Toward a Life-span Model of Emotion: How Aging Shapes our Affective Responses

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Abstract

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Aging has long been associated with a *(i)* systematic bias in both attention and in memory towards positive stimuli compared with negative, and *(ii)* a gradual increase in self-reported positive affect and decrease in negative affect in daily life. The findings are considered to be paradoxical, because as people get older, the neural mechanisms responsible for cognitive functioning undergo gradual decline in structure and function. This dissertation aims to break down the mechanisms of aging that allow for the age-related changes in emotion to prevail in the midst of other ongoing aging processes. Here, I present three papers that address age-related changes in emotional experience. Study 1 showed that age predicted feeling more positive and less negative when faced with a pandemic that disproportionality impacted older adults. Study 2 showed that while younger adults are better than older adults at regulating negative images, all participants rely on similar brain regions for accomplishing the same regulatory goals. Study 3 showed that when given the explicit goal to up or down-regulate positivity, older adults do not have an advantage over younger adults. One way to explain these results is that there are age-related distinctions between the way participants behave in lab-based studies and when they are observed in daily life, which account for inconsistencies between my three studies.

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Dedication

In memory of my dear friend and colleague, Shane Colombo, whose infectious chuckle will forever live in my heart.

Chapter 1: Introduction

With the average life-span continuing to increase (estimates suggest it will be 86 years in 2060) and the aging of the baby boomer population, the United States is facing an unprecedented healthcare challenge (U.S. Census Bureau, 2020). Our economic systems simply cannot handle the demographic shifts, with older adults spending significantly more on health expenditures than any other age group. National health expenditures are projected to grow at an average annual rate of 5.5% with Medicare baring a large chunk of this burden (*National Health Expenditure Projections, 2018–27*, 2019). There is therefore a great need for our growing society to better understand the effects aging has on health and well-being of older adults. The more information we gather about the psychology of older adulthood, the better equipped we will be for our new world.

It is well-documented that healthy aging (i.e., without clinical disease) negatively impacts cognitive functioning. Performance on neuropsychological batteries for fluid intelligence declines dramatically throughout adulthood (Hasher & Zacks, 1988; Park et al., 2002; Salthouse, 1994). Age-related changes in neural mechanisms and brain structure underlie the observed behavioral changes (Fjell & Walhovd, 2010). Throughout the normal course of life, the adult brain undergoes depletion in both white and grey matter, a weakening of synapses, and the introduction of disruptive proteins in many areas of the cortex. The lateral parts of the prefrontal cortex tend to show the most shrinkage, while more medial areas of the brain are more likely to be preserved over the life-span (Nyberg et al., 2010; Reuter-Lorenz & Cappell, 2008).

Despite the generally negative consequences that aging has for cognitive functioning and physical health, adults consistently report higher levels of positive affect at older ages

(Blanchflower & Oswald, 2007; Gross et al., 1997). In a historic longitudinal study of aging and emotion, Laura Carstensen and her colleagues used an experience sampling method to survey a life-span sample of 184 adults over a ten year period beginning in 1993 (Carstensen et al., 2011). Participants were sampled for one week over three different waves (approximately 3-5 years apart). Each wave of the study, participants received a pager that was manually set to beep at four random time points each day over a 7-day period. At each beep, participants reported the degree to which they were feeling 19 different emotions on a 7-point scale and at the end of the week they mailed all their reports to the researchers. In additional to emotional functioning, the researchers also assessed participants cognitive abilities and survival rate.

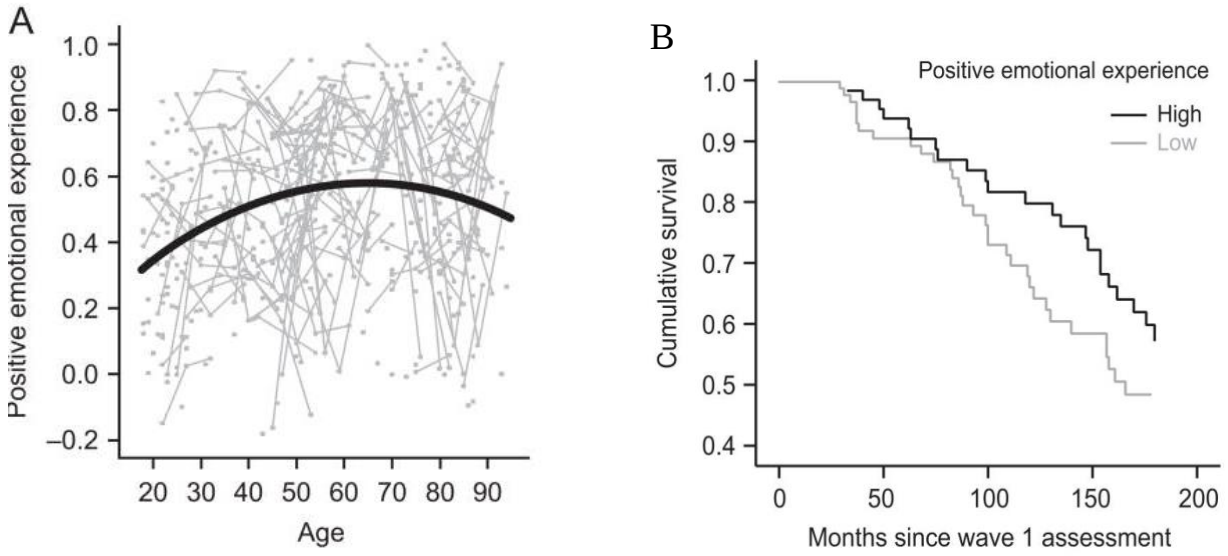

Figure 0.1: Prototypical age trajectories for (A) positive emotional experience (frequency of positive emotions minus negative emotions) (B) Survival function over 13 years for Wave 1 participants with high versus low positive emotional experience (From: Carstensen et al., 2011).

Over time, people reported feeling negative emotions at lower rates and positive emotions in higher rates. Within each wave, as expected, cross-sectional results found age to be predicative of less variability in both positive and negative emotion. Age was associated with

greater poignancy. They also found that emotional experience was associated with mortality (i.e., the participants who reported more positive than negative emotions in daily life were more likely to have survived over the 13-year period) controlling for covariates (Carstensen et al., 2011). These results prove that, not only is aging associated with greater positivity, but also maintaining higher levels of positive affect as people age is beneficial for their health.

In laboratory settings, research participants display an age-related bias in attention and memory towards positive stimuli over negative and neutral stimuli (Mather & Carstensen, 2005; Reed et al., 2014; Reed & Carstensen, 2012). Older adults are more likely to be looking at a happy compared to a sad face than a younger adult, in the absence of explicit instructions. Older adults are also more likely to remember positive images than they are to remember neutral and negative images compared with middle- aged and younger adults. Interestingly, the positivity bias is no longer present when older adults have to divide their attention, which suggests that despite being a subconscious process, it is in fact process that requires effortful engagement (see Mather & Knight, 2005).

One proposed explanation for this advantage in emotional status is an age-related difference in emotion regulation behavior. To address this hypothesis, in this chapter I ask, what is emotion regulation and what do we know about how it changes over the life-span?

People of all ages encounter emotion-eliciting situations daily, whether it's sitting through traffic on the morning commute, a pleasant call from a sibling, or turning on the news. Often, the initial emotional response can be of the wrong intensity or duration, and they must regulate the emotions they experience in order to carry on with daily life. According to James Gross' processing model of emotion regulation, regulatory strategies fit into five distinct categories: *situation selection, situation modification, attentional deployment, cognitive change*

and response modulation (Gross et al., 1997). All strategies can lead to successful emotion regulation and one strategy is not always the right fit for the same situation or person.

The inability to effectively choose a strategy and execute it can have detrimental effects on mental health (Gross & Muñoz, 1995). Failure to regulate appropriately can also disrupt all other processing, harming someone's ability to make decisions (Stetz et al., 2007). Thus, the ability to regulate emotions directly contributes to the experience of wellbeing over time. There are, however, significant differences across people in their ability to regulate their emotions and in the strategies they choose to use (Sheppes et al., 2011). The emotional response is considered to be an outcome of the interaction between the person, the situation itself, and the strategy they employ in order to regulate (Doré et al., 2016). Putting aside individual differences in personality, lifestyle factors and social factors, we can examine how age-related changes occur on the person-level affect emotion regulatory success and the overall emotion all experience. In a sense, holding the other variables in the interaction constant, and merely focusing on age-related change will allow for greater understanding of how cognitive aging affects emotion regulatory abilities.

The life span theory of motivation and emotion, known as Socioemotional Selectivity Theory (SST), provides a clear interpretation of changes in selectivity, the first family of regulatory strategies, with regard to aging. According to SST, as a function of shrinking time horizons, older adults prioritize situations with emotionally meaningful partners over all other interactions (Carstensen, 1995). When given the choice between spending time with a close family member or a new person, older adults with almost always pick the former, whereas younger adults prioritize new situations (Carstensen, 2006). By systematically selecting situations that maximize emotional meaning, older adults demonstrate an age-related

improvement in both situation and situation selection domains of emotion regulation. In other words, older adults demonstrate the goal-directed behavior of enhancing emotional meaning.

Furthermore, the Strength and Vulnerability Integration (SAVI) model, put forth by Susan Charles and Gloria Luong, suggests that age-related situation selectivity is an adaptive process that occurs in reaction to limited cognitive resources (Charles & Luong, 2013). According to SAVI, since other regulatory strategies may be too cognitively demanding for older adults, they choose to buffer themselves from future negative situations by targeting situation selectivity. This suggests that, while older adults may rely more on situation selection and modification, they are perhaps getting worse at other types of regulation because of age-related declines.

The research on cognitive change and aging is mixed and far from conclusive (T. L. Sims & Carstensen, 2014). Cognitive reappraisal, the process of altering one's response through reinterpretation of the emotion-eliciting situation, is the primary regulatory process studied in this domain of cognitive change. Neuroimaging studies show that performing cognitive reappraisal requires the same brain circuitry as working memory and executive control, more broadly (Kanske et al., 2011), which show age-related declines in functioning abilities (Salthouse, 1994). Based on this alone, one would predict older adults are worse at reappraisal, when in fact with self-report, they report using reappraisal more than younger adults (John & Gross, 2004). It is important to note, however, the distinction between using reappraisal and successfully executing it as a regulatory strategy.

Researchers have shown older adults do perform better than younger adults when instructed to find positivity in a negative situation to reduce negative affect, or increase negativity when given a negative situation (Opitz, 2013; Shiota & Levenson, 2009). When

instructed to reduce negative emotions by distancing themselves or minimizing the importance of a situation, older adults perform worse than younger adults (Shiota & Levenson, 2009; Winecoff et al., 2011).

On an anatomical level, the brain regions responsible for emotion regulation experience varying degrees of structural depletion in aging. In older adults, typically, the amygdala and ventromedial prefrontal cortex are relatively well-preserved, while the dorsolateral prefrontal and hippocampal regions experience the most atrophy (Fjell et al., 2009). Depletion of the latter brain regions is consistent with age-related decline in executive functioning generally. Preservation of the amygdala and ventromedial prefrontal cortex; however, suggest that affective processing may in fact be conserved through old age.

Functional models allow for further understanding of how the brain continues to function, despite biological change. The Hemispheric Asymmetrical Reduction in Older Adults (HAROLD) model put forth by Roberto Cabeza states that with age there is a shift towards more bilateral activation of frontal brain networks while completing cognitive tasks (Cabeza, 2002). The shift in functional activation has been shown for a range of cognitive tasks, including both inhibitory control and working memory. The Compensation-Related Utilization of Neural Circuits Hypothesis (CRUNCH) proposed by Reuter-Lorenz & Cappell in 2008, builds off of HAROLD, stating that the aging brain responds to biological and functional deficits by recruiting new or previously unused neural circuits (Reuter-Lorenz & Cappell, 2008). With this compensatory increase in neural circuitry, older brains are able to perform at a similar level to younger brains on tasks that require a minimal to medium amount of cognitive effort (Reuter-Lorenz & Cappell, 2008).

The Scaffolding Theory of Aging and Cognition, later proposed by Park and Reuter-Lorenz (2009) expands upon CRUNCH, presenting a viable pathway for neural compensation (Park & Reuter-Lorenz, 2009a). Despite volumetric loss, white matter depletion, and other neurological degeneration, the aging brain still has the ability to activate the broader networks from the early stages of learning (Park & Reuter-Lorenz, 2009a). Scaffolding could be seen as a supplement to current networks, or it could be a new, alternative network used that completely replaces the now inefficient networks.

The Posterior shift with aging (PASA) model adds to the three other models, suggesting that there is also an age-related shift towards more activation in the frontal lobe and less in the occipital lobe (Davis et al., 2008). The PASA hypothesis is likely to be the most relevant model for discussing emotion regulation, since frontal regions are active during successful reappraisal. Despite age-related depletion in these areas, the PASA hypothesis suggest that older adults may engage the frontal areas to complete top-down cognitive processes, including reappraisal, just as regularly, if not more regularly than younger adults. This is an excellent counter to Susan Charles' SAVI hypothesis that older adults compensate for cognitive decline by relying on other regulatory strategies (Charles & Luong, 2013). According to PASA, they may in actuality, be compensating by recruiting new neural networks in the frontal lobe. Age-related improvements in situation selection and modification; therefore, may be completely independent from cognitive aging.

The adaptive functional models are built on the notion that cognitive resources are diminished with age. As previously discussed, inhibition, executive functioning, processing speed, and attention are all resourced that show limitations in later life. Theories of cognitive aging are built off of the understanding that resources are limited in aging. According to SAVI, it

is this depletion of cognitive resources that that causes a shift in behavior. In 2012, Opitz and colleagues put forth another theory relating resources to emotion regulation, known as Selection, Optimization, and Compensation in the Domain of Emotion Regulation (SOC-ER). SOC-ER suggests that emotion regulation success depends on an optimization of someone's individual resources, both internal and external. According to SOC-ER, decreases in working memory capacity and processing speed, typical of aging, negatively impact one's ability to reinterpret situations and implement cognitive change.

Using multi-level modeling, Optiz and colleagues showed fluid cognitive abilities, measured by perceptual speed and working memory capacity, are predictive of greater success at altering one's emotional response using reappraisal in older adults (Opitz et al., 2014). This finding fits with the findings from Winecoff and colleagues' fMRI study showed that fluid intelligence predicts amygdala down-regulation during active reappraisal tasks (Winecoff et al., 2011). Their individual differences analysis explains how variance across people in emotion regulation choices may be an outcome of variance in cognitive capacities. Perhaps it is those with depleted working memory capacities that first attempt to compensate by recruiting supplementary regions in the prefrontal cortex before opting to rely on non-cognitively demanding regulation strategies.

How do changes in cognitive functioning affect the emotion regulatory practices of older adults? Older adults activate the same brain regions as younger adults when completing cognitive reappraisal tasks in the lab (Winecoff et al., 2011). Even though these neural networks, primarily ones in the prefrontal cortex, undergo considerable change in structure and function in aging, their importance for cognitive reappraisal does not change over time. In other words, the brain functions supported by the prefrontal cortex remain critical for cognitive reappraisal, even

in older adults. Additionally, fluid cognitive abilities are predictive of both successful reappraisal and of connectivity between the prefrontal cortex and the amygdala while modifying ones' emotional response to stimuli (Opitz, 2013; Opitz et al., 2014; Winecoff et al., 2011). These findings together, present a clear pathway for how aging affects emotion regulatory abilities. Controlling for age, the predictive power of cognition for functional connections and behavioral performance still holds. Thus, changes in lab-based reappraisal abilities are understood to be a direct result of changes in cognitive functioning, and not of aging generally.

There is significant evidence to suggest that older adults successfully compensate for age-related declines in resources by recruiting additional neural networks when completing cognitive tasks. Recruiting additional networks is not only an adaptive process, but it is also beneficial across tasks and individuals (Park & Reuter-Lorenz, 2009a). Given the importance of prefrontal activation for regulatory emotional response, it is reasonable to infer that compensatory activation is beneficial for reappraisal, as well. The age-related shift from occipital to pre-frontal activation supports the notion that brain systems are plastic even in later stages of life (Davis et al., 2008).

Winecoff and colleagues identified the left inferior frontal gyrus as a region that predicted regulatory success in the older adults, but not the younger (Winecoff et al., 2011). In response to the depletion of prefrontal regions necessary to successfully use cognitive change to reshape an emotional response, older adults call upon the left inferior frontal gyrus. The right inferior frontal gyrus is involved in executing the go/no-go regulatory task (Chikazoe et al., 2009). The left inferior frontal gyrus is also involved in some inhibitory processing, (see Sharot et al., 2012), so it's logical to infer that the old brain would selectively call on the corresponding brain region in the left hemisphere it to regulate the amygdala response to emotional stimuli.

The brain compensates for diminishing resources on the neural level, but does compensation also occur on a behavioral level? According to SAVI, it is the depletion of cognitive resources in aging that motivates older adults to engage in situation selection and situation modification. By engaging in it more often, they become better at executing it and rely on it more (Charles & Luong, 2013). While there is an age-related increase in performance on these antecedent domains of regulation, it is not clear from any scientific research that cognitive aging drives this change.

There is far more evidence to support limited future time perspectives, not limited cognitive resources as the mechanism responsible for improvements in situation selectivity in older adults (Lang & Carstensen, 2002). When younger adults are primed to think about endings they behave similarly to older adults, prioritizing emotional meaning in situation selection (Fung & Carstensen, 2006;Fung et al., 1999). It is unknown if younger adults would behave the same way when their cognitive resources are limited. It is also unknown if cognitive abilities are predictive of situation selectivity. Thus, the SAVI model is likely incorrect in proposing that cognitive aging is responsible for age-related improvements in situation selection and modification.

Similar to situation selection, attention selectivity may also improve with age (Reed et al., 2014). Since the effect goes away when attention is divided, the positivity bias is most likely a cognitively demanding process that is preserved in healthy aging (Mather & Knight, 2005). Furthermore, when younger adults are instructed to think about limited future time horizons, they too demonstrate a bias towards positive information (Barber et al., 2016). Together, these results suggest that the positivity bias is occurring completely independently from age-related cognitive decline. It is certainly possible that at some level of pathological aging, cognitive resources are

too restrained for older adults to execute a bias in situation and attention selectivity; however, cognitive change in non-pathological aging does not appear to have a negative impact on these two domains of regulation.

Present Studies

In order to advance our knowledge on the emotional life of older adults, I present three studies that all ask novel questions regarding the impact of age on an individuals' emotional reactivity and emotion regulation.

In the second chapter, I consider the effect national events have on people of all ages. I ask (*i)* how does age impact general reactivity to the event, *(ii)* regulation of the event, *(iii)* the strategies people use to regulate the event, and *(iv)* the success they have with each given strategy? I explore all of these questions in a life-span sample of research subjects who were surveyed repeatedly throughout the COVID-19 outbreak and subsequent pandemic.

I then compare the effectiveness of different regulatory strategies between older and younger adults in the lab. Varying both the regulatory goal (i.e., to increase vs decrease the affective state) and the valence of the stimuli, I test for differences and similarities within the younger and older brain.

In the third chapter, I look at the age-related differences in the regulation of negative images whilst participants are instructed to up and down-regulate their negative affect.

Lastly, in the fourth chapter, I consider how aging affects positive affect and the chronic goals older adults have to up-regulate positive emotions by testing for the behavioral and neural correlates of reappraising positive emotions.

Chapter 2: Age Differences in Emotions Surrounding COVID-19

ABSTRACT

An individual's emotional status at any moment is understood to be the product of an interaction between person-level variables, the situation and the emotion regulation strategy/strategies they choose to engage in (Doré et al., 2016). We utilize the framework to understand, *(1)* why aging is associated with an increase in positive emotions and a decrease in negative emotions? And *(2)* how appraisals and regulatory behaviors impact this age-related shift in emotion? In order to assess how age, as a person-level variable, impacts the other components in the model, we chose to study emotions surrounding a highly stressful event—the COVID-19 Pandemic. Beginning in January of 2020 and continuing for 8-months, we tracked over 654 participants who spanned in age from 18-79 and assessed factors related to their emotions towards the pandemic, appraisals of the pandemic, and the frequency with which they used different regulation strategies to influence their feelings around the pandemic. With 10 waves during the pandemic and one pre-pandemic baseline, we were able to collect over 4,000 total observations of data. We found, at baseline, age was associated with a linear increase in positive affect and a decrease in negative affect. The same was true during the pandemic, despite the age-related risks in complications associated with contracting COVID-19. We attribute this age association with better emotional outcomes to a combination of baseline affect, age-related differences in appraisals and regulatory behavior. With age came an increase in ratings of appraisal dimensions, including commitment and attention. We also saw that the use of more adaptive emotion regulations strategies (i.e., cognitive reappraisal and social regulation) increased with age, while the use of more maladaptive strategies (i.e., suppression and substance use) decreased with age.

INTRODUCTION

"Thick darkness has gathered over our squares, our streets and our cities. It has taken over our lives, filling everything with a deafening silence and a distressing void that stops everything as it passes by; we feel it in the air, we notice it in people's gestures, their glances give them away."

The words of Pope Francis from March 27th, 2020 capture the feelings of many people impacted by the COVID-19 pandemic across the globe. The pandemic, which is believed to have reached U.S. cities as early as December 2019, has affected nearly every aspect of life since, from the way we work to the ways in which we care for our loved ones (Basavaraju et al., 2020). The pandemic continues to threaten our existence, not only by posing a public health threat, but also by causing massive shutdowns in businesses, schools and many institutions we come to rely on. Even with vaccines widely available, given the prolonged nature of our battle with the virus, the effects of the pandemic are likely to outlive the pandemic itself. Thus, there is a grave need to understand the complexities of people's emotional response to the pandemic and how those responses evolve over time.

To address this issue, we start with the premise that a given emotional response is the product of an interaction between person-level factors, a given situation and whether and how they strategically regulate their response (Doré et al., 2016). As such, we sought to characterize variability in emotional reactivity to the pandemic (the situation) in terms of individual differences at the person-level, such as age and how one appraises the meaning of the pandemic, as well as in terms of the Emotion Regulation strategies deployed.

On the person-level, there is reason to believe age explains a great deal of variance in emotional response to the pandemic, with increased aging predicting higher levels of positive and lower levels of negative affect (Carstensen et al., 2020; Kivi et al., 2020). These effects persist, despite the age-related risk in severity of complications from contracting the virus (Jordan et al., 2020). The pandemic appears to have a lower effect on stress in addition to negative affect for older adults (Knepple Carney et al., 2020), which raises the critical question: *why do people of different ages respond differently to the same situation?* Below, we discuss previous literature on age differences in affective responding, appraisals, and Emotion Regulation. We then introduce a longitudinal study that tests the interaction of these components in a representative U.S. sample during the first ten months of the pandemic in the United States.

Age differences in affective responding

Both field and lab data suggest that older adults may have a propensity to focus on the upsides of complex situations, such as the COVID-19 pandemic. For example, field studies show that—relative to younger or middled aged adults—older adults experience higher levels of positive and lower levels of negative emotion in daily life (Burr et al., 2020; Carstensen et al., 2000, 2011; Gross et al., 1997). They also report higher levels of global well-being and lower levels of mental illness (Blanchflower & Oswald, 2007). Lab-based findings paint a similar picture, with older adults showing a preference to attend to, and better remember, positive as compared to negative or neutral stimuli (Mather & Carstensen, 2005; Reed et al., 2014). Aging is also associated with the goal to prioritize time with close others rather than navigating the complexities of novel relationships and environments, a shift that is likely to enhance well-being (Carstensen, 1995; Charles & Luong, 2013).

Age differences in patterns of appraisal

Although the pandemic has exposed us all to a common situation, there may be age-related likely differences in the way people appraise its meaning, and therefore, how they respond with different emotions (Moors et al., 2013). In general, theories posit that appraisal involves assessing the meaning of a situation along a number of dimensions, and some of the most commonly posited dimensions—including attention, certainty, novelty, and control – may be important for assessing the meaning of the pandemic (Clore & Ortony, 2000; Ellsworth, 1994; Lazarus, 1994; Moors et al., 2013; Scherer, 2001). To date, however, comparatively little research has asked how the use of these (or other) appraisal dimensions vary across age. In the domain of novelty in particular, increased life experience is likely to impact the appraisal of situations for people of different ages with degrees of novelty for most life events waning with age. A 65-year-old may rate the loss of a close friend as more familiar and less novel than a 25-year-old undergoing the same circumstance. While an older adult may never have experienced a pandemic on the scale of the COVID-19 pandemic, the experience of health stress and loss of loved ones may seem more familiar to them than their younger counterparts. In the face of uncertain threats, greater life experience could connote a greater sense of certainty, familiarity (less novelty) and control. As such, appraisals along these dimensions could predict age-related differences in emotional responding to the pandemic.

Age differences in use of emotion regulation strategies

The ability to adaptively regulate our emotions generally is associated with greater levels of emotional satisfaction (Gross & John, 2003). In the context of the pandemic, it may be adaptive to actively regulate—and thereby change—one's emotions so as to lessen fear, anxiety or other negative emotions. Being able to select appropriate regulatory strategies for this purpose may therefore be essential.

While the study of strategy choice/selection is relatively new, there is reason to believe there may be important age-related differences. Older adults, who have greater life experience, may be better at fitting a particular strategy to a situation. Although older adults may show gradual declines in higher cognitive functions used to implement strategies (Mather, 2016; Nyberg et al., 2010), their tendency to nonetheless report more positive and less negative emotions, suggests that they might be adept at some other aspect of the regulatory process. Perhaps they are better at picking situation-appropriate strategies that they are capable of implementing effectively and that lead to regulatory success.

For adults of all ages, having greater fluid cognitive resources predicts enhanced success down-regulating negativity when instructed to reappraise negative images (Opitz et al., 2014). In one study older adults showed no differences in their ability to reduce negative affect by distraction with a Working Memory task, but were impaired with instructed reappraisal (Tucker et al., 2012). Relative regulatory success in lab-based studies of aging are mixed, with age predicting decreased success with some strategies, but less so with others (for summary, Helion et al., 2019). In surveys of strategy preferences in daily life, older adults have reported using suppression more, but no differences in other strategies (Eldesouky & English, 2018). Aging also predicts greater levels of self-reported success with regulating desires in daily life (Burr et al., 2020).

The present study

We tested three hypotheses about the emotions experienced in response to the Coronavirus pandemic. First, given that age tends to predict higher levels of positive and lower levels of negative affect in typical life circumstances, we predicted that during the pandemic, individuals' differences in baseline emotions might predict emotions during the pandemic itself.

Second and third, we hypothesized that age-related differences in emotional responding may be related to differences in the appraisal dimensions used to assess the meaning of the pandemic as well as the choice to use different regulatory strategies.

To test these hypotheses, we launched a longitudinal study in January of 2020 with a representative U.S. sample of adults ages 18 to 79. Because at that point in time COVID-19 was not widely discussed on the news and cases were believed to be isolated to China, for this first assessment we did not ask questions pertaining to the Coronavirus Outbreak and instead collected baseline measures of affect and political ideology. As awareness of COVID rose and lockdowns began in February and early March, we followed participants for 10 additional assessments spread over the course of the pandemic from March through October. This enabled to track participants' emotions, appraisals and regulatory strategy use throughout the first 8-months of the pandemic.

METHODS

Participants

Baseline:

Between January 29th and February 10th of 2020, we recruited a representative U.S. sample of 654 participants on the platform, Prolific. Prolific uses the most recent U.S. Census data to provide a pool of potential participants currently residing in the U.S. that represents national averages for age, gender, and race. To recruit this Time 0 sample, we specified inclusion criteria for age (18 to 79) and gender, with a nationally representative distribution of ethnicity/race. The resulting Time 0 sample had a mean age of 43 (*SD = 16 years, range = 18-79; 306 Male, 340 Female, 8 Other*). All survey protocols were approved by the Columbia University Institutional Review Board.

Participants were recruited for a study titled "Emotion in Daily Life" and were told "In this study we will ask you to complete questionnaires about how you are feeling in the moment. There will also be the option to participate in future surveys over the next year." Only participants who completed the survey were included in our analysis and all analyses are adjusted for missing data for particular items. All participants reported currently residing in the U.S. with 44 states and the District of Columbia in representation.

Longitudinal sampling: Time points 1-10

After the initial survey, 10 subsequent surveys that focused on emotions around the pandemic were available to any and all participants who had completed the first wave of the study. Each survey was available to the participants over a 2-days window and data were collected on a rolling basis. The time point between surveys vary between 2 weeks to 2 months, because we were following predictions in the virus trend over time and initially planned for a shorter overall time period. Of all initial 654 participants, 356 completed 7 or more of the COVID-19-related surveys. All analyses were run with both the complete dataset and one restricted to the 356 participants. Given that the results were unchanged, we report results taking all observations into account (4,096 total observations). Participants were compensated at $8/hour for each window of the survey. The surveys were all self-paced and took participants between 10 minutes to 45 minutes to complete depending on individual speed.

Table 2.1: Sample statistics at each wave time point

Age	**Baseline**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
18-29	172 (88 M, 79 F, 5 Other)	112	94	97	102	92	73	75	78	60	58
30-39	118 (57 M, 59 F, 2 Other)	88	76	83	84	81	68	76	76	63	61
40-49	131 (66 M, 65 F)	101	82	95	88	93	68	78	82	65	67

50-59	110 (40 M, 69 F)	86	78	84	84	75	65	67	71	64	62
60-69	102 (43 M, 58F, 1 Other)	88	82	88	81	79	71	72	80	72	77
70-79	21 (11 M, 10 F)	16	15	18	17	17	13	16	16	16	14
Total	**653 (306 M, 340 F, 8 Other)**	**491**	**427**	**465**	**456**	**437**	**358**	**384**	**403**	**340**	**339**

Age and gender breakdowns for each wave of the study with gender distributions at baseline (M = Male, F = Female)

Measures

Pre-pandemic baseline:

In the baseline survey, we collected trait level emotion surveys using a selection of terms from the PANAS that were known to be sensitive to age-related differences. The terms included were *sad, anxious, guilty, lonely, angry, happy, excited, calm, interested, proud and amused* (Carstensen et al., 2000; Watson, 1988). For each item, participants were asked "*to what extent are you now feeling each of the following emotions?*" and responses were collected on a 1-7 Likert scale (*1 = Not at all, 4 = Somewhat, and 7 = Very much so*). We also collected demographic information along with responses to the Future Time Perspective Scale (Lang & Carstensen, 2002), Emotion Regulation Questionnaire (Gross & John, 2003) and a variety of political ideology questions (Everett, 2013).

Time points 1-10

Pandemic emotions:

In survey waves 1-10, in addition to all the psychological questions from the first time point, we first asked participants to reflect on the impact that the COVID-19 pandemic was having on their lives. Then they told us how they had been feeling in the last 2-3 days about the

pandemic on 24 different emotion terms. Each term was randomized between and within people. Ratings were reported on a 100-point sliding scale from *1-not at all* to *100-very much so*.

Appraisal dimensions:

Participants were then asked to rate how the pandemic made them feel on 7 different appraisal dimensions—Attention, Commitment, Arousal, Control, Certainty, Novelty and Fairness (Clore & Ortony, 2000; Ellsworth, 1994; Lazarus, 1994; Scherer, 2001). Participants were asked *"How much have you been feeling each of the following towards the coronavirus outbreak over the last 2-3 days?"* Each item was asked on a 100-point sliding scale from 1-not at all to 100-very much so and question order was randomized both within and between people (see supplemental material for item details).

Emotion Regulation strategies:

Participants were then asked "*Have you used any of the following approaches to influence or change your emotions in response to the coronavirus outbreak over the last 2-3 days?*" Response items were selected from experience sampling studies of emotion regulation and from the authors' own experiences with the pandemic. Each response was recorded as a binary "yes" —used strategy or "no" —did not use strategy and all strategies are independent from one another.

Data analysis

All surveys were collected on Qualtrics and then analyzed in R 3.6.0. All the time series models were run in lme4 package which allows for multi-level modeling. The time variable in the models is the time in days from the start of the year mean-centered and scaled by 28-days, since there is not an equal amount of time between each wave. The age variable in the models is also mean-centered ($M = 43$) and scaled by decade for easier interpretation of effects.

RESULTS

Baseline Assessments

At baseline, for all age groups, people reported more positive emotion (*M = 2.07, SD = 1.16*) than negative emotion (*M = 3.91, SD = 1.22*;). This effect was stronger with increasing age (see table 2 for interaction effects). At baseline age also predicted decreased Future Time Perspective (*b = -0.17 p<0.001*), less depression (on the CES-D; *b = -0.13, p <0.001*). On trait levels of emotion regulation, age predicted lower use of suppression (*b = -0.01, p <0.001*) and greater use of reappraisal (*b = 0.01, p <0.001*).

Older tended to be more politically conservative (*b = 3.89, p<0.001*). Given the politicization of events surrounding the pandemic, we ran all analyses both with and without a covariate for political ideology at baseline. All of effects were unchanged, so we report results without this covariate.

Table 2.2: Pre-pandemic baseline

	M	SD	SE
Negative Emotions			
Sad	2.14	1.56	0.06
Anxious	2.58	1.75	0.07
Guilty	1.56	1.14	0.04
Lonely	2.47	1.74	0.07
Angry	1.59	1.20	0.05
Positive Emotions			
Happy	4.29	1.61	0.06

Excited	3.13	1.69	0.07
Calm	4.96	1.57	0.06
Interested	4.88	1.52	0.06
Proud	3.38	1.82	0.07
Amused	2.82	1.66	0.06

The table shows participants' response to the question of how much they had been feeling each of the emotions over the last week. All questions were collected on a 7-point Likert scale.

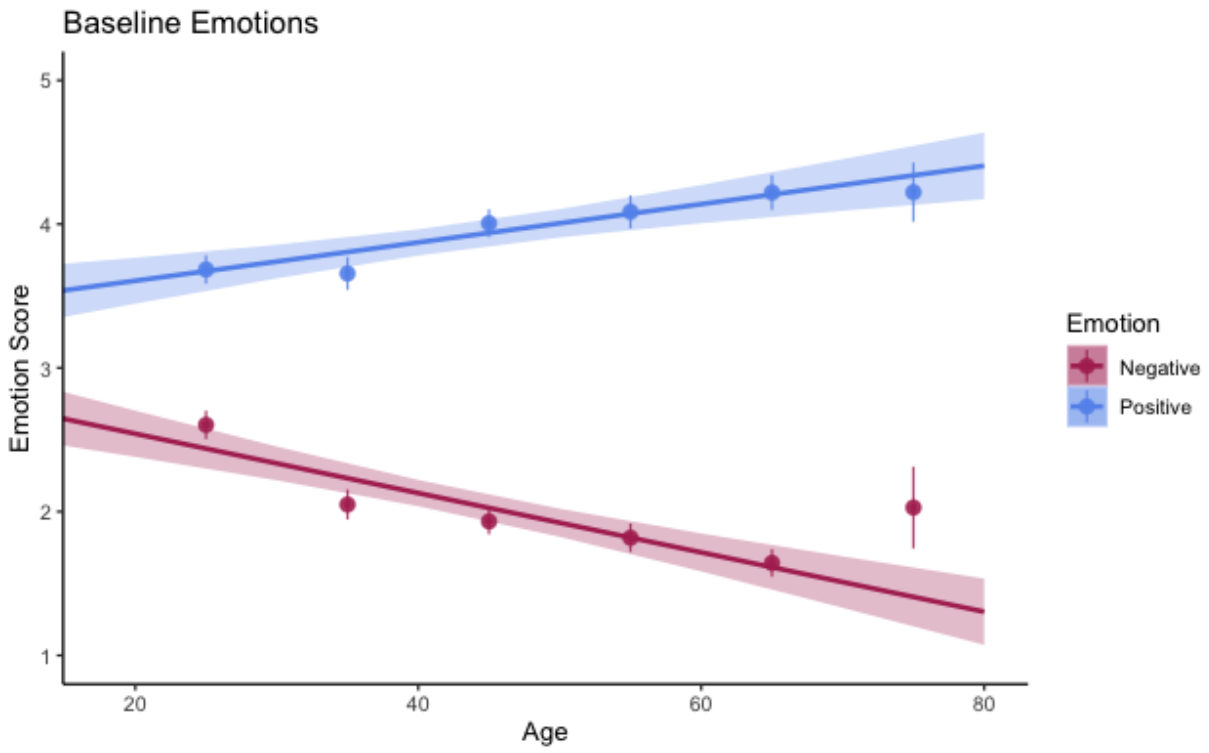

Figure 0.1: Model output with age as a continuous variable predicting emotion allowing for each person to have their own random intercept. Points indicate arithmetic means for each age group over all the time points and error bars represent standard error for those means.

Longitudinal assessments during the pandemic

Below we report the results of assessments of emotional reactivity, patterns of appraisal, and emotion regulation strategy use for the 10 sampling windows during the pandemic.

COVID-19 Emotional Reactivity:

We observed a main effect of age on emotions, such that with increased age came an increase in positive emotions associated with the pandemic and a decrease in negative emotions.

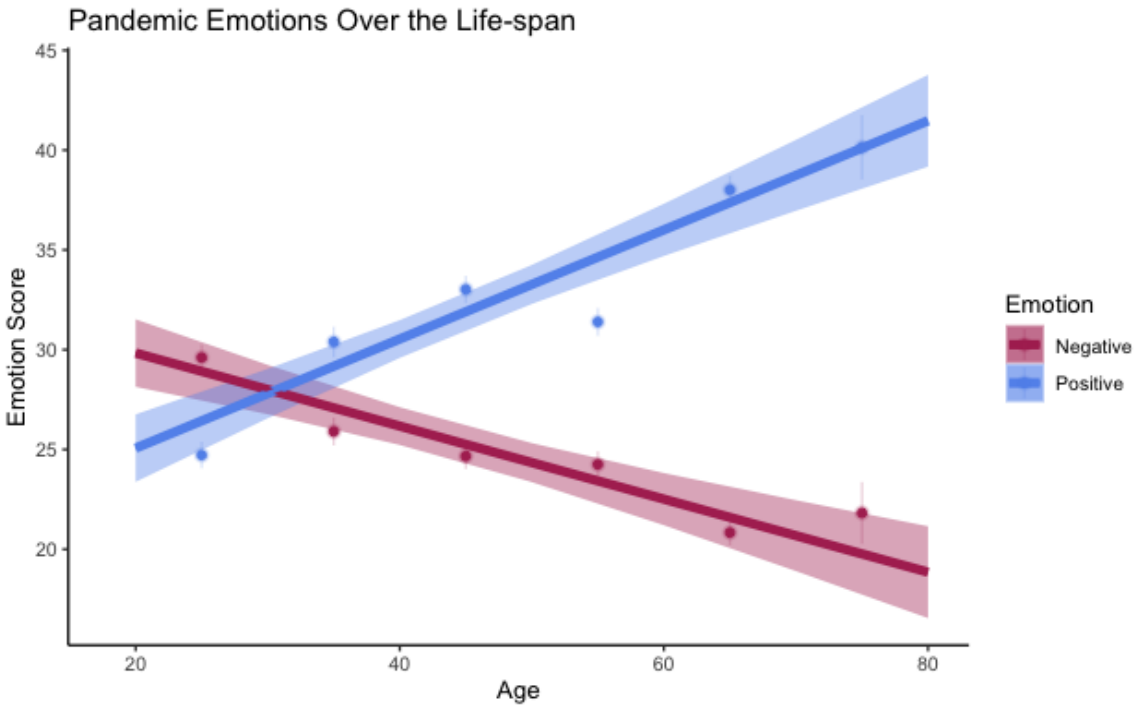

Figure 0.2: Pandemic Emotion Scores. Model output with age as a continuous variable predicting positive and negative emotions over the course of the first 8-months of the pandemic. Points indicate arithmetic means for each age group over all the time points and error bars represent standard error for those means.

Over time, all participants in the study reported feeling less negative towards the pandemic (b = *-0.89, p <0.001*). Additionally, negative affect at baseline fully mediates the effect of age on how negative participants reported feeling towards the pandemic, while positive affect was a partial mediator

Table 2.3: Age predicts pandemic emotions

	Negative	**Positive**

Predictors	*Estimates*	*CI*	*Estimates*	*CI*
(Intercept)	25.29 ***	24.02 – 26.56	31.80 ***	30.54 – 33.07
Age	-1.73 ***	-2.54 – -0.92	2.72 ***	1.91 – 3.53
Time	-0.89 ***	-1.04 – -0.75	-0.13	-0.31 – 0.05
Random Effects				
σ^2	103.84		164.59	
τ_{00}	224.29 $_{id}$		210.21 $_{id}$	
ICC	0.68		0.56	
N	596 $_{id}$		596 $_{id}$	
Observations	4022		4022	

** p<0.05 ** p<0.01 *** p<0.001*

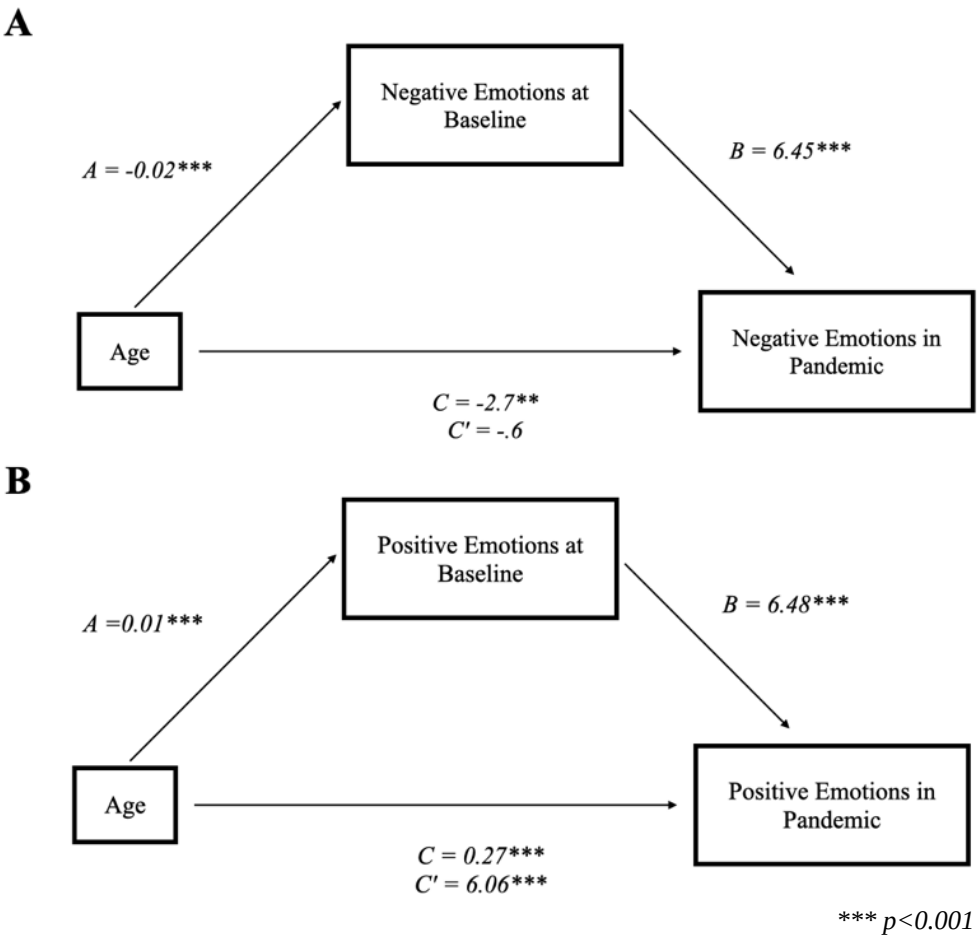

Figure 0.3 Baseline emotion mediation models. (A) Negative emotions at baseline mediate the effect of age on negative emotions during the pandemic. (B) Baseline positivity is a partial mediator of the effect of age on positive emotions during the pandemic.

Appraisals of the pandemic

Increased age predicted increased reporting of Attention, Commitment, Certainty, and Control. There were no observed age differences in Novelty, Fairness, and Arousal. Of the 7 appraisal dimensions, ratings were highest for Attention and Commitment.

We observed an interaction with both Commitment and Attention, such that reporting greater feelings of both dimensions predicted greater positive affect during the pandemic for older adults more so than for younger (see supplemental material). For all participants, higher

ratings of Commitment and Attention predicted more positive affect during the pandemic, however the effects were less pronounced with increased age. We also observed an interaction for the Arousal dimension, such that higher levels of Arousal predicted greater negativity for younger adults and lower negativity for older adults.

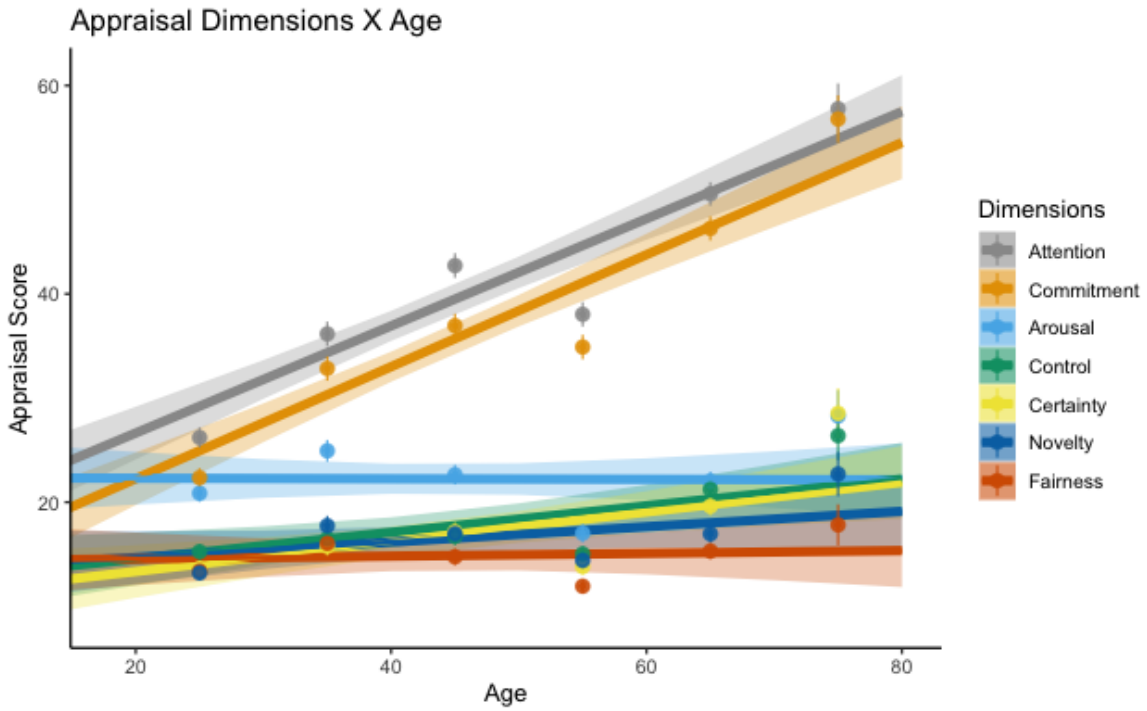

Figure 0.4: Appraisals of the Pandemic. Model output from an interaction between ratings for each appraisal dimension and age, controlling for total number of strategies used, time and the random effects of individual. Points indicate arithmetic means of appraisal dimension ratings for each age group over all the time points and error bars represent standard error for those means.

Emotion Regulation of the COVID-19 Outbreak:

Overall, the strategies all participants reported the most often were Distraction, Situation Selection, Exercise, and Social Regulation. Of these five common strategies, Reappraisal use and Social Regulation increased with age, while the others showed no main effect of age. Because there was a lot of overlap between strategies reported and we wanted to address age differences

in reported strategy use, we reduced the items with a confirmatory factor analysis. This analysis revealed three factor groupings that we named *action*, *cognitive*, and *exercise* (see factor groups in Table 2.4). Using these three factor groupings, we calculated a mean score for each of the three factors for each time point.

We found that the use of cognitive strategies increased with increased age and the use of action strategies decreased (see Table 2.5). Cognitive strategies increased in usage with increased time, while there was no change in the use of action strategies over time. We found an interaction between cognitive strategies and age, such that for younger, but not older adults the use of cognitive strategies predicted more positivity towards the pandemic (*b = 1.77, 95% CI 0.25-3.28, p<0.05)*. We found no other age-related interactions with strategy use on pandemic affect.

Table 2.4: Regulatory strategies and age-related model outcomes

Strategy	**Item**	**Log-Odds**	**Factor Grouping**
Reappraisal	"Thinking about the situation in a different way"	0.35 ***[.21, 45]	Cognitive
Social Regulation	"Talking to someone about it in person"	0.15* [.02, .28]	Cognitive
	"Talking to someone about it not in person"	0.19*[.06, .31]	Cognitive
Distraction	"Distracting yourself by thinking about something else"	0.11 [0, .22]	Cognitive
	"Distracting yourself by doing something"	0.21*** [.09, .32]	
Expressive Suppression	"Not letting your feelings show"	-0.28*** [-.41,-.13]	Action

Situation Modification	“Changing the situations you're in”	-0.12*[-.22,-.01]	Action
Situation Selection	“Avoiding certain situations all together”	0.05[-.04,-.15]	Action
Information Seeking	“Seeking information from experts”	0.37***[.25,.49]	Cognitive
	“Seeking information from authority”	0.38***[.24,.51]	
Exercise	“Walking”	0.06[-.13,.15]	Exercise
	“Not walking form of exercise”	0.01[-.13,.15]	
Substance	“Drinking Alcohol”	-0.13[-.40,.15]	Action
	“Using Marijuana”	-0.26[-.75,.24]	
	“Using Tobacco (cigars, cigarettes or vaping)”	-0.16[-.44,.23]	

*p<0.05 ** p<0.01 *** p<0.001*

Table 2.5: Strategy use age models

	Cognitive Strategies		**Action Strategies**	
Predictors	*Estimates*	*CI*	*Estimates*	*CI*
(Intercept)	-0.15 ***	-0.17 – -0.12	0.04 *	0.01 – 0.07

Age	0.02 ***	0.01 – 0.03	-0.04 ***	-0.05 – -0.02
Total Strategies Used	0.08 ***	0.07 – 0.08	0.04 ***	0.04 – 0.05
Time	-0.01 **	-0.01 – -0.00	0.00	-0.00 – 0.01
Random Effects				
σ^2	0.08		0.10	
τ_{00}	0.03 id		0.06 id	
ICC	0.27		0.36	
N	596 id		596 id	
Observations	4048		4048	

** p<0.05 ** p<0.01 *** p<0.001*

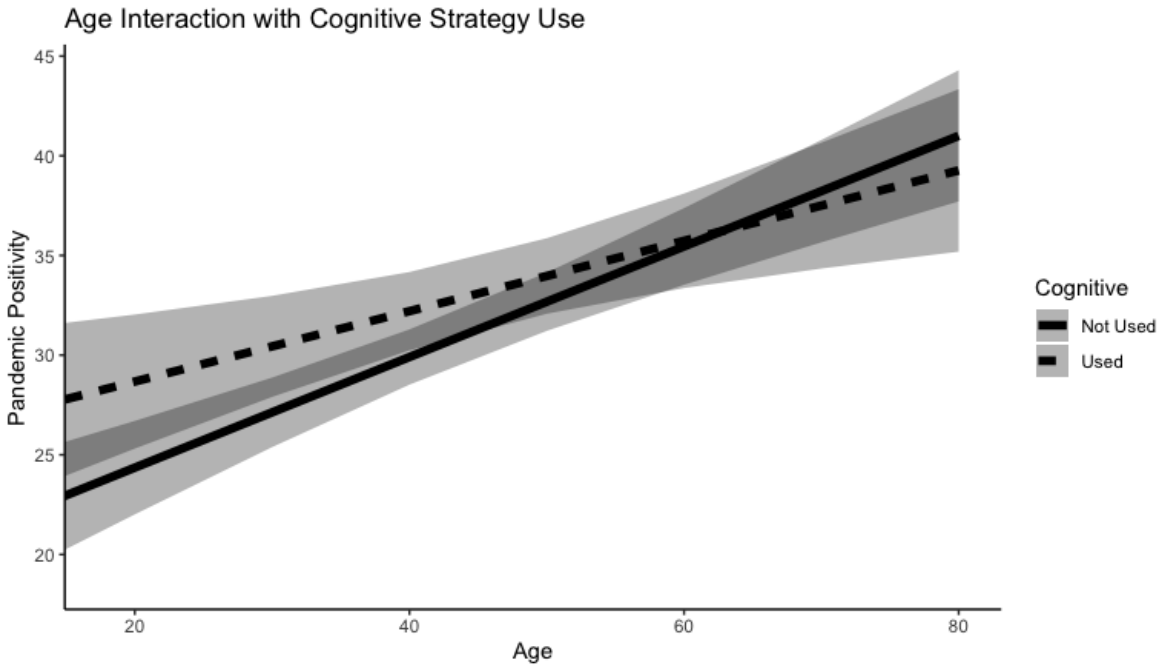

Figure 0.5: We observed an interaction with the use of cognitive regulation and age, such that using cognitive regulation (dotted line) predicted higher positivity than not using the strategy (straight line) more the younger you are than the older.

DISCUSSION

Most research on age differences in emotions has assessed how adults of different ages react to either daily life stressors or laboratory stimuli. While studying daily stressors has the advantage of being ecologically valid, given the endless categories of daily events that people experience, it is incredibly difficult to control for the individual situations. In this present study, we aimed to reduce the noise that comes from people experiencing different situations in daily life, while still holding onto the ecological validity of a natural event by assessing how people of different ages react to, appraise and regulate the same event.

The purpose of this study was to examine age-differences in how individuals responded to and coped emotionally with the pandemic, which continues to have a devastating impact on so many lives. We tested hypotheses about the ways in which emotional responses to the pandemic

resulted from pre-pandemic differences in baseline emotion, how the meaning of the pandemic was appraised, and how responses to the pandemic were regulated (Doré et al., 2016). Below, we describe the key results with respect to each of these factors and consider their theoretical and practical implications.

At baseline, age was associated with greater positivity and less negativity. In response to the pandemic that notably disproportionately impacts older adults, we found the age-related relationship with affect continued to hold (Bonanad et al., 2020). Increasing age was associated with higher rates of positive emotions in relation to the pandemic and lower rates of negative emotions. The maintenance of well-being in the face of a prolonged stressful event provides evidence against the Strength and Vulnerability Integration model of affective aging model, which suggests that age-related affective benefits occur as a result of avoidance of stress-inducing circumstances (Charles & Luong, 2013). The age benefits we observed at baseline persist during the pandemic, a highly stressful and persistent event.

Furthermore, baseline negative affect mediated the relationship between age and how negative people felt towards the pandemic. In other words, age-related differences in negative feelings towards the pandemic could be fully explained by how negative people felt before the pandemic. We take this as strong evidence that the age-related reduction in negative affect in daily life serves as a buffer for older adults when they encounter negative events, potentially independent of the situation. Since baseline positive affect was only a partial mediator, we predict that positivity towards negative events may be more influenced by other factors surrounding the event itself, such as cognitive appraisals.

As we predicted, appraisals of the pandemic varied significantly by age. We found that age was associated with feeling the highest rates of attention and commitment towards the

pandemic. Increased age was associated with an increased risk for developing severe complications from contracting the Coronavirus, which may explain why we see an age-related increase appraisal of the pandemic. Older adults, for example, may be paying closer attention to information around the pandemic because it has a greater effect on their health. The relationship between age and risk, however, is not linear, while the age-related increase in reporting of appraisal dimensions is linear. This suggests that, while risk may be driving some of this effect, it cannot be the only explanation. Age must therefore be predictive of some changes in the way people appraise situations leading them to think about things differently and attribute more meaning to them over time.

As a function of more life experience, people are more likely to find associations and similarities between events in their lives. Interestingly, the dimension of Novelty did not appear to vary by age, which leads us to the belief that the experience of the pandemic was an equally unfamiliar event for all individuals, even the older adults. Similarly, reporting's of Fairness did not vary by age, indicating that despite being at greater risk, older adults did not perceive themselves as being in a more or less fair position. We did, however, see that age predicted increases in reported ratings of Attention, Commitment, Certainty, and Control. All of the differences on these appraisal dimensions likely contribute to the age-related differences in the emotions they report around the pandemic. Since greater ratings of both Attention and Commitment predicted feeling more positive towards the pandemic for younger adults, we propose that teaching younger adults to enhance their sense of focus and commitment may help improve their positive affect.

Age-related differences were not only observed in the way people appraised the pandemic, but also in the strategies they used to regulate their responses. As was hypothesized,

we observed significant age differences in the types of Emotion Regulation strategies people deploy in daily life, which has long been an open question in the field (T. L. Sims & Carstensen, 2014). We find it particularly important that we observed reappraisal use increasing with increased age and suppression use decreasing, given the associations those two strategies have with well-being. While the use of neither strategy mediated the age effects of emotional status, we do know that spontaneous use of reappraisal is much more effective for down-regulated negative emotions than suppression and suppression use is associated depression symptoms (Ehring et al., 2010). When we grouped the strategies into the two factors–cognitive and action, we saw that age predicted an increased use of cognitive strategies and decreased use of action strategies. With age came a shift away from using strategies that are action focused (i.e., substance use and suppression) towards strategies that required more cognitive effort (i.e., reappraisal and distraction).

Since our sample is cross sectional, we cannot conclude whether aging is a consequence or precursor to the differences we observe. Although our sample includes are large range in ages, future longitudinal studies would be necessary in order to determine whether our results are cohort effects or true effects of aging. We are also limited by an online sample of participants who have a baseline level of technological abilities. Without capturing the population of participants who may lack the level of computer competence that our subjects needed in order to participate, we are limited in the generalization of our findings. Nevertheless, we considered many different covariates (e.g., political ideology, vulnerability to the virus, education, socioeconomic status) and our age effects were unchanged, which suggests demographics are unlikely to drive our results.

Aging is associated with an increase in the use of strategies that are more cognitive in nature (e.g., reappraisal, talking to someone else, and distraction) and a decrease in the use of expressive suppression and situation modification. These findings serve as further contradiction of the SAVI model, which suggests aging is associated with an impairment in cognitive faculties and an increase in the use of suppression in situations of distress (Charles, 2010). The increased use of reappraisal, in particular, demonstrates a shift towards the use of a more advantageous regulation of emotions in response for psychological health (Goldin et al., 2014; McRae et al., 2012). Reappraisal is very applicable in situations that cannot be controlled (Haines et al., 2016; Troy et al., 2013). Other than wearing a mask and taking necessary social distancing measures, there was very little people could do in those 8-months to respond to the COVID-19 pandemic, making it an uncontrollable situation.

Previous work on the use of regulation in daily life has not taken into account the variability in the situations people where report regulating (Eldesouky & English, 2018; Livingstone & Isaacowitz, 2019). Here, we provide an ecologically valid emotion eliciting event that is unchanged between participants. In our data, it also appears that the benefits of relying on reappraisal and other cognitive strategies on positive affect towards the pandemic diminish with increase age. This finding suggests some sort of adaptive process that occurs through the life span whereby people learn that using cognitive strategies in response to a negative event effectively increases their positive emotions and continue to institute those strategies in the future.

In conclusion, the present study provides clear support that age served as a significant moderator for many components of people's emotional reactivity to the pandemic. Both before and during the pandemic, age was associated with higher levels of positive affect and lower

levels of negative affect. Age also predicted differences in the way people appraised the pandemic and regulated their responses to it, which as we demonstrate, are not independent from one another. These findings have important implications for theoretical models of emotional experience over the adult life-span.

Chapter 3: Age-Related Differences in the Goal-Directed Regulation of Negativity

ABSTRACT

Functional neuroimaging studies that examined age-related differences in the regulation of negative emotion are limited and the results are mixed. It is unknown whether *(i)* younger adults are more effective at regulating negative affect when given explicit instructions to do so and *(ii)* how the nature of the goal impacts people of different ages task performance. Aging has consistently been associated with a shift in attention and memory towards positive stimuli, leaving open the question of how age impacts the neural mechanisms that underly regulation. In this study, we take a novel approach to studying emotion regulation over the adult life-span by training a group of 40 younger adults (ages 18-35) and 40 older adults (ages 55-82) to regulate negative stimuli by minimizing and enhancing negative emotions. We measured our participants' behavioral responses with self-reported measures of negative and positive emotion ratings. We also looked for age-related differences in similarities in task-related levels of neural activity. We found that younger adults report greater reduction in negative affect than older adults when instructed to minimize and greater increases when instructed to enhance. In fact, older adults reported no change between conditions when they naturally viewed negative images and when they were told enhance their emotional response. Younger and older adults displayed similar patterns of brain activity while minimizing negative affect, but there were some key differences in activation for the enhance condition. Younger adults displayed significantly greater activity in the ventral medial PFC while older adults showed a significantly more bilateral pattern of dorsal lateral PFC activity. These results are consistent with theories of aging and emotional status, and extend our knowledge to the instructed use of a contra-hedonic goal (i.e., enhancing negativity).

INTRODUCTION

In our daily lives, we constantly encounter situations that make us feel differently from our desired emotional states. While the outcomes are often out of our control, we have the power to reframe our appraisals of the situations to get back to our desired emotional states. Imagine you are at the airport waiting to fly home from a conference and the gate attendant informs everyone through the loudspeaker that the flight is canceled. You will have to go to the customer service counter to rebook your ticket.

As frustrating as this situation may make you feel, you might quickly realize that being calm and friendly with the customer service agent is your best bet in terms of getting rebooked on the next flight out. To reduce your negativity towards the airline, you tell yourself that the plane has some kind of technical issue that may impair the safety of those onboard and you would much rather wait to fly on a plane that you know will be safe. Here, your desired emotional state was to feel *less anger* and you reappraised the situation to that end.

Your desired emotional state, however, is not always a good one. What if you watched the person ahead of you kindly request to be rebooked, and saw that they were put on a flight tomorrow? You know there have to be spots on the other flight tonight, but the agent might not sense your urgency unless you appear angry. In order to ensure you are rebooked quickly, you set the goal to feel outraged and tell yourself that the multi-billion-dollar industry has no excuse for delays. Again, you reappraised the situation, but this time it was to make yourself feel *more anger*.

There are several reasons people of all ages might reappraise situations to both increase and decrease their emotional status, however, the majority of research on emotion regulation over the adult life-span has focused on pro-hedonic reappraising (i.e., minimizing negative

feelings and maximizing positive feelings) (Helion et al., 2019). The distinction between pro-hedonic and contra-hedonic regulation goals is important when considering life-span changes in emotion processing, since aging has been linked with increases in positive and decreases in negative affect in daily life (Carstensen et al., 2000). This age-related trend in emotional status has perplexed psychologists for decades, because older adulthood is also marked by steady declines in cognitive abilities and general health, which we would expect to have a negative impact on our ability to effectively execute many emotion regulation strategies (Mather, 2012; Park & Reuter-Lorenz, 2009a).

One proposed explanation for this paradox of emotional status in aging is that there are age-related changes in emotion regulation (T. Sims et al., 2015; Urry & Gross, 2010). As a product of increased life experience, the older you are the better you may be at applying and implementing emotion regulation strategies to achieve your specific emotional goals. While research on strategy use has been pretty limited, one study that surveyed people in daily life found that older adults reported using emotion regulation strategies to the same extent as younger adults (Eldesouky & English, 2018). Differences in emotional status may therefore be explained by fr age-related differences in *the ability* to implement these strategies, rather than *the frequency* with which they are used.

Older adults display a goal-oriented selection bias towards situations that add emotional value, which has led many to suggest that the age differences in emotional status may stem from earlier (i.e.i, antecedent) stages in the emotion regulation process (Carstensen, 1995; Lang & Carstensen, 2002). Older adults may therefore be better at implementing situation selection and situation modification than cognitive change or response modulation. In naturalistic studies, however, older adults report using reappraisal to an equal degree or even more so than younger

adults (see: Chapter 2; John & Gross, 2004). Furthermore, neuroimaging studies show that performing cognitive reappraisal requires the same brain circuitry as working memory and executive control, more broadly (Kanske et al., 2011), which show age-related declines in functioning abilities (Salthouse, 1994). Given these conflicting results, we sought to answer the open question–are there are age-related differences in goal-directed cognitive reappraisal?

In the limited research that has been done on age-related behavioral differences in reappraisal, results are inconsistent. When given explicit instructions to "find positivity in a negative situations" and "enhance negativity", older adults are more effective at moving negative affect in the goal-oriented direction (Opitz, 2013; Shiota & Levenson, 2009). When instructed to minimize negative emotions by using either distancing or minimizing strategies; however, younger adults are the ones who demonstrate the advantage (Shiota & Levenson, 2009; Winecoff et al., 2011). Furthermore, while task-related neural activation has been shown to be relatively stable between age groups, for older adults, underlying cognitive abilities predict the extent of amygdala deactivation (Winecoff et al., 2011). Across age groups, cognitive ability also tracks with regulatory success, which would imply that implementing cognitive reappraisal relies on cognitive functions that deteriorate with age.

At the biological level, the brain regions responsible for emotion regulation experience varying degrees of structural depletion in aging (Mather, 2016). In older adults, typically, the amygdala and ventromedial prefrontal cortex (vmPFC) are relatively well-preserved, while the dorsolateral prefrontal cortex (dlPFC) and hippocampal regions experience the most atrophy (Fjell et al., 2009). Depletion of the latter brain regions is consistent with age-related decline in executive functioning generally. Preservation of the amygdala and ventromedial prefrontal cortex; however, suggest that affective processing may in fact be conserved through old age.

The present study

Since the results from research on cognitive reappraisal in aging are mixed and inconclusive, in the present study, we took a novel approach to studying reappraisal. Here, we took into account the fact that older adults have the chronic goal to increase positive and decrease negative emotions when considering which reappraisal strategies to focus on (Reed & Carstensen, 2012).

Building off well-established reappraisal paradigms (see: Ochsner et al., 2002), we devised a task where participants practice specific regulation strategies in response to negatives images, and collected neuroimaging data with an fMRI scanner. Participants were told to make negative images *(i)* more negative and *(ii)* less negative. This allowed us to capture a wider range of regulatory strategies that would better map onto the behaviors people engage in in daily life.

In line with the positivity effect, we expected to see a pattern, such that, within age-group, older adults are better at regulating when the regulatory goal is pro-hedonic (i.e. diminishing negative), and younger adults would be better when the goal is contra hedonic (i.e. enhancing negative). We also predicted that older adults would report baseline higher levels of positive and lower levels of negative affect over all trials when they were instructed to look naturally at negative images.

Additionally, we anticipated contrasts for the natural viewing and the reappraisal trials would track with behavioral findings, such that greater regulation success would be accompanied by greater prefrontal modulation of subcortical regions. More specifically, we expected that dmPFC activity would track with the goal to enhance emotional response and vlPFC would track with decrease goals. We also expected to see greater activation overall in older adults compared to younger adults, consistent with prior research on compensatory activation.

METHODS

Participants

Our original sample included 40 younger adults (ages 18-35) and 40 older adults (ages 55-82) who were recruited based on previous involvement with research at Columbia or from Facebook advertisements targeting New York City area residents. All participants were screened for contraindications for MRI, dementia and psychological disorders. The Columbia University Institutional Review Board approved all procedures. We collected all of the data at the Zuckerman Mind Brain Behavior Institute in New York, NY.

Four younger and three older adults were removed from the analysis for poor data quality (i.e. excessive motion artifacts; <20 motion outliers within each scan run as determined by a motion detection correction) or a failure to complete the protocol successfully. The final sample included 36 younger adults (*18-35, Mage = 26 years, SD= 6 years) and 37 older adults (55-82, Mage=67 years, SD=6 years*).

Procedures

Participants first completed 30 minutes of training to make sure they understood task instructions. During the training, they were given ample time to ask the experimenter clarifying instructions and practice doing the task. During the task, they viewed a set of 60 digital pictures from the OASIS stimulus set (Esteban et al., 2019). Of the 60 images, 45 were judged to be negative and 15 were neutral. Following the task, participants completed a series of demographic survey questions including health-related questionnaires, trait regulation behavior, and the future time perspective questionnaire (Lang & Carstensen, 2002).

Stimulus presentation:

Stimuli and instructions were displayed using PsychoPy2 and were displayed with a rear projection system (Peirce, 2007).

Behavioral paradigm:

All participants respond two 3 different cues, view negative and neutral images, and rate their positive and negative affect after each trial. When the "Look" cue precedes an image, they are told to respond naturally to the image. When the "Enhance" cue preceded the image, the participants are told to reinterpret the image to make it *more negative*. In the training, they were given the example of viewing an image of violent rioting and imagining that this rioting lead to a civil war and many innocent deaths. When the "Minimize" cue precedes a negative image, participants were told to reinterpret the image to make it *less negative*. They were given the example of imagining the same violent riot is actually a scene from a fictional movie. Following each image, participants are asked to provide a negative and a positive rating in a counterbalanced order using a 1-5 scale.

Figure 0.1: Trial structure for the fMRI task. On each trial, a cue proceeding the stimulus instructed participants which strategy to use. They were either told to Enhance, Minimize or Look naturally at the following image. Images were neutral or negatively rated. Participants viewed the stimulus and then provided negative and positive ratings. Between the stimulus and the ratings was a jittered fixation period of approximately 2.5 seconds and between trials there was a jittered fixation of approximately 3.5 seconds.

Stimuli counterbalancing:

The cue and stimulus assignments followed a Latin Square rotation between participants with 8 different potential groupings. The order positive and negative affect ratings was counterbalanced between trials.

fMRI image acquisition

Imaging data were collected with a 3T Siemens Prisma MRI scanner with a 64-channel head/neck coil. Structural volumes were acquired using a high-resolution T1-weighted sagittal 3D MPRAGE sequence yielding 1-mm^3 isotropic voxels. Functional volumes were acquired using a T2*-sensitive multiband echo-planar imaging sequence with the following parameters: repetition time = 2000 ms, echo time = 30 ms, flip angle = 77°, field of view = 204 mm. Each volume consisted of 66 interleaved 2-mm slices with a multiband factor of 3, acquired near parallel to the anterior commissure-posterior commissure axis. Three functional runs of 196 volumes each were collected from each participant.

Analysis

Behavioral analyses were conducted in the R statistical software language. All runs associated with the task were grouped and analyzed together. For behavioral data analysis, we ran multi-level interaction models with the binary age term interacted with condition type to predict affective rating. We also included random intercepts for each person to account for within-person variances since we had multiple observations of condition type for each person (Bates et al., 2014). Positive and negative affect ratings were analyzed in separate models.

All MRI data were transferred from the Flywheel to a local server for analysis. Raw imaging files were preprocessed using fMRIPrep version: 1.5.1rc1 (Esteban et al., 2019).

Subsequent run, subject and group level analyses were performed in FSL 6. We used FLAME (FMRIB's Local Analysis of Mixed Effects) to compute group-level contrasts, because if its low family-wise error rate (Eklund et al., 2016). We used a threshold of $p < 0.005$.

We conducted small volume corrected analyses using ROIs from the Harvard-Oxford Atlas in the bilateral amygdala (Desikan et al., 2006). Results for ROI analyses that did not survive thresholding at $p < 0.005$ were not reported in the results below.

RESULTS

Older adults in our sample had higher vocabulary performance than younger adults and younger adults performed better than older adults on the digit symbol test for processing speed (see supplementary material). The two age groups did not differ on our measure of socioeconomic status.

Reactivity and Regulation have Distinct Effects on Affective Experiences

Negative Reactivity

First, we asked whether responses to negatively valanced images were associated with different levels of positive and negative affect. We observed a main effect of age, such that older adults reported higher ratings on negative affect ($b_{\text{young-old}}$= -0.29, 95% CI, -0.41 to -0.17, p<0.001) and higher ratings on positive affect ($b_{\text{young-old}}$= -0.29, 95% CI, -0.42 to -0.016, p=<0.001). As expected, there was a main effect of condition on negative affect ($b_{\text{LNeg-LNeut}}$ =0.77, 95% CI, 0.72 to 0.82, p<0.001) and positive affect ($b_{\text{LNeg-LNeut}}$ = -0.47, 95% CI, -0.52 to -0.42, p<0.001). We also observed interactions, such that the increase in negative affect was greater for younger adults ($b_{\text{groupXcondition}}$= -0.06, 95% CI, -0.11 to -0.01, p=0.016) and the decrease in positive affect was greater for older adults ($b_{\text{groupXcondition}}$= -0.05, 95% CI, -0.09 to 0, p=0.043).

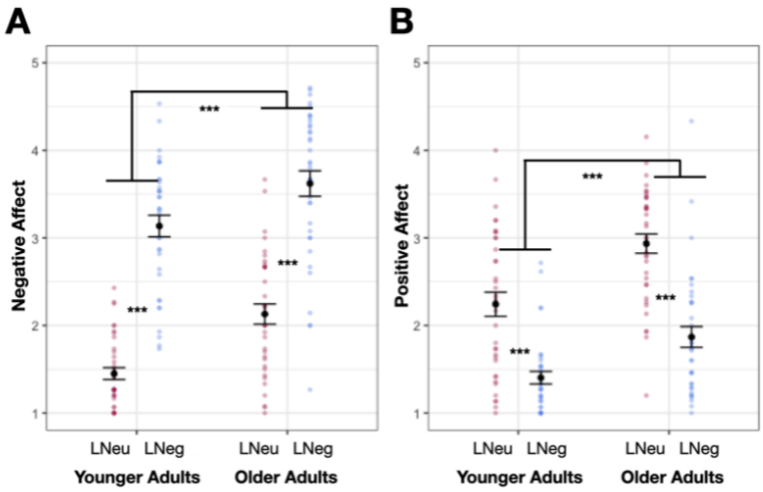

Figure 0.2: Effects of "look neutral" and "look negative" experimental conditions on self-reported negative (A) and positive (B) affect. There was a main effect of age such that older adults reported greater negative affect and less positive affect. Between group bars indicate a mean effect of age. There was a main effect of condition, such that negative images were rated as less negative and more positive than neutral images. There were also interactions, such that the change in negative affect was greater for the younger adults and the change in positive affect was greater for older adult. * *p<0.05* ** *p<0.01* *** *p<0.001.* LNeu, look neutral, LNeg, look negative.

Minimizing Negative

We then asked what effect regulating negative images had on the affective experience of younger and older adults. We observed a main effect of age on negative affect, such that older adults reported greater negativity ($b_{\text{young-old}}$= -0.31, 95% CI, -0.47 to -0.15, p<0.001) and greater positivity ($b_{\text{young-old}}$= -0.24, 95% CI, -0.38 to -0.10, p<0.001) We found that all participants reported less negative affect when minimizing compared to looking naturally ($b_{\text{MNeg-LNeg}}$ = 0.31, 95% CI, -0.26 to 0.36, p<0.001) and there was an interaction, such that the difference in negativity is greater for younger adults ($b_{\text{groupXcondition}}$=0.08, 95% CI, 0.03 to 0.13, p<0.005).

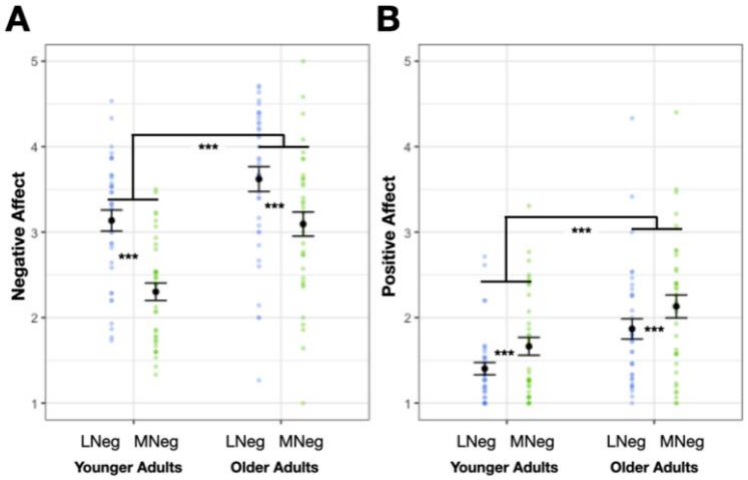

Figure 0.3: Effects of "look negative" and "minimize negative" experimental conditions on self-reported negative (A) and positive (B) affect. There was a main effect of age such that older adults reported greater negative affect and less positive affect. Between group bars indicate a mean effect of age. There was a main effect of condition, such that images that were minimized were rated as less negative and more positive than the images that were viewed naturally. There was also an interaction, such that the change in negative affect was greater for the younger adults. * *p<0.05* ** *p<0.01* *** *p<0.001*. LNeg, look negative, MNeg, minimize negative.

E*nhancing Negative*

Lastly, we looked at the enhancing negativity condition and found that, while all participants enhanced negative affect ($b_{ENeg-\ LNeg}$ = 0.17, 95% CI, -0.12 to -0.22, p<0.001), younger adults showed a greater increase than older adults ($b_{groupXcondition}$=-0.15, 95% CI, -0.20 to -0.10, p<0.001). There were no effects of condition on positive affect ratings, however there was a main effect of age, such that older adults rated the images as more positive ($b_{young-old}$= -0.15, 95% CI, -0.20 to -0.10, p<0.001).

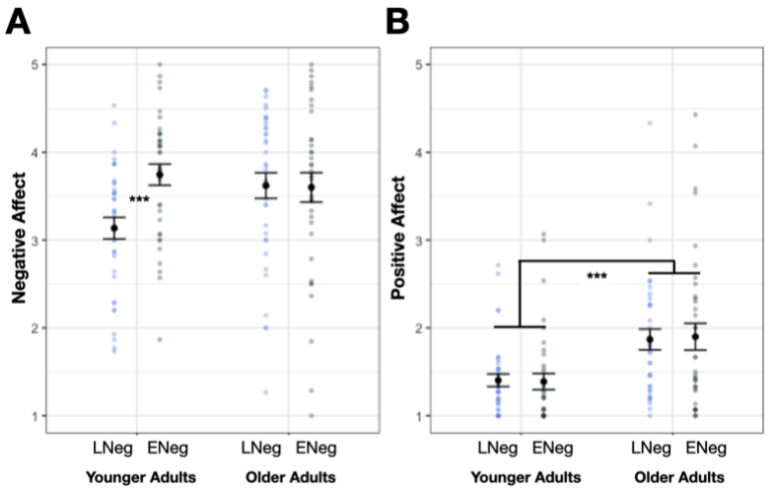

Figure 0.4: Effects of "look negative" and "enhance negative" experimental conditions on self-reported negative (A) and positive (B) affect. There was a main effect of age such that older adults reported greater positive affect. Between group bars indicate a mean effect of age. There was a main effect of condition, such that enhanced images were rated as less negative than neutral images. There was an interaction, such that the change in negative affect was greater for the younger adults than for the older adults. * *p<0.05* ** *p<0.01* *** *p<0.001*. LNeg, look negative, ENeg, enhance negative.

Age-related differences in behavior across all conditions

In addition to the aforementioned results, we also tested for age related differences in reported ratings of positive and negative emotions over all trials. Collapsing across conditions, older adults rated all negative images as both more negative ($b_{young\text{-}old}$= -0.19, 95% CI, -0.34 to -0.03, p=0.021) and more positive ($b_{young\text{-}old}$= -0.24, 95% CI, -0.38 to -0.11, p=0.001) than younger adults.

Differences and similarities in reactivity and regulation in the brain

Next, we examined fMRI responses for the four different conditions focusing on the time period while participants viewed the images. To identify the regions of the brain associated with reactivity, minimizing reappraisal and enhancing reappraisal, we computed contrasts of natural response to valanced image (negative or positive) > natural response to neutral, minimizing valanced image > natural response to valanced image, and enhancing valanced image > natural response to valanced image (within the positive and negative image blocks separately). We computed contrasts with subjects in a model, with younger > older adults and older > younger adults, and the conjunction of younger and older adults. These analyses were conducted within the whole brain and also within the a priori ROIs—the bilateral amygdala.

Negative Reactivity

When looking naturally at negative images compared with neutral images for all participants, we see heightened activity in the bilateral IFG, the caudate and the occipital lobe. Younger adults showed greater activity in the right IFG than older adults and there were no observed brain regions from the conjunction of younger and older adults. Our ROI analyses on all subjects revealed heightened activity in the bilateral amygdala, and when we ran the conjunction of both age groups, we observed activity in the right amygdala and not the left.

Minimizing Negative

When all subjects are included in contrast of minimizing with naturally look at negative images, we see activity in the bilateral vlPFC, bilaterial dlPFC and the dmPFC. The conjunction of older and younger adults revealed activation in the left vlPFC, left dlPFC and the dmPFC.

Enhancing Negative

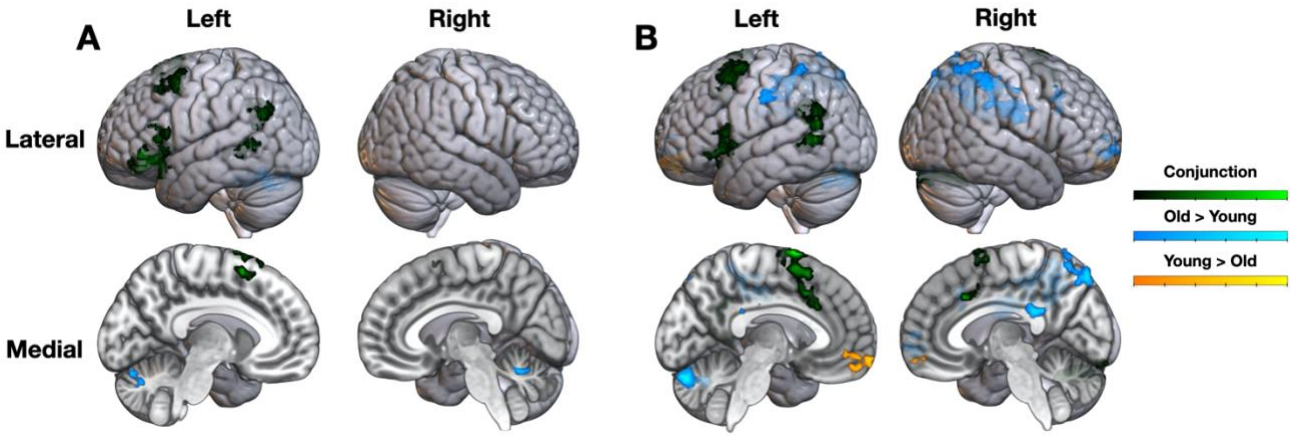

Figure 0.5: A) Whole brain analysis of Minimize Negative > Look Negative contrast. B) Whole brain analysis of Enhance Negative > Look Negative contrast. Activity for conjunction of older and younger adults (green), contrast of old > young (blue) and the contrast of young > old (yellow). All contrasts were held to a threshold of $p<0.005$ and whole brain FWE corrected at $p<0.05$.

When all subjects are included in the model contrasting enhancing negative with looking naturally at negative images, we see activity in the bilateral vlPFC, dmPFC, left dlPFC and the bilateral insula. The vmPFC was more active for younger adults than older adults and the right premotor and orbitofrontal regions were more active for older adults compared with younger adults. The conjunction of both age groups revealed activity in the left vlPFC, dmPFC, left dlPFC and bilateral insula.

DISCUSSION

As predicted, clear patterns emerged in behavioral performance across all conditions in the experiments. First, we found age predicted greater ratings of both negative and positive affect when viewing negative images, independent of the cue that preceded the stimuli. Older adults are overall more reactive to negative images than younger adults. While it is consistent with past research that older adults would find negative images to be more positive than younger adults, we were surprised to see that older adults also reported feeling greater negativity. With regard to the reactivity condition, where we compared the look negative trials to the look neutral trials, we saw that age predicted a greater decrease in positive affect and a smaller increase in negative affect. In other words, reactivity for negative affect was greater for younger adults, but the opposite was true for positive affect.

Furthermore, when given explicit regulation instructions to make negative images less negative, younger adults report reducing less negative affect than older adults. We saw a similar pattern emerge when participants were given the instruction to increase feelings of negativity—younger adults reported increases in negative affect while older adults reported no change in their negative affect. In both of the emotion regulation conditions, younger adults were more effective than older adults with moving their negative affect in the goal-oriented direction. Other than main effects of age, we did not observe any age-related differences in positive affect ratings while regulating.

The bilateral amygdala was reactive in the negative reactivity condition, but did not survive correction for either of the regulation contrasts. While participants were successfully able to modify their feelings of negative affect in the task, our study failed to pick up any amygdala modulation. The conjunction data from the two regulation tasks were otherwise consistent with

previous regulation studies with all subjects demonstrating activity in the dmPFC and the left dmPFC (Buhle et al., 2014). When instructed to regulate by minimizing, there were no age differences in neural activity beyond the cerebellum, which provides further evidence that older and younger adults rely on comparable brain regions for minimizing negativity. Age-related differences were, however, present when we looked at the enhance condition. For this condition, the conjunction revealed overlapping activity in the dmPFC, left dlPFC, and the bilateral insula, but there were many other areas that were more active for younger than older adults and vis a versa. Younger adults recruited the vmPFC to a significantly greater extent than older adults.

The novel approach of looking at goal-oriented regulation in the context of an older adult sample provided us with greater insights into how the aging brain regulates negative affect. Older adults were overall more reactive to negative images, rating them as both more negative and more positive and when instructed to regulate, they reduced and enhanced less negative affect than younger adults. Given the explicit instruction to modify their feelings of negativity, we take this as evidence that younger adults are more effective at accomplishing the task-relevant goals (i.e., up and down-regulating negative affect). Older adults have the implicit goal to attend to positive information and therefore struggle when the goal of the task differ from that goal. It also may be the case, that younger adults have the opposite goal—a bias towards negative information and negative emotions (Carstensen & DeLiema, 2018). A growing body of research suggests that age is associated with a shift away from maladaptive strategies towards ones that are pro-hedonic (Allard & Kensinger, 2014; Brummer et al., 2014; Opitz et al., 2012)

In the context of our neuroimaging results, we were unable to identify significant age-related differences that underly an age-associated difficulty with minimizing negativity. These results combined with our behavioral results suggest that while older and younger adults rely on

similar neural mechanisms to down-regulate negative affect, there may be differences in their efficacy in accomplishing the goal. Cognitive functioning, which was not a component of our analysis, may be an explanation for the age-related differences in behavior, but not in brain activity (Winecoff et al., 2011). In other words, cognitive functioning may directly impact older adults' efficacy at regulation in ways that existing fMRI experiments fail to measure. Future experiments should incorporate a variety of measures that test for individual differences in cognitive abilities in order to sort out its relationship to emotion regulation success.

Enhancing negativity is a regulatory goal that has not been well-studied, especially in the context of aging. Our research supports past findings that there distinct neural systems involved in supporting up-regulation of negative affect (Ochsner et al., 2004; Sokołowski et al., 2021). We also saw behavioral results with this particular regulatory goal to be consistent with studies of emotions in daily life. Older adults failed to up-regulate negative affect, a regulatory goal that is very inconsistent with their implicit goals. It not only requires enhanced attention to negative stimuli, but it also is maladaptive, akin to rumination, which is understood to be harmful for overall well-being (Nolen-Hoeksema, 2000).

Interestingly, we observed greater activity for younger than older adults in the vmPFC when enhancing negative. We had no hypotheses about the vmPFC and therefore our interpretation of this finding is purely speculative. It is possible that younger adults find enhancing negative to be more rewarding than younger adults. An experience sampling study with a life-span sample found that people in the youngest age group were far more likely to report having contra-hedonic goals than any other group (Riediger et al., 2009). If younger adults have the goal to achieve a contra-hedonic emotional state, than it would follow that they would find implementing that strategy tracked with heightened activity in the vmPFC (Rushworth et al.,

2011). This logic would also transfer to the behavioral findings with younger adults more effectively implementing the goal to enhance negative affect.

In conclusion, there were several age-related differences in both individuals' affect ratings and their underlying neural mechanisms while implementing goal-relevant regulation of negative emotions. Younger adults performed better than older adults in our task-based measures of emotion regulation ability, while relying on overlapping brain regions. As one of few studies that has compared younger adults to older adults in a neuroimaging study of emotion regulation, we strongly recommend that future work is needed to further tease apart age-related differences both the brain and behavioral outcomes.

Chapter 4: The Neural Correlates of Regulating Positive Emotions

ABSTRACT

The vast majority of neuroimaging research on emotion regulation has focused on the regulation of negative emotions. Given the age-related bias in attention and memory towards positive information compared to negative, we hypothesized that past age-related research on emotion regulation may fail to pick up on regulation goals that are more congruent with older adults' goals. To test the hypothesis, we ran an experiment with 40 younger adults (ages 18-35) and 40 older adults (ages 55-82). The participants were all instructed to: *(i)* look naturally at positive and neutral images, and *(ii)* both increase and decrease their positive emotions in response to positive images. We predicted that, consistent with their emotional goals, older adults would perform as well or better than younger adults with up-regulating positive affect, but that since down-regulating was inconsistent with their goals, they may struggle. We anticipated that the neuroimaging results would further support what we saw in the behavioral data. Overall, older adults rated positive images as more positive than younger adults and there were no age-related differences in negative ratings of positive images. Contrary to what we predicted; younger adults enhanced positive affect to a greater extent than older adults did. As expected, younger adults were also more effective at minimizing positive affect when given the explicit goal to do so. Previous research on the age-related positive bias, has shown that the effects only exist at early stages of attention and are no longer present when older adults are given explicit instructions (Kennedy et al., 2020; Mather & Knight, 2005). Taken with our findings, we speculate that these demonstrated limitations to the age-related positivity bias also extend to explicit emotion regulation paradigms.

INTRODUCTION

While it may not be the first thing that comes to mind when we think about regulating our emotions, we have all been in a situation where we have had to either up-regulate or down-regulate something positive.

Take, for example, the case of receiving good news on the later stages of a job application process. The hiring manager wrote you an email to say they loved your ideas for the company and you should look out for an email regarding next steps. You are probably feeling pretty good about the feedback, but want to institute a healthy dose of guarded optimism; you work to minimize how positive you feel, so to protect yourself from getting your hopes crushed.

Perhaps you have been in this situation before—hearing you were a great fit for the role, but later learning they went with a different candidate. In this case, you may feel disillusioned by the process, but know that you will never get hired unless you appear excited about the role. Thus, you take the encouraging email and enhance how positive you feel about it.

The ability to effectively regulate positive situations is not just useful when navigating a competitive job market—knowing to institute different goals with regard to positive affect is associated with a host of both physical and mental health benefits. Higher positive affect in daily life is associated with lower morbidity and mortality (Pressman et al., 2019). People with higher positive affect in daily live are less likely to get the cold or the flu (Cohen et al., 2003). There is even some research to suggest that teaching people with chronic illness to better regulate positive affect through interventions, improves their overall health outcomes (Pressman et al., 2019).

Past research on regulating positive affect has largely focused on the method of *savoring*, where participants reminisce about positive autobiographical memories. When faced with an acute stressor, savoring a positive memory compared with a neutral memory dampened cortisol response and negative affect (Speer & Delgado, 2017). This type of positive memory retrieval

engages similar neural mechanisms as the regulation of negative affect through cognitive reappraisal, such as the vlPFC and the dlPFC (Buhle et al., 2014; Speer et al., 2014). Another relevant line of work involves positivizing (i.e., finding silver linings in negative contexts). When participants use past positive memories or when they come up with new reappraisals with the goal to make negative images more positive, they regions associated in reward processing, such as the ventral striatum and the vmPFC (Doré et al., 2017; Speer et al., 2014).

While types of stimuli vary between savoring-based regulation and reappraisals that aim to find positive meaning, both target an initial situation that is negative, whether it be an emotional video clip, a cold-presser task, or a normatively-rated negative image. This begs the question—**what happens when the situation itself is positive, and participants are instructed to change how positive they feel?** The few studies that compared the regulation of positive to negative stimuli found there to be little agreement over what regions distinguish between valence, independent of regulation strategy type (Mak et al., 2009; Sokołowski et al., 2021).

Furthermore, previous fMRI research has primarily focused on the regulation of positive stimuli in health adults, failing to incorporate people over the age of 25 (Helion et al., 2019). Limiting the research to this younger demographic, restricts the translational value of the research. Older adults, not only represent a growing portion of our global demographics, but also they experience significantly higher levels of positive and lower levels of negative affect in daily life (Anderson & Hussey, 2000; Carstensen et al., 2000). Age is also associated with a systematic shift in socio-emotional goals towards situations that add emotional value, which is understood to promote more effective emotion regulation behavior (Barber et al., 2016; Burr et al., 2020; Eldesouky & English, 2018). In studies that compared positive to negative stimuli, older adults consistently show a bias in attention and memory towards the positively valenced

information (Mather & Carstensen, 2005; Reed et al., 2014; Reed & Carstensen, 2012). Taken together, this suggests that older adults may have an advantage with regard to regulating positive stimuli over younger adults, despite age-related declines in executive functions that overlap with necessary regulatory networks (Mather, 2012).

In the singular study we know of that measured the neural correlates of regulating positive stimuli in older adults, Winecoff and colleagues found that older and younger adults reported comparable activity when down-regulating positive images (Winecoff et al., 2011). In the context of regulating negative stimuli, older adults have demonstrated similar, and sometimes weaker brain signatures of reappraisal as their younger counter parts (Allard & Kensinger, 2014; Opitz et al., 2014; Winecoff et al., 2011). One potential explanation for the failure to pick up on age differences in regulation is that lab-based cognitive reappraisal paradigms are cognitively demanding and the positivity bias is understood to be a less conscious process occurring in early stages of attention (Kennedy et al., 2020). Once older adults are given explicit instruction to regulate their emotional responses, they may lose sight of their non-conscious pro-hedonic goals. That said, the use of positive stimuli in experimental paradigms is very limited and we only know of its use with the explicit instruction to down-regulate, which is contra-hedonic and in opposition of age-related emotional goals (Eldesouky & English, 2019).

In behavioral research, older adults have demonstrated an enhanced efficacy with up-regulating positivity, which is a distinct construct from the down-regulation of negative affect (Burr et al., 2020; Livingstone & Srivastava, 2012). Having the goal to down-regulate positive affect, while contra-hedonic in outcome, may be useful in some circumstances, such as the job interview example. Older adults may very well be just as motivated to down-regulate positivity if it is situationally appropriate in daily life (Allard et al., 2021). Does the implicit goal to attend to

positive information over negative therefore lend itself towards more effective strategies when it comes to the regulation of positive stimuli, independent of goal direction?

The present study

In the present study, we sought to test for the similarities and differences between younger and older adults when given the explicit instruction to up-regulate and down-regulate positive stimuli. Our aim was to examine both the behavioral and brain-based correlates of emotion reactivity and regulation. We first looked for age-related differences in the reactivity to positive stimuli compared to neutral stimuli. Will older adults display a bias towards positive affect compared to younger adults, even in the context of a focused lab paradigm? Measuring both positive and negative affect ratings, we predicted that if we did observe differences, they would be in the ratings of positive affect rather than negative based on behavior in daily life. In the context of positive stimuli, we believed older and younger adults would rate them as equally negative.

Second, we aimed to study the behavioral and neural correlates of the up-regulation of positive affect. Here, we believed that because older adults have the implicit goal to up-regulate, they would be more effective at implementing the strategy. Since older adults are better at regulating desires, we believed they would demonstrate their success in up-regulating positive images by increase their reported positive affect. Further, we hypothesized that the behavior would be accompanied by similar patterns of neural activation to savoring and positivizing reappraisal, with increases in the vmPFC and striatum (Doré et al., 2017; Speer et al., 2014). There is some evidence to suggest that healthy aging is associated with progressive structural and functional alterations of the reward system, so we predicted we may see varying recruitment of these brain regions by age (Braver & West, 2008).

Lastly, we wanted to know how participants would behave when instructed to down-regulate positive affect. Would they increase negative affect or would we mostly see the change in their reports of positive affect? We were also interested to see if we would replicate the work of Winecoff and colleagues and see no age differences in regulation (Winecoff et al., 2011). Since the down-regulation of positive is a very understudied goal with regard to regulation, we did not have strong hypothesize about age differences. One study of reward sensitivity found that older adults displayed gain-related, but not loss-related activation change in the anterior insula and medial caudate, while younger adults showed it under both conditions (Samanez-Larkin et al., 2007). Perhaps, therefore, in the down-regulation of positive condition, where there is a loss in positive reward, we would see age-related decrease mesolimbic reactivity.

METHODS

Participants

40 younger adults (ages 18-35) and 40 older adults (ages 65 and older) were recruited from the population. All participants were screened for contraindications for MRI, dementia and psychological disorders. The Columbia University Institutional Review Board approved all procedures. All data collection occurred at the Zuckerman Mind Brain Behavior Institute in New York, NY.

Five younger and four older adults were removed from the analysis for poor data quality (i.e. excessive motion artifacts; <20 motion outliers within each scan run as determined by a motion detection correction) or a failure to complete the protocol successfully. The final sample included 35 younger adults (*18-35, Mage = 26 years, SD= 6 years) and 36 older adults (55-82, Mage=67 years, SD=6 years*).

Procedures

Participants first completed 30 minutes of training to make sure they understood task instructions. During the training they are given ample time to ask the experimenter clarifying instructions and practice doing the task. During the task, they viewed a set of 160 digital pictures from the OASIS stimulus set (Kurdi et al., 2017). Of the 160 images, 60 were judged to be negative and 60 positive and 40 were neutral. Following the task, participants completed a series of demographic survey questions, including the Future Time Perspective Scale, and trait level emotion regulation questionnaires (Gross & John, 2003; Lang & Carstensen, 2002).

Stimulus presentation

Stimuli were displayed using PsychoPy and were displayed with a rear projection system.

fMRI Image Acquisition

Imaging data were collected with a 3T Siemens Prisma MRI scanner with a 64-channel head/neck coil. Structural volumes were acquired using a high-resolution T1-weighted sagittal 3D MPRAGE sequence yielding 1-mm^3 isotropic voxels. Functional volumes were acquired using a T2*-sensitive multiband echo-planar imaging sequence with the following parameters: repetition time = 2000 ms, echo time = 30 ms, flip angle = 77°, field of view = 204 mm. Each volume consisted of 66 interleaved 2-mm slices with a multiband factor of 3, acquired near parallel to the anterior commissure-posterior commissure axis. Three runs of 196 volumes were collected.

Behavioral Paradigm

All participants respond to three different cues, view positive and neutral images, and rate their positive and negative affect. When the “Look” cue precedes a positive image, they are told

to respond naturally to the image. When the "Enhance" cue precedes a positive image, the participants are told to reinterpret the image to make it more positive. In the training, they are given the example of being presented with an image of a happy couple and imagining that they are celebrating an anniversary or were just reunited after several weeks apart. When the "Minimize" cue precedes a positive image, participants are told to reinterpret the image to make it less positive. They are told, for example, if you were viewing an image of a delicious chocolate sundae, you could imagine that the sundae actually tastes bland or has flavors you don't like. Positive and negative affect ratings were collected on a 1-5 scale from *1 = not at all* to *5 = very much so*. The order of the positive and negative ratings are counterbalanced between trials.

Stimuli counterbalancing

Forty-five of the 60 positive images are shown to each subject. Fifteen images are paired with each cue, and the remaining 15 images are presented for the first time in the passive viewing task (not discussed in current paper). The cue and novel stimuli assignment follow a Latin Square rotation between participants.

General Task Design

Cue varies between "Look", "Enhance," and "Minimize". The images vary between positive, negative and neutral. Ratings include both a positive and negative ratings for each trial. The order of the ratings is counterbalanced between each trial.

Figure 0.1: Trial structure for the regulation task. On each trial, a cue proceeding the stimulus instructed participants which strategy to use. They were either told to Enhance, Minimize or Look naturally at the following image. Participants viewed the stimulus which was either positive or neutral and then provided negative and positive ratings in counterbalanced order. Between the stimulus and the ratings there was a jittered fixation period of approximately 2.5 seconds. Between trials there was a jittered fixation of approximately 3.5 seconds.

Analysis

Behavioral analyses were conducted in R using the lmer package. All image image blocks were analyzed together separately, but we ran regressions with and without the order information and found our results held. For behavioral data analysis, we ran multi-level linear models with random intercepts for each person. Positive and negative affect ratings were analyzed in separate models.

All MRI data were transferred from the Flywheel to a local server for analysis. Raw imaging files were preprocessed using fMRIPrep version: 1.5.1rc1(Salthouse, 1994). Subsequent run, subject and group level analyses were performed in FSL FEAT. We conducted small volume corrected analyses using ROIs from the Harvard-Oxford Atlas in the Nucleaus Accumbens (i.e., Ventral Striatum). We also used a vmPFC ROI from a previous study of positivizing reappraisal (Doré et al., 2017). Results for ROI analyses that did not survive thresholding were not reported in the results.

RESULTS

Reactivity and Regulation Have Distinct Effects on Affective Experiences

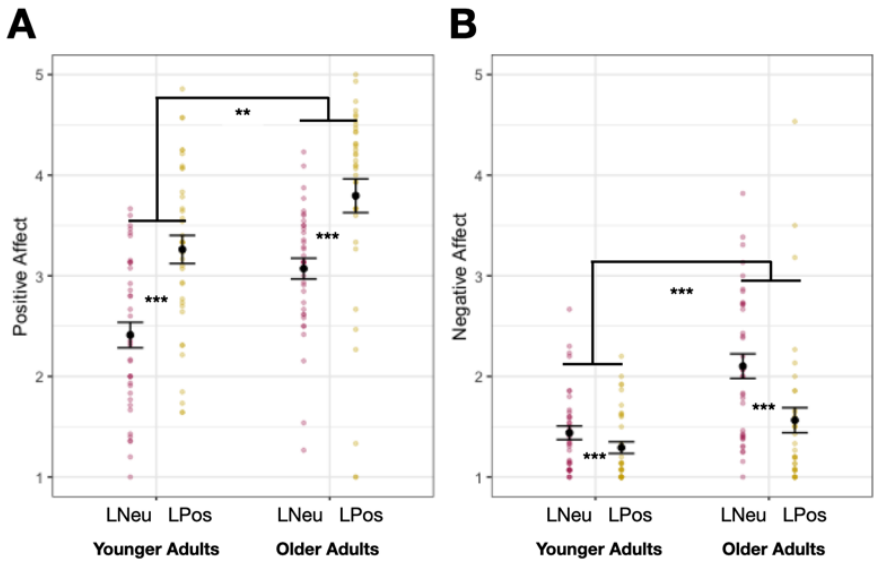

Figure 0.2: Effects of "look neutral" and "look positive" experimental conditions on self-reported positive (A) and negative (B) affect. There was a main effect of age such that older adults reported greater positive and greater negative affect. There was a main effect of condition, such that positive images were rated as more positive and less negative than neutral images. There was also an interaction, such that the change in negative affect between conditions was greater for the older adults. * *p<0.05* ** *p<0.01* *** *p<0.001*. LNeu, look neutral, LPos, look positive. Between group significant bars indicate main effects of age.

Positive Reactivity

First, looking at reactivity to positive images compared to neutral, we ran multi-level regression models for both positive affect and negative affect separately. As expected, relative to looking at neutral images, all participants reported greater positive affect ($b_{\text{LNeu-LPos}}$ = 0.38, CI 95%, 0.34-0.44, p<0.001) and lower negative affect ($b_{\text{LNeu-LPos}}$ = -0.18, CI 95%, 0.14 to 0.21, p<0.001). There was also a main effect of age on positive affect ($b_{\text{young-old}}$ = -0.29, CI 95%, -0.45 to -0.12, p=0.001) and on negative affect ($b_{\text{young-old}}$ = -0.23, CI 95%, -0.35 to --0.10, p<0.001). There was an interaction such that the decrease in negative affect was greater for older compared to younger adults ($b_{\text{conditionXage}}$ = -0.23, CI 95%, -0.35 to -0.10, p<0.001).

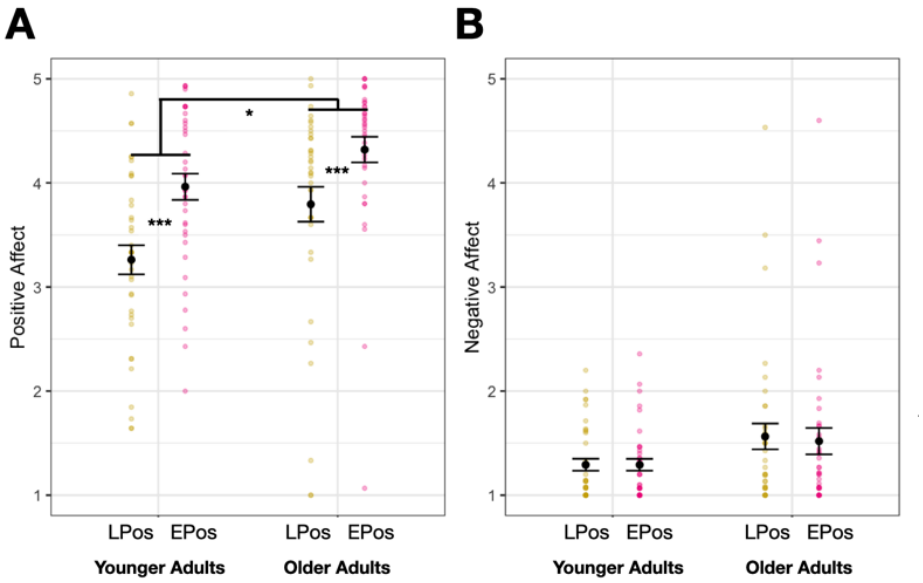

Figure 0.3: Effects of "look positive" and "enhance positive" experimental conditions on self-reported positive (A) and negative (B) affect. There was a main effect of age, such that older adults reported greater positive affect. There was a main effect of condition, such that enhanced images were rated as more positive than naturally viewed images. There was also an interaction, such that the change in positive affect between conditions was greater for younger adults. ** $p<0.05$ ** $p<0.01$ *** $p<0.001$.* LPos, look positive, EPos, enhance positive. Between group significant bars indicate main effects of age.

Enhancing Positive

Next, we looked at enhancing positivity and found both older and younger adults reported greater positive affect when instructed to enhance ($b_{\text{EPos-LPos}}$ = 0.29, CI 95%, 0.25 to -0.34, p<0.001), however the increase is greater for younger adults than it is for older adults ($b_{\text{conditionXage}}$ = 0.05, CI 95%, 0.01 to 0.10, p=0.02). There was also a main effect of age with older adults also reporting greater positive affect ($b_{\text{young-old}}$ = -0.21, CI 95%, -0.39 to -0.02, p=0.026).

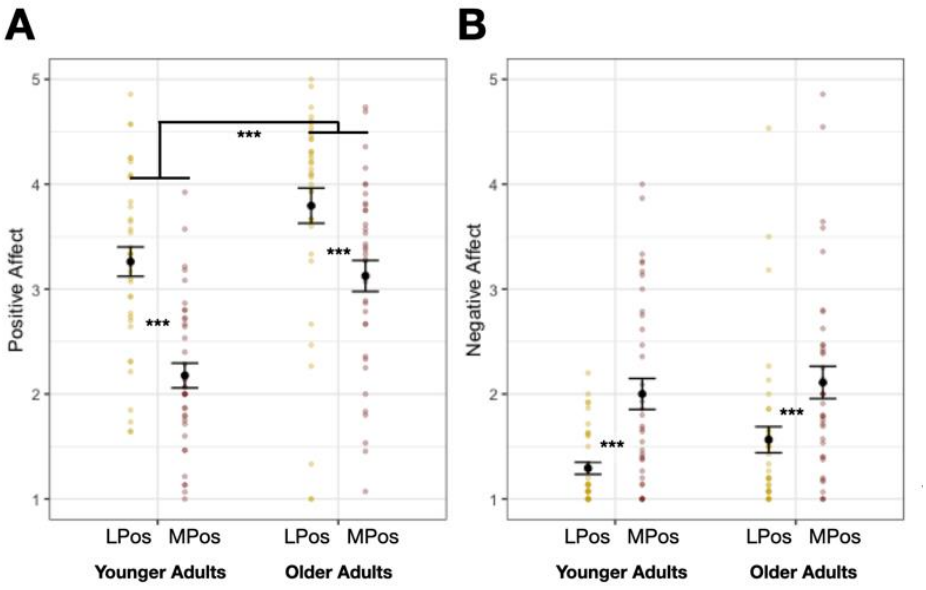

Figure 0.4: Effects of "look positive" and "minimize positive" experimental conditions on self-reported positive (A) and negative (B) affect. There was a main effect of age, such that older adults reported greater positive affect. There was a main effect of condition, such that minimized images were rated as less positive and more negative than naturally viewed images. There was also an interaction, such that the change in positive affect between conditions was greater for younger adults. * *p<0.05* ** *p<0.01* *** *p<0.001.* LPos, look positive, MPos, minimize positive. Between group significant bars indicate main effects of age.

Minimizing Positive

When instructed to minimize positive, we observed a main effect of condition on both positive affect ($b_{\text{MPos-LPos}}$ = -0.43, CI 95%, -0.47 to -0.38, p<0.001) and negative affect ($b_{\text{MPos-LPos}}$ = 0.31, CI 95%, 0.27 to 0.35, p<0.001). There was a main effect of age on positive affect, with older adults reporting greater positive affect ($b_{\text{youg-old}}$ = 0.37, CI 95%, 0.19 to 0.55, p<0.001). We also observed an interaction such that younger adults reported a greater decrease in positive affect than older adults ($b_{\text{conditionXage}}$ = -0.11, CI 95%,-0.16 to -0.07, p<0.001).

Age Differences in Affective Experience

In addition to the aforementioned results, we also tested for age related differences in reported ratings of positive and negative emotions over all trials. Collapsing across conditions, older adults rated all of the positive images as more positive ($b_{\text{youg-old}}$ = -0.3, CI 95%, -0.46 to -

0.13, p<0.001), but the age groups did not differ significantly in their ratings of negative affect ($b_{youg\text{-}old}$ = -0.1, CI 95%, -0.24 to 0.03, p=0.13).

Differences and Similarities in Reactivity and Regulation in the Brain

Next, we looked at fMRI responses for the four different conditions focusing on the time period while participants viewed the images. To identify the regions of the brain associated with reactivity, minimizing reappraisal and enhancing reappraisal, we computed contrasts of natural response to valanced image (negative or positive) > natural response to neutral, minimizing valanced image > natural response to valanced image, and enhancing valanced image > natural response to valanced image (within the positive and negative image blocks separately). We computed contrasts with subjects in a model, with younger > older adults and older > younger adults, and the conjunction of younger and older adults. These analyses were conducted within the whole brain and also within the priori ROIs—the bilateral ventral striatum, and the vmPFC .

Positive Reactivity

The contrast of looking at positive images compared to neutral images for all subjects showed heightened activity in the vmPFC, ACC and bilateral TPJ. The bilateral TPJ was the only region to show overlapping activity in the conjunction of younger and older adults for positive reactivity. In subsequent ROI analyses, the right striatum and the vmPFC were both active when we included all subjects were included in the model.

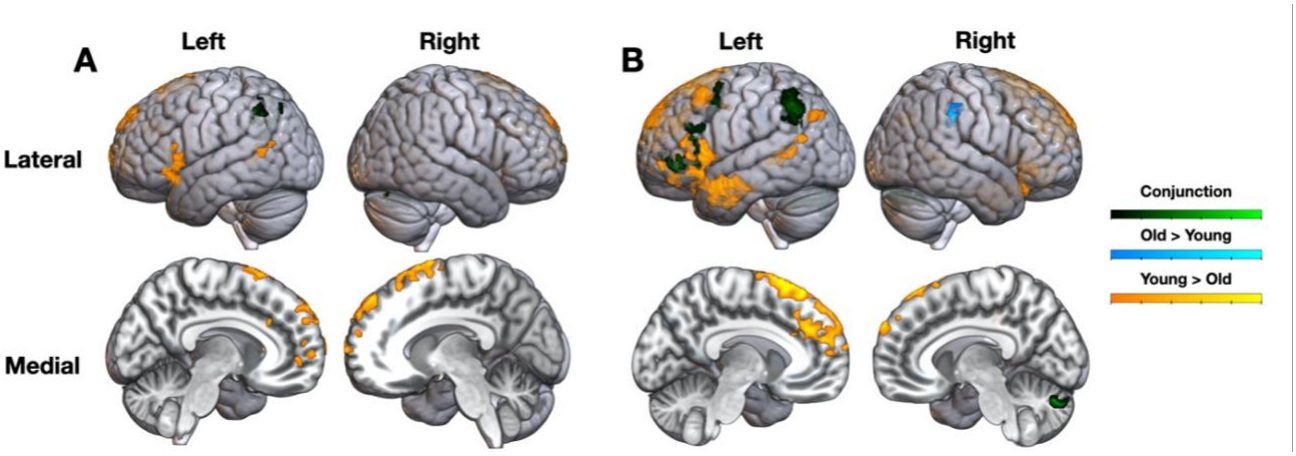

Figure 0.5: A) Whole brain analysis of Enhance Positive > Look Positive contrast. B) Whole brain analysis of Minimize Positive > Look Positive contrast. Activity for conjunction of older and younger adults (green), contrast of old > young (blue) and the contrast of young > old (yellow). We used a threshold of a $p<0.005$ and whole brain FWE corrected at $p<.05$.

Enhancing Positive

When we contrasted enhancing positive images with looking naturally at them, we saw increase activity in the caudate, the bilateral ventral striatum, and the left IFG for all participants. The vmPFC and the dmPFC were more active for younger adults than older adults and the left TPJ was the only region that came out of our conjunction analysis. The bilateral striatum was active for enhancing when all participants were included in the model and we also saw it was more active for younger than older adults. Additionally, the vmPFC ROI was more active for younger than older adults.

Minimizing Positive

When we contrasted minimizing positivity with naturally looking at positive for all subjects, we saw increased activity in the bilateral vlPFC, dmPFC, bilateral dmPFC, and bilateral IFG. Younger adults compared with older adults showed greater activity in bilateral vlPFC,

bilateral dlPFC and dmPFC. We also saw increased activation in the left dlPFC and left IFG for the conjunction of both age groups. In the ROI analysis for the minimizing contrast, we saw activity in the right ventral striatum was active for all participant.

DISCUSSION

We found that older adults rated all the positive images, regardless of condition, as more positive than younger adults. There were no age group differences in negative affect ratings. In terms of reactivity, older adults reported a greater reduction in negative affect than younger adults, but an equal change in positive affect. When instructed to up-regulate positive affect, we saw that all participants successfully increased positive affect but there was no change in their negative affect ratings. The increase in positive affect was also greater for younger adults than older adults, contrary to what we predicted. When instructed to down-regulate positive affect all participants decreased their positive affect ratings and increased negative affect, but the change in positive affect was greater for younger adults. When it came to the explicit regulation of positive affect in accordance with task instructions, younger adults outperformed older adults in both goal directions, but the older adults were overall more positive.

The vmPFC and the bilateral ventral striatum were more active for all adults when viewing positive compared to neutral images consistent with previous literature (Speer et al., 2014; Winecoff et al., 2011). Up-regulating positive affect was associated with greater activity in the vmPFC, the bilateral striatum and the dmPFC for older adults than younger adults. There was overlapping recruitment of the left dlPFC when down-regulating positive affect, and younger adults showed greater activity in the bilateral vmPFC, dlPFC and the dmPFC. Both age groups recruited the right striatum while down-regulating. Our younger adults appear to display a

similar pattern of regulation related activity as a recent experiment that used the same regulation goals with positive stimuli (Sokołowski et al., 2021).

Age appeared to have a negative effect on regulation success in both the up and down-regulation directions, suggesting that aging predicts decreasing regulation success. These impairments were also accompanied with less activation in prefrontal regions known to be important for the reappraisal of negative emotions (Buhle et al., 2014). The ventral striatum appeared to track with positive affect and its regulation for all adults, but more so for younger adults than older adults. The vmPFC ROI we identified due to its previous association with finding positive meaning was significantly more active for younger adults than older adults in the up-regulation condition (Doré et al., 2017). The neuroimaging results support what we see in the behavioral data, with younger adults showing an advantage over older adults at regulating in both of the two directions.

One potential explanation why we failed to pick up on any age-related enhancement in regulation of positive stimuli, is that nature of the task itself. Past work on the age-related positivity bias in attention and memory has emphasized the sub-conscious nature of the effect (Reed & Carstensen, 2012). Participants only display the bias towards positive information when they are not given any explicit instructions about what to attend to in the task. In fact, the effects all wash out when participants are told to follow certain instructions (Mather & Carstensen, 2005). In our paradigm, participants were given explicit instructions to up and down-regulate positive affect making it a more cognitively demanding task than tasks used to measure the positivity bias.

Furthermore, the stimuli in the task were taken from more recent internet resources than images from previous tests of age-related affective responding (Kurdi et al., 2017). It is certainly

possible that the younger adults would be more familiar with the types of images displayed because they spend more time looking at pictures on the internet, on average than older adults do (Chen & Persson, 2002). The photos themselves may be therefore less relevant and harder to make sense of to the older adults in our sample than the younger adults. If we had tracked participants longitudinally instead of comparing groups in a cross-sectional analysis, we would be able to account for these cohort effects.

The task also required participants to engage with the stimulus before developing cognitive reappraisals of the them. Where older adults display an advantage over younger adults in terms of regulation success may in the situation selection phase, occurring before they even choose to engage with the stimulus. In other words, the previously observed age-related differences in affective experiences we see in daily life may be an outcome of enhanced situation selection rather than enhanced reappraisal abilities (Sims et al., 2015; Sims & Carstensen, 2014). This assumption fits within our results, with older adults showing an overall bias towards rating images as more positive but no performance benefits with regard to reappraisal in either direction.

Chapter 5: General Discussion

This dissertation examined age-related differences in emotional experience, emotion regulation, and the instructed use of goal-directed regulation. We varied the situations participants managed, first testing people while enduring a major life event (i.e., the first 8 months of the Covid-19 pandemic), and then while viewing negative and positive stimuli. The participants in study one came from a life-span sample of over 600 adults ages 18 to 79, and the participants in studies two and three included 40 younger adults and 40 older adults.

We asked whether age predicted enhancements in emotional experience in daily life, in the absence of an emotional stimulus of the sort presented in typical lab studies, and saw that indeed it did. With increased age, people reported feeling greater positive emotions and less negative emotions in daily life. Those age effects were maintained over the course of the pandemic, in spite of its disproportionate impact on the elderly. The age-related decrease in ratings of negative affect in response to the pandemic was fully mediated by pre-pandemic baseline negative affect ratings. Furthermore, age predicted an increased use of cognitive reappraisal and a decreased use of expressive suppression. However, the use of these strategies did not ,mediate the relationship between age and people's feelings toward the pandemic.

After we learned that older adults were more likely to report using reappraisal, we asked– are they more effective at implementing goal-directed reappraisal? Regardless of image valence or goal direction (i.e., contra-hedonic or pro-hedonic) younger adults were better at executing goal-directed task instructions. With increased age, people were less effective at regulating their interpretations of situations to meet their emotional goals.

While the findings from studies two and three do not contradict what was found in study one, they do highlight potential limitations to comparing more ecologically valid paradigms to

task-based ones. In the lab, we introduce confounds that may not exist when people are observed in their daily life. For example, completing tasks in an MRI may make older adults, who more frequently visit medical facilities, feel a sense of stereotype threat (Hess et al., 2003; Steele & Aronson, 1995). Knowing we are studying them because of their age may indirectly make them perform worse than they would in their daily lives. Another potential confound is the introduction of cohort effects. Younger adults who spend more time with screens are more familiar with viewing photographic images like those we used in our reappraisal tasks. Familiarity with stimuli could prove very advantageous when it comes to reframing content. Furthermore, implementing instructed regulation may map onto a completely different process than spontaneous regulation that we observe in daily life. The age-related positivity bias, for example, only exists at early stages of attention and is no longer present when older adults are given explicit instructions (Mather & Knight, 2005).

There is also a great need to operationalize the role that life experience plays in our observed age-related changes in behavior. With more age inevitably comes more life experiences, such as the loss of loved ones or the birth of children. These instances are bound to impact the way individuals appraise situations. With better measurements of life experience, we could ask whether these affective changes are a product of greater life experience or some other aspects of the aging process.

In order to discern the underlying mechanisms of age-related differences in emotion regulation performance, future work should examine regulation success both in daily life and in a longitudinal sample. If reappraisal efficacy when studied in daily life decreased with increased age as we saw in studies two and three, we could rule out the contextual confounds described above. Moreover, if performance within the same individual over time also declined, we could

rule out the potential for cohort effects that likely impact all cross-sectional research. Nevertheless, this body of work provides novel insights to the aging process, bringing us closer to understanding how aging shapes our affective experience.

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Appendix A: Study 1

Supp Table 2.1: Survey Timeline

Baseline: 1/29/20-2/10/20

Wave 1: 3/19/20-4/3/20

Wave 2: 4/2/20-4/3/20

Wave 3: 4/16/20-4/17/20

Wave 4: 4/30/20-5/1/20

Wave 5: 5/14/20-5/15/20

Wave 6: 5/28/20-5/30/20

Wave 7: 6/25/20-6/27/20

Wave 8: 8/6/20-8/8/20

Wave 9: 9/11/20-9/14/20

Wave 10: 10/6/20-10/8/20

Supp Table 2.2: Survey Measures

Time	Measures
0	Modified PANAS, Demographics, Emotion Regulation Quotient, Future Time Perspective Scale, Center for Disease Control Depression Scale, Interpersonal Regulation Questionnaire, Major Life Events Survey, Political Spectrum, Life Satisfaction Rating
1-10	COVID mood contributor rating, COVID emotion ratings, COVID appraisal ratings, regulatory strategy tendencies, COVID beliefs and safety behaviors, Future Time Perspective, Depression Scale, Life Satisfaction Rating
6	Major Life Events Survey Repeated

Supp Table 2.3: Appraisal dimensions and items used for assessing them

Dimension	**Item**
Arousal	*Stimulated*
Attention	*Focused*
Certainty	*Certain*
Commitment	*A sense of commitment*
Control	*Like things are under control*
Fair	*Like things are fair*
Novelty	*Familiar*

Supp Table 2.4: Appraisal Dimensions

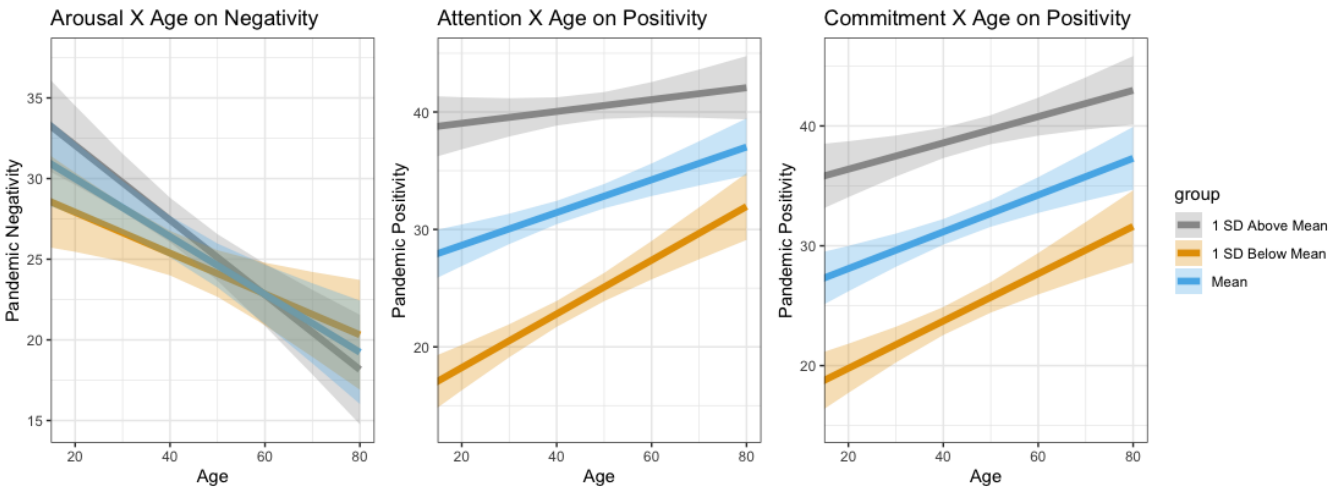
	Focused		**Commitment**		***Stimulated***		**Control**	
Predictors	*Estimates*	*CI*	*Estimates*	*CI*	*Estimates*	*CI*	*Estimates*	*CI*
(Intercept)	38.99 ***	37.02 – 40.96	35.42 ***	33.51 – 37.34	21.95 ***	20.31 – 23.59	17.62 ***	16.20 – 19.04
Age	5.08 ***	3.82 – 6.35	5.18 ***	3.96 – 6.41	0.13	-0.92 – 1.18	1.17 *	0.26 – 2.08
Time	-0.67 ***	-0.98 – -0.36	-0.49 **	-0.80 – -0.17	-0.65 ***	-0.91 – -0.39	-0.22	-0.46 – 0.02
Random Effects								
σ^2	483.58		501.66		347.81		292.49	
τ_{00}	496.42 $_{id}$		460.86 $_{id}$		341.44 $_{id}$		250.06 $_{id}$	
ICC	0.51		0.48		0.50		0.46	
N	596 $_{id}$		596 $_{id}$		596 $_{id}$		596 $_{id}$	
Observations	4035		4036		4033		4035	

	Certain		**Familiar**		**Fair**	
Predictors	*Estimates*	*CI*	*Estimates*	*CI*	*Estimates*	*CI*

(Intercept)	16.56 ***	15.14 – 17.97	16.06 ***	14.69 – 17.42	14.51 ***	13.24 – 15.77
Age	1.31 **	0.40 – 2.22	0.77	-0.11 – 1.64	0.13	-0.68 – 0.94
Time	0.23	-0.02 – 0.47	0.81 ***	0.54 – 1.07	-0.29 *	-0.52 – -0.06

Random Effects

σ^2	314.76	351.06	266.14
τ_{00}	246.29 $_{id}$	219.76 $_{id}$	192.81 $_{id}$
ICC	0.44	0.38	0.42
N	596 $_{id}$	596 $_{id}$	596 $_{id}$
Observations	4035	4033	4035



Supp Figure 2.1: Appraisal dimensions interact with age on emotions during the pandemic. Blue lines represent model-predicted behavior at the mean. Grey lines represent one standard deviation above the mean and the orange lines represent one standard deviation below the mean.

Appendix B: Study 2

Supp Table 3.1: Enhance Negative >Look Negative

		MNI Coordinates		
Label	Voxels	X	Y	Z
Young > Old				
Frontal_Med_Orb_L	187	-8.5	51.5	-8.5
Old > Young				
Angular_R	1533	39.5	-50.5	35.5
Parietal_Inf_L	435	-46.5	-46.5	61.5
Cerebelum_Crus1_L	419	-12.5	-80.5	-24.5
Precuneus_R	339	3.5	-76.5	49.5
Frontal_Sup_Orb_R	194	21.5	59.5	-6.5
Cingulum_Post_R	188	9.5	-38.5	23.5
Frontal_Inf_Tri_R	143	43.5	21.5	29.5
Young + Old				
Cerebelum_6_R	18977	35.5	-58.5	-24.5
Supp_Motor_Area_L	4730	-4.5	7.5	71.5
Insula_R	1980	47.5	7.5	1.5
SupraMarginal_R	850	51.5	-36.5	27.5
Frontal_Mid_L	433	-34.5	49.5	27.5

Cuneus_L	343	-14.5	-82.5	33.5
Frontal_Sup_R	327	25.5	45.5	19.5
Frontal_Mid_R	326	45.5	3.5	57.5
Temporal_Mid_R	259	45.5	-34.5	1.5
Young X Old				
Frontal_Sup_R	967	16	39	42
Frontal_Sup_R	841	46	70	75
Frontal_Inf_Tri_R	751	66	37	27
Frontal_Sup_R	462	23	75	38
Frontal_Sup_R	344	28	67	70

Supp Table 3.2: Minimize Negative > Look Negative

		MNI Coordinates		
Label	Voxels	X	Y	Z
Old > Young				
Cerebelum_6_L	314	-22.5	-64.5	-26.5

Cerebelum_6_R	311	35.5	-46.5	-26.5
Young + Old				
Supp_Motor_Area_L	14033	-2.5	15.5	61.5
Frontal_Inf_Orb_R	1991	45.5	31.5	-10.5
Cerebