings for the first factor ranged from 0.48 to 0.89; see the Supplement for scree plots).

Childhood socioeconomic status. Participants were also asked to provide information on their socioeconomic status (SES) during childhood. We used previously established items to measure childhood SES (Griskevicius et al., 2013, e.g., 2011; Mittal & Griskevicius, 2014; Mittal et al., 2015; White et al., 2013). The four items were: (a) "My family usually had enough money for things when I was growing up," (b) "I grew up in a relatively wealthy neighborhood," (c) "I felt relatively wealthy compared with the other kids in my school," and (d) "What was your yearly household income when you were growing up?" (with eight response options: $15,000 or less; $15,001–$25,000; $25,001–$35,000; $35,001–$50,000; $50,001–$75,000; $75,001–$100,000; $100,001–$150,000; $150,000 or more). These items were averaged to construct a childhood SES composite (M = 3.80, SD = 1.46, α = 0.85).

Results

Based on past findings, we expected that exposure to more unpredictability early in life would generally have a negative association with working memory in the control condition. However, our central and novel prediction based on the sensitized-specialization hypothesis was that exposure to more unpredictability early in life would have a positive association with updating under conditions of current uncertainty. That is, people who grew up in an unpredictable environment would exhibit significantly *better* working memory updating performance when tested in the uncertainty experimental condition versus the control condition. We also expected that this effect would be specific to childhood unpredictability and not to general childhood socioeconomic standing.

To test this hypothesis, we performed a regression analysis with the experimental conditions as an effects-coded categorical variable (control = −1, economic uncertainty = 1), childhood unpredictability as a continuous grand-mean centered variable, and the interaction of the two variables. We also entered childhood SES as a grand-mean centered variable and the interaction between childhood SES and experimental condition into this analysis to compare the effect of childhood SES and childhood unpredictability directly. This analysis did not reveal a main effect of experimental condition [B = −0.01, $t(366)$ = −0.18, p = .86] as well as no main effect of childhood SES [B = 0.03, $t(366)$ = 0.61, p = .54], no main effect of childhood unpredictability [$B = -0.05$, $t(366) = -0.90$, $p = .37$], and no interaction between childhood SES and experimental condition [$B = 0.06$, $t(366) = 1.04$, $p = .30$]. However, there was a significant interaction between childhood unpredictability and the uncertainty manipulation [$B = 0.17$, $t(366) = 3.18$, $p = .002$], which is shown in Figure 2.

To probe this interaction, we performed simple slopes analyses for individuals at high (+1 *SD*) and low (−1 *SD*) levels of childhood unpredictability. People who experienced a highly unpredictable childhood environment displayed significantly better working memory updating in the uncertainty condition compared with those who experienced high childhood unpredictability in the control condition [$b = 0.02$, $t(366) = 2.16$, $p = .031$]. In other words, experiencing an unpredictable childhood environment was associated with improved working memory updating when people were tested under conditions of uncertainty. In contrast, working memory updating for people who experienced a predictable childhood environment was diminished in the uncertainty condition compared with the control condition [$b = -0.03$, $t(366) = -2.41$, $p = .017$].

To examine the findings a different way, the association of childhood unpredictability with updating was significantly negative in the control condition [$b = -0.02$, $t(366) = -2.83$, $p = .005$], such that people who had predictable early life environments performed considerably better than those who had unpredictable early environments in the control condition. However, this negative effect was erased in the uncertainty condition. In fact, people who experienced unpredictable environments performed slightly better on updating in the uncertainty condition than did those who experienced predictable environments, although this effect did not reach conventional levels of significance [$b = 0.01$, $t(366) = 1.64$, $p = .10$].

To ensure these results were both sample and task-type independent, we also tested for two specific three-way interactions between the experimental condition, childhood unpredictability, and type of task (continuous counters vs. keep track, within-subjects) or sample type (MTurk vs. lab). To account for nonindependence between performance on the two updating tasks for a given person, we used a mixed modeling approach. To do so, we tested these two three-way interactions simultaneously in the same model by running a four-way interaction between experimental condition, childhood unpredictability, type of task, and sample type. We found a nonsignificant three-way interaction involving task-type [$b = -0.01$, $t(364) = -1.74$, $p = .08$]. For the three-way interaction involving study-type, we also found a nonsignificant interaction [$b = 0.00$, $t(364) = -0.33$, $p = .74$]. Thus, our results did not depend on either the type of task or the sample type. (See the Supplement for the findings for each task by each subsample.)

Discussion

Experiment 1 revealed that growing up in an unpredictable environment is negatively associated with working memory updating performance in the control condition. This finding is consistent with previous research demonstrating the negative effects of highly stressful childhood environments on working memory (e.g., Bos et al., 2009; Farah et al., 2006; Hackman et al., 2014; Noble et al., 2007). Importantly, Experiment 1 also confirmed that exposure to more unpredictability early in life is not always negatively associated with working memory performance. The results revealed that the negative effect of an unpredictable childhood environment was virtually erased when people were tested under conditions of uncertainty. In fact, people who grew up in unpredictable environments showed significantly *better* working

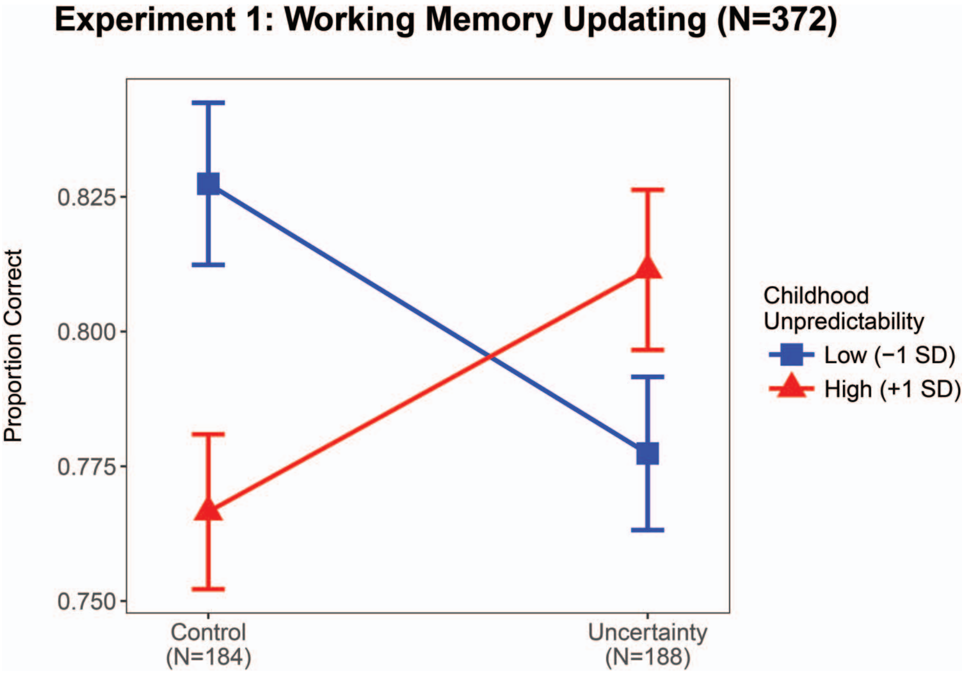

Figure 2. Working memory updating ($N = 372$). See the online article for the color version of this figure.

memory updating when they were tested under conditions of uncertainty compared with a control condition. Importantly, although we found that growing up in an unpredictable environment was associated with enhanced working memory, whether people from unpredictable backgrounds might actually perform better than those from predictable backgrounds under some conditions should be replicated and examined more closely in future research. These novel effects were obtained in a relatively large sample (*N* = 372), with the same pattern of findings emerging in both the subsample of laboratory participants (students and staff at a large North American university) and the subsample of MTurk online participants. The same pattern emerged for both working memory updating tasks that were used (see the Supplement).

These findings provide support for the sensitized-specialized hypothesis. We hypothesized that growing up in an unpredictable environment ought to be associated with enhanced performance on the updating component of working memory because this component allows one to detect and rapidly process information in an environment characterized by constant change. This enhanced ability should facilitate the detection of changing opportunities and threats in the immediate environment, enabling the mind to quickly update working memory with novel information and adapt to changing circumstances. As anticipated by the sensitized-specialization hypothesis, this enhanced updating effect was specific to growing up in an unpredictable environment, but not one characterized merely by low socioeconomic status. Furthermore, the effect of unpredictable environment on enhanced memory updating emerged only under current uncertainty. This means that people who grew up in unpredictable environments displayed improved working memory updating, but only when tested in a condition of uncertainty.

Experiment 2: Working Memory Retrieval

Experiment 2 was designed to test how growing up in an unpredictable versus predictable environment influences working memory retrieval. Whereas Experiment 1 revealed that an unpredictable childhood environment is linked with enhanced performance on the updating component of working memory under uncertainty, we hypothesized in Experiment 2 that an unpredictable environment should have a very different effect on working memory retrieval, which is believed to be more adaptive in predictable rather than unpredictable environments.

Experiment 2 used the same experimental paradigm as Experiment 1, except that Experiment 2 assessed the retrieval component, rather than the updating component, of working memory. Because Experiment 2 was a variant on the well-established theme that bad childhoods lead to worse adult outcomes, we did not attempt to overpower the study. Instead, we relied on the same level of power used in a similar type of study conducted by Mittal et al. (2015; Study 3). Following this approach, Experiment 2 had 0.68 power to detect our hypothesized effect.[2]

Method

Participants. Two-hundred one people were recruited from MTurk to participate in an online study in exchange for a small monetary payment. We used the same exclusion criteria as in Experiment 1 in that participants were dropped if they did not pass the attention check or were not fluent in English. In addition, we used a task-specific exclusion criterion for the working memory task used in Experiment 2. Namely, participants were excluded if they left all recall items blank. This resulted in a final analysis sample of 160 (52 males and 108 females). The mean age of participants was 38.64 (*SD* = 13.53).

Regarding level of education, 8% had a high school diploma or equivalent, 30% completed some college/university, 42% had a college/university diploma, 7% completed some graduate school, and 13% had a graduate degree. The ethnic background of the sample was 2% Asian/Asian American, 9% Black/African American, 4% Hispanic/Latino, 81% White, 2% mixed descent, and 1% indicated other. The current household income was: 16% made $15,000 or less, 9% made $15,001–$25,000 16% made $25,001–$35,000, 21% made $35,001–$50,000, 14% made $50,001–$75,000, 11% made $75,001–$100,000, 9% made $100,001–$150,000, and 4% made $150,000 or more.

Procedure. The procedure of Experiment 2 was highly similar to Experiment 1. We used the same experimental manipulations in the control and the uncertainty conditions, the same cover story, and the same measures of childhood unpredictability (*M* = 2.44, *SD* = 1.59, α = 0.93) and childhood SES (*M* = 1.56, *SD* = 1.56, α = 0.87). The only two differences in Experiment 2 were a different working memory task (to assess retrieval rather than updating) and the lack of a manipulation booster shot. All of the tasks and measures assessed in Experiment 2 are reported below.

Working memory retrieval task. To assess working memory retrieval, we used the delayed free-recall task, which is a common and well-validated measure of working memory retrieval (Unsworth, 2007; Unsworth & Spillers, 2010; Unsworth et al., 2014). Figure 3 shows the task. In the task, participants were shown a sequence of 10 common nouns, which were displayed one at a time for 1 second each. After all of the words had been presented, participants completed a 30-s distractor task, which entailed sorting lists of three-digit numbers in ascending order. After the distractor task, participants were asked to recall the 10 words from the sequence they saw before the distractor task. Participants were given 45 seconds to recall as many words as possible in any order. There were 4 rounds for a total of 40 possible correct answers (*M* = 18.23, *SD* = 6.86). We counted the total number of correctly recalled words from all rounds and computed a proportion correct score as the outcome variable (*M* = 0.46, *SD* = 0.17).

Results

We used the same data analysis approach as in Experiment 1. Specifically, we conducted a regression analysis with working memory retrieval as the dependent measure. The predictor variables were experimental condition as an effects-coded categorical variable (control = −1, economic uncertainty = 1), childhood unpredictability as a continuous grand-mean centered variable, childhood SES as a continuous grand-mean centered variable, the interaction between childhood SES and experimental condition,

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[2] We used the interaction effect size reported in Mittal et al.'s (2015) Study 3 (*N* = 181), which focused on the interaction of early childhood unpredictability and experimental condition on the executive function of inhibition (*r* = .19). Using this effect size as a benchmark, Experiment 2 had a power of 0.68.

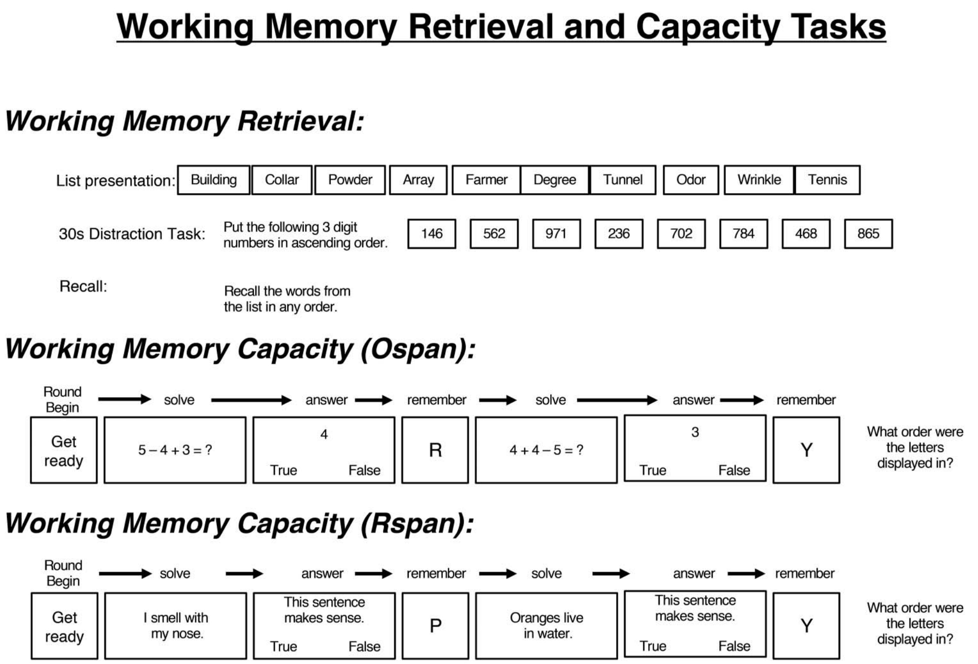

Figure 3. Other working memory tasks.

and the interaction between childhood unpredictability and experimental condition.

The findings are displayed in Figure 4. The analyses indicated no main effect of experimental condition [$B = 0.06$, $t(154) = 0.75$, $p = .45$], childhood SES [$B = -0.02$, $t(154) = -0.30$, $p = .76$], or childhood unpredictability [$B = -0.13$, $t(154) = -1.52$, $p = .13$], and no interaction between childhood SES and experimental condition [$B = -0.07$, $t(154) = -0.85$, $p = .40$]. However, we found a significant interaction between economic uncertainty and childhood unpredictability [$B = -0.20$, $t(154) = -2.46$, $p = .015$].

As shown in Figure 4, the pattern of effects for working memory retrieval was very different than the pattern for working memory updating found in Experiment 1. To probe this interaction, we performed simple slopes analyses for individuals at high (+1 *SD*) and low (−1 *SD*) levels of childhood unpredictability. As indicated in Figure 4, people who grew up in a predictable environment (with low levels of unpredictability) exhibited a significant increase in working memory retrieval in the uncertainty condition compared with the control condition [$b = 0.05$, $t(154) = 2.33$, $p = .021$]. In other words, they showed *better* working memory retrieval when tested under conditions of uncertainty. In contrast, people exposed to high levels of childhood unpredictability showed a slight decrease in working memory retrieval in the uncertainty condition compared with the control condition, although this effect did not reach conventional levels of significance [$b = -0.03$, $t(154) = -1.26$, $p = .21$].

Viewed another way, in the control condition, there was little difference in working memory retrieval between people who grew up in unpredictable versus predictable environments [$b = 0.01$, $t(154) = 0.67$, $p = .51$]. In the uncertainty condition, however, people from predictable childhood environments were considerably better at working memory retrieval than those from unpredictable childhood environments [$b = -0.04$, $t(154) = -3.02$, $p = .003$].

Discussion

Experiment 2 examined how growing up in an unpredictable versus predictable environment influenced working memory retrieval under conditions of uncertainty. Findings revealed that people who grew up in an unpredictable environment had diminished working memory retrieval when facing uncertainty. This is consistent with the notion that working memory retrieval is less useful in unstable and unpredictable environments, so unpredictable early environments should not shape the mind to better remember and retrieve old information. Interestingly, people from predictable environments displayed *enhanced* working memory under uncertainty. This pattern was not expected. Experiment 3 tested whether this pattern would replicate with a different aspect of working memory

Experiment 3: Working Memory Capacity

Experiment 3 examined how growing up in an unpredictable versus predictable environment influences working memory capacity. Working memory capacity, which closely resembles working memory retrieval, is the ability to hold information in mind while performing secondary tasks. Working memory capacity, therefore, reflects the ability to retain information and control attention while suppressing memory interference from distractions. Accordingly, we expected that working memory capacity, like working memory retrieval, should be less useful in unpredictable environments, but perhaps more useful in predictable ones. Thus, we expected that Experiment 3 would show a similar pattern of findings as Experiment 2.

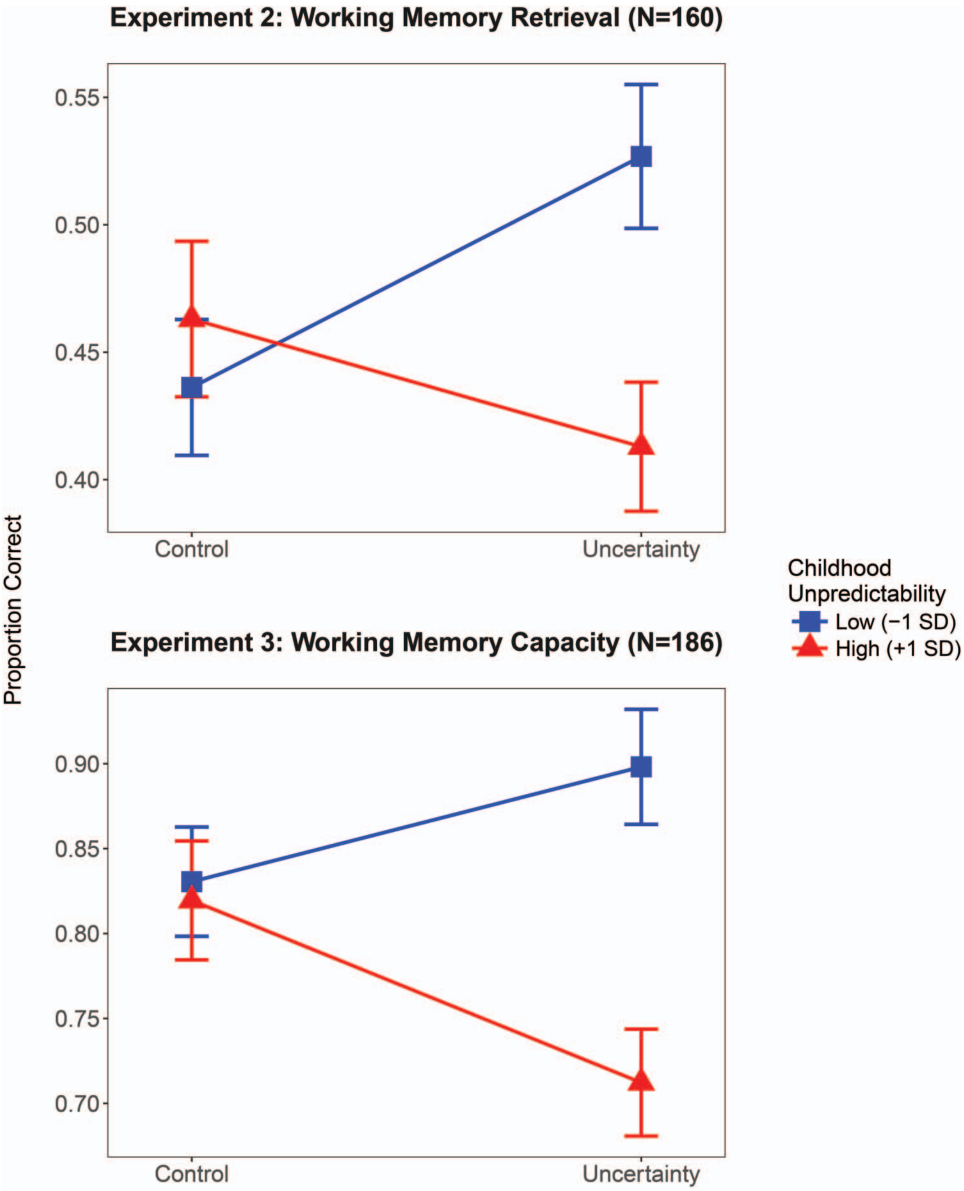

Figure 4. Working memory retrieval and capacity. See the online article for the color version of this figure.

To test working memory capacity, we used two popular working memory capacity tasks: the Operation Span (Ospan) task and the Reading Span (Rspan) task (Redick et al., 2012; adapted from Unsworth, Heitz, Schrock, & Engle, 2005). These tasks require individuals to memorize a sequence of letters while performing a distraction processing task, such as doing simple math problems or reading sentences (see Figure 3). These tasks are good measures of working memory capacity because they involve the simultaneous use of several cognitive processes, such as attention control, memory storage, and mental arithmetic or reading.

Experiment 3 employed the same experimental paradigm as Experiments 1 and 2, except it focused on working memory capacity. Similar to Experiment 2, Experiment 3 was a variant on the well-established theme that bad childhoods are linked to worse adult outcomes, so we did not overpower the study. Instead, we relied on the same level of power used in a similar type of study conducted by Mittal et al. (2015; Study 3). Following this approach, Experiment 3 had 0.74 power to detect our hypothesized effect.[3]

Method

Participants. We recruited 204 participants via MTurk for a small monetary reward. We applied the same exclusion criteria

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[3] We adopted the same approach used in Experiment 2 to calculate power for Experiment 3. Using the same interaction effect size obtained in Mittal et al.'s (2015) Study 3 (*N* = 181) for inhibition (r = .19), Experiment 3 had 0.74 power.

used in Experiments 1 and 2, which resulted in a final analysis sample of 186 participants (81 males and 105 females).

The mean age of the sample was 39.37 (*SD* = 12.67). Regarding education, 12% had a high school diploma or equivalent, 33% completed some college/university, 36% had a college/university diploma, 6% completed some graduate school, and 13% had a graduate degree. Regarding ethnicity, 5% were Asian/Asian American, 10% were Black/African American, 4% were Hispanic/Latino, 79% were White, 1% were Native American, 1% were Native Hawaiian/Pacific Islander, and 1% were of mixed descent. The sample's household income distribution was: 13% made $15,000 or less, 15% made $15,001–$25,000 16% made $25,001–$35,000, 15% made $35,001–$50,000, 17% made $50,001–$75,000, 13% made $75,001–$100,000, 8% made $100,001–$150,000, and 3% made $150,000 or more.

Procedure. The procedure was exactly the same as Experiments 1 and 2. First, participants were introduced to the working memory capacity tasks. They were then randomly assigned to either the control or the economic uncertainty slideshow used in the previous experiments. After this, all participants completed 3 rounds of the Operation Span task and 3 rounds of the Reading Span task. Immediately following this, they completed the experimental manipulation booster, similar to Experiment 1. Directly after the booster, participants then completed 3 more rounds of the Operation Span task and another 3 rounds of the Reading Span task. All participants then completed the childhood unpredictability questionnaire ($M = 2.20$, $SD = 1.47$, $\alpha = 0.93$) and childhood SES questionnaire ($M = 3.55$, $SD = 1.45$, $\alpha = 0.81$) used in the previous experiments. All of the tasks and measures assessed in Experiment 3 are reported below.

Working memory capacity: Ospan and Rspan. The Ospan and Rspan tasks are identical except for one difference: The Ospan task requires participants to solve math problems, whereas the Rspan task requires reading sentences. In the Ospan task, participants were asked to memorize a sequence of letters drawn from a fixed pool of letters (F, H, J, K, L, N, P, Q, R, S, T, Y). On each round, a letter was displayed on the screen for 1 second. Between each letter presentation, participants were given a simple math problem (e.g., $7 + 5 – 1 = ?$). They were instructed to solve each problem as quickly as possible, and were given a 7-s time limit to solve each problem. If they solved the problem before the 7 seconds were up, participants clicked to proceed to the next screen; if they took longer than 7 seconds, they were automatically advanced to the next screen.

On the next screen, a number appeared (e.g., 10). Participants were asked to determine whether this number was the correct or incorrect solution to the math problem they just viewed by clicking "True" or "False" on the screen. They were given 5 seconds to submit each answer. After each math problem, the next letter in the list was presented for 1 second, followed by a new math problem (see Figure 3). All trials began and ended with a math problem. The length of each letter sequence ranged from 4 to 6 letters. After all letters and math problems were presented in a round, a 4 × 3 grid of letters was displayed and participants were asked to recall all of the letters from the sequence in the order they were presented. Participants completed 3 rounds of the task after the experimental manipulation (one round of 4, 5, and 6 letters) and 3 rounds after the manipulation booster (one round of 4, 5 and 6 letters) for a total of 6 rounds (30 possible correct answers for the letter recall task; $M = 23.81$, $SD = 7.69$) and 36 math problems. All letter sequences were randomly presented.

In the Rspan task, participants also had to remember sequences of letters from the same pool of letters (similar to the Ospan task), but they read sentences instead of solving math problems. The task structure was the same as the Ospan task. Participants were presented with a letter for 1 second, then they were given a sentence that either made sense (e.g., "Shoes are worn on feet") or did not make sense (e.g., "The rocket went up into outer farms"). Participants had 7 seconds to read the sentence and determine whether it made sense. Then, on the following screen, they indicated whether or not the sentence made sense by clicking "True" or "False" on the screen. They were given 5 seconds to submit each answer (see Figure 3).

Similar to the Ospan task, all rounds began with a sentence and ended with a sentence and letter sequence lengths ranged from 4 to 6 letters. After all the letters and sentences in each round were presented, participants were asked to recall the letters from the sequence in the order they saw them. Participants completed 3 rounds of the task after the experimental manipulation (one round of 4, 5, and 6 letters) and 3 rounds after the manipulation booster (one round of 4, 5 and 6 letters) for a total of 6 rounds (30 possible correct answers for the letter recall task; $M = 24.92$, $SD = 6.65$) and 36 sentences. The Ospan and Rspan tasks measure working memory capacity because they both involve remembering the proper sequence of letters while concurrently performing a secondary processing task. Thus, both tasks measure an individual's *capacity* to retain relevant information, even when distracting tasks vie for attention.

To create the outcome measure, we first computed the proportion of correct responses on the Ospan task ($M = 0.79$, $SD = 0.26$) and the Rspan task ($M = 0.83$ $SD = 0.22$). We then averaged the two scores to create a total working memory storage proportion correct score ($M = 0.81$, $SD = 0.23$), which was the dependent measure.

Results and Discussion

We used the same data analysis approach as in Experiments 1 and 2. Specifically, we conducted a regression analysis with working memory capacity as the dependent measure. The predictor variables were: experimental condition as an effects coded categorical variable (control = −1, uncertainty = 1), childhood unpredictability as a continuous grand-mean centered variable, childhood SES as a continuous grand-mean centered variable, the interaction between childhood SES and experimental condition, and the interaction between childhood unpredictability and experimental condition.

The results appear in Figure 4. The analyses revealed no main effect of either experimental condition [$B = -0.04$, $t(180) = -0.61$, $p = .54$] or childhood SES [$B = -0.12$, $t(180) = -1.57$, $p = .12$], and no interaction between childhood SES and experimental condition [$B = -0.02$, $t(180) = -0.31$, $p = .76$]. There was, however, a significant main effect of unpredictability [$B = -0.21$, $t(180) = -2.91$, $p = .004$], which indicated that higher childhood unpredictability was, on average, associated with lower scores on the working memory capacity tasks. As expected, there also was a significant interaction between uncertainty and childhood unpredictability [$B = -0.19$, $t(180) = -2.58$, $p = .011$].

As illustrated in Figure 4, the working memory capacity effects were different than the working memory updating effects in Experiment 1, but similar to the working memory retrieval effects in Experiment 2. We probed this interaction by performing simple slopes analyses for individuals at high (+1 *SD*) and low (−1 *SD*) levels of childhood unpredictability. As shown in Figure 4, people who grew up in a predictable environment (with low levels of unpredictability) had an increase in working memory capacity in the uncertainty condition compared with the control condition, although this effect did not reach conventional levels of significance [$b = 0.03$, $t(180) = 1.44$, $p = .15$]. In contrast, people exposed to high levels of childhood unpredictability displayed a significant decrease in working memory capacity in the uncertainty condition compared with the control condition [$b = -0.05$, $t(180) = -2.27$, $p = .024$].

Construed another way, in the control condition, there was little difference in working memory capacity between people who grew up in unpredictable versus predictable environments [$b = -0.00$, $t(180) = -0.20$, $p = .84$]. In the uncertainty condition, however, people from predictable childhood environments performed considerably *better* than those from unpredictable childhood environments [$b = -0.06$, $t(180) = -4.00$, $p < .001$]. Consistent with the findings of Experiment 2, growing up in an unpredictable environment was negatively associated with working memory capacity under uncertain conditions.

General Discussion

A sizable body of prior research has documented that adverse childhood environments tend to impair many important features of cognitive functioning (e.g., Bos et al., 2009; Farah et al., 2006; Hackman et al., 2014; Noble et al., 2007). According to evolutionary-developmental theory (Ellis & Del Giudice, 2014; Frankenhuis & de Weerth, 2013; Mittal et al., 2015), however, childhood environments ought to *shape* cognitive functioning in adaptive ways, suggesting that even being reared in adverse environments might enhance certain types of cognitive functioning. In the current research, we tested the sensitized-specialization hypothesis (Ellis et al., 2017), which posits that a person's mind should become "developmentally specialized" to solve the types of challenges repeatedly found in one's childhood environment. For example, growing up in an unpredictable childhood environment should specialize the mind to function better in an unpredictable, chaotic ecology. These specialized abilities, however, should manifest primarily when the current (adult) environment is uncertain.

We tested the sensitized-specialization hypothesis in three experiments, with each one examining a different component of working memory. Our model predicted that exposure to unpredictable childhood environments should enhance the updating component of working, but it should not enhance the retrieval and capacity components of working memory.

Experiment 1 revealed that exposure to more unpredictable environments early in life was negatively associated with the updating component of working memory under benign conditions. This general negative effect is consistent with traditional models of early life adversity and working memory functioning (e.g., Bos et al., 2009; Farah et al., 2006; Hackman et al., 2014; Noble et al., 2007). However, Experiment 1 also revealed that exposure to more unpredictable early life environments does not always result in impaired working memory updating. Instead, the negative effects of early unpredictability vanished when the current context was uncertain. In fact, individuals exposed to more unpredictable environments in childhood performed significantly *better* on working memory updating tasks when tested under conditions of uncertainty compared with control conditions. This makes sense to the degree that it is advantageous to track and rapidly update information about the immediate surrounding environment, particularly if it continually changes in unpredictable ways. These efficient updating abilities should enable swift adaptation to changing circumstances and orient the mind toward novel—and perhaps more useful—information. These findings were obtained in a well-powered study ($N = 372$), and the patterns were similar across two different working memory updating tasks and two different subsamples.

Experiments 2 and 3 examined working memory retrieval and capacity. In contrast to Experiment 1, Experiments 2 and 3 revealed that growing up in an unpredictable environment was negatively associated with performance on tasks on working memory retrieval and working memory capacity. Critically, these enhancement effects were observed only when people were tested under conditions of uncertainty. The function of working memory retrieval and capacity is to store and maintain important information, even during interference. These abilities are likely to be less adaptive in unpredictable environments and perhaps even maladaptive, because storing and retrieving information from earlier experiences typically should not be helpful—and might be detrimental—when the environment constantly changes.

Viewed as a whole, the current findings highlight the specificity of the sensitized-specialization hypothesis, paving the way for future research to uncover the precise ways in which different childhood environments specialize cognitive functioning. More broadly, the current work adds to the growing literature on evolution and cognition (Becker, Anderson, Mortensen, Nuefeld, & Neel, 2011; Krasnow et al., 2011; New, Krasnow, Truxaw, & Gaulin, 2007).

Working Memory Versus Executive Function

The current experiments show similar patterns of working memory effects relative to other recent executive function findings (e.g., Mittal et al., 2015). This raises an important question: To what extent do the working memory outcomes in the current experiments overlap with prior executive function findings?

Historically, executive function and working memory have been treated as separate constructs grounded in fairly distinct literatures. Executive function refers to the ability to guide and manage complex behavior toward goals (Banich, 2009; Miller & Cohen, 2001), and it has a deep literature in psychology (e.g., Friedman & Miyake, 2017; Friedman et al., 2008; Miyake et al., 2000). When considering the current findings in relation to those of Mittal et al. (2015), two questions arise: (a) To what extent are the current memory updating findings the same as Mittal and colleagues' (2015) shifting results?; and (b) To what extent are the current working memory retrieval/capacity findings the same as Mittal et al.'s (2015) inhibition findings?

Recent research indicates that updating and shifting are distinguishable. Friedman et al. (2008), in fact, claim that inhibition, shifting, and updating constitute the three primary executive functions. Shifting is typically measured with reaction time (RT) tasks that detect how quickly an individual adjusts when a rule suddenly changes. Updating, on the other hand, is primarily an accuracy task. Scores are based on the number of correctly recalled items. To perform well on updating tasks, one must quickly remove irrelevant information and update working memory with the relevant information. Nevertheless, shifting and updating latent variables are correlated between .38 (Miyake & Friedman, 2012) and .40 (Friedman et al., 2008), indicating that they do share some similarities. Both shifting and updating, for example, involve responding appropriately to incoming and changing information. However, whereas shifting reflects responding quickly to changes, updating involves removing old information and replacing it with new information.

Research also indicates that working memory capacity/retrieval and inhibition are distinguishable constructs, but are also related in important ways (Kane et al., 2004; Redick et al., 2012; Unsworth et al., 2014). Inhibition tasks measure how well individuals can suppress a prepotent response (such as looking at a bright flash), focus on the task, and respond appropriately. Working memory capacity and retrieval, in contrast, measure one's ability to retain information in memory, even with distractions, and then correctly retrieve it upon recall. Thus, accuracy in inhibition tasks reflects pure distraction suppression abilities, whereas working memory capacity/retrieval reflects information storage and retrieval abilities in addition to distraction suppression abilities. Inhibition and working memory tasks also differ in how distractions affect performance. Distractions in working memory tasks, for example, usually require information processing (e.g., doing math problems), whereas distraction inhibition tasks are more sensory in nature and invoke more reflexive responses. Despite these clear differences, individuals who are good at inhibition tasks also tend to be good at working memory capacity tasks, with correlations ranging from .30 to .36 between these tasks and about .52 at the latent variable level (Unsworth et al., 2014; Unsworth et al., 2015). Nevertheless, working memory capacity and retrieval involve more than merely inhibition abilities; they also involve memory storage, retrieval, and processing efficiency.

Taken together, this initial work on cognitive abilities from an evolutionary-developmental perspective suggests that there may be broad "cognitive profiles" that emerge in response to early life experiences. The sensitized-specialization hypothesis can inform and guide the study of individual differences in cognitive abilities and can generate interesting and novel predictions regarding different cognitive abilities. Future research needs to delineate how distinct components of different cognitive abilities might be calibrated by the early environment in nuanced ways.

Predictability and the Stress Response System

An intriguing pattern was found in Experiments 2 and 3: A sense of current uncertainty enhanced working memory retrieval and capacity for individuals from *predictable* environments. This effect was not predicted, but it emerged in both experiments that contained different samples and two different, conceptually related outcomes. One possible explanation for this effect is that these abilities might be particularly helpful and perhaps adaptive in predictable environments. In such stable environments, critical information that was useful in past situations should often generalize to new and similar future situations. However, it remains difficult to explain why these patterns were found under conditions of current uncertainty. In other words, why should feelings of uncertainty *improve* certain cognitive functions in people who grew up in predictable environments? To the extent that predictable childhood environments enhance abilities such as working memory retrieval and capacity (specialization), one might expect these abilities would primarily be witnessed under conditions signaling greater predictability (sensitization). In contrast, we found enhanced working memory retrieval and capacity effects for people from predictable environments exposed to current uncertainty.

Although the sensitized-specialization hypothesis did not anticipate this effect a priori, it might be helpful to speculate about why we might have obtained this pattern. One possibility is that the childhood environment plays a fundamental role in shaping the stress response system, which governs how people react to stress across the life span (Del Giudice et al., 2011; McEwen, 2012; Taylor, 2010). Unpredictable childhood environments chronically activate the stress response system and, over time, alter the stress response and its associated biological structures. For example, a stressful early life environment changes how the body copes with the release of stress hormones, such as cortisol, when threats are encountered later in life (McEwen & Stellar, 1993; Taylor et al., 2004). Early stressful environments also shape the brain's fear circuitry and brain structures such as the amygdala, which then influence the detection, processing, and behavioral response to later threats (Callaghan & Tottenham, 2016; Fareri & Tottenham, 2016; Teicher & Samson, 2016). Together, these neurobiological effects of early childhood adversity may lead people who have unpredictable versus predictable childhood backgrounds to behave differently when confronted with stressful situations in adulthood because their stress response systems were calibrated differently in childhood.

With respect to the concept of sensitized-specialization, one possibility is that the process of sensitization is governed by the stress response. Current stressors may trigger a psychological and biological stress response, which in turn triggers specialized behaviors and cognitions that were adaptive in one's childhood environment. For example, if high levels of working memory retrieval were adaptive in childhood (because the environment was typically predictable), triggering a stress response with a threat may bring such abilities online. Likewise, if high levels of working memory updating were adaptive in childhood (because the environment was typically unpredictable), the stress response should activate enhanced updating abilities. The central idea is that childhood calibrates peoples' response to threats via the stress response system. As such, the activation of the stress response system later in life may explain the display of specialized cognitive abilities, specifically those that were most adaptive in childhood.

Our pretest of the uncertainty manipulation (see Experiment 1) showed that the manipulation led people from both predictable and unpredictable childhood backgrounds to feel significantly more distressed and scared. Thus, one possible reason why people from predictable environments showed enhanced working memory retrieval and capacity is that the manipulation produced a mild stress response and activated the brain's neural fear circuitry. Although these individuals may not be specially adapted to coping with current uncertainty, they may have responded to current uncertainty with improved retrieval and capacity because their stress response system was nonetheless activated. For example, Chipman and Morrison (2015) examined how the cold-pressor task, a domain general acute stressor, interacts with childhood adversity to influence people's desired reproductive timing. They found that people's response to the stressor differed depending on whether they experienced an adverse versus nonadverse childhood environment. These results suggest that developmentally specialized behaviors may be activated by both mental and physical stressors and could be mediated by a physiological stress response. Future research is poised to investigate whether and how different stressors and the stress response system itself plays a role in activating specialized cognitive abilities.

Limitations and Contributions

One important contribution of this research is that it confirms that specialized working memory abilities emerge only under conditions of current uncertainty. Across all three experiments, the effects of childhood environment were evident primarily when people were tested under conditions of uncertainty. When conditions were uncertain, people reared in unpredictable childhood environments displayed enhanced updating and diminished retrieval and capacity.

These context-specific results shed light on why specialized working memory effects have not been found in prior correlational studies: Past research has not considered current uncertainty. Our context-dependent effects, however, have clear parallels in the animal literature (e.g., Bagot et al., 2009; Chaby et al., 2015), and they are consistent with other effects recently found in humans (Griskevicius et al., 2011, 2013; Mittal & Griskevicius, 2014; Mittal et al., 2015). Future research needs to clarify when, how, and why instilling a sense of uncertainty is—and is not—needed to witness the impact of childhood environments on different cognitive functions.

The current findings also indicate that a specific form of early life adversity—experiencing changing, unpredictable childhood environments rather than stable but still harsh ones—produces these results. In the current research, we document that early unpredictability—but not harshness (indexed by low SES)—is associated with working memory specialization and sensitization effects. These findings both build on and extend prior work by suggesting that unpredictability plays a special role in shaping specific executive functioning outcomes.

The current research also raises an intriguing puzzle. Experiment 1 revealed clear differences in working memory updating outcomes in the control condition, whereby people raised in predictable environments performed better than those who grew up in unpredictable environments. This effect is consistent with previous correlational studies of working memory (e.g., Bos et al., 2009; Farah et al., 2006; Hackman et al., 2014; Noble et al., 2007). However, similar main effects of childhood unpredictability were not found in the control conditions of Experiments 2 or 3. This raises the question as to why working memory updating was impaired in the control condition of Experiment 1 for people exposed to high levels of childhood unpredictability, whereas working memory retrieval (in Experiment 2) and capacity (in Experiment 3) were not impaired in individuals from unpredictable backgrounds. Future work needs to replicate these findings and clarify why they exist.

Another limitation of the current research is that our measures of early life environments were all retrospective. Thus, it is important to replicate these studies on samples on which early life information comes from different sources. Even though we relied on retrospective measures of unpredictability, previous research has found that childhood unpredictability has highly consistent effects on executive function when childhood unpredictability is measured either retrospectively or prospectively (Mittal et al., 2015).

Another important limitation is that our findings do not address the role of genetics. For example, it could be the case that the working memory effects reported in the current research were due to inherited genetic predispositions and not the childhood environment. Indeed, previous research has found substantial heritability estimates for many cognitive abilities, including working memory updating (Friedman et al., 2008). We believe that genetics are likely to contribute to the types of effects documented in the current research. We also believe that the environment contributes to these effects in important ways, consistent with previous research demonstrating that the nonshared environment contributes to such outcomes (e.g., Friedman et al., 2008; Friedman et al., 2016; Friedman & Miyake, 2017). Ultimately, there are likely to be meaningful contributions from both genetic predispositions and childhood environments on working memory abilities.

In addition, we did not measure general intelligence in any of our experiments. General intelligence correlates strongly with measures of working memory (Friedman et al., 2008; Unsworth et al., 2014), which suggests that individual differences in working memory underlie individual differences in intelligence. Given the current set of findings, however, it is unclear which facets of working memory most strongly predict intelligence and, more interestingly, how they are related to different subcomponents of intelligence and childhood environments. For example, even though general intelligence is defined as the shared variance among many different intelligence measures (i.e., the g-factor), it can be subdivided into tasks that measure fluid intelligence (e.g., the Raven advanced matrices, spatial reasoning tasks) and tasks that measure crystallized intelligence (e.g., vocabulary, reading comprehension). Thus, it is possible that childhood unpredictability is linked with higher fluid intelligence (but not crystallized intelligence) under uncertainty if fluid abilities are more useful in unpredictable environments. The broader point is that the sensitized-specialization hypothesis offers a theoretical framework to investigate how broad constructs, such as working memory and intelligence, might show nuanced cognitive performance patterns, depending on childhood factors, current environmental conditions, and the type of cognitive functioning examined.

Conclusion

This research is the first to formally test the sensitized-specialization hypothesis. In doing so, it shows that being raised in a predictable versus unpredictable environment has specific—and specialized—associations with cognitive functioning in adulthood. Although previous work has documented that exposure to adverse childhood environments, such as those characterized by unpredictability, have negative consequences for memory, we found that unpredictable environments are associated with positive outcomes for working memory updating under conditions of uncertainty. These findings are important because they suggest that early life experiences play a more functionally nuanced role in the development of certain cognitive abilities. Using this model as a guide, future research needs to systematically document whether and how different types of cognitive functions are influenced by different kinds of early life experiences, and how different abilities can be altered to improve performance in contemporary environments.

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Received November 14, 2016
Revision received October 24, 2017
Accepted November 6, 2017 ■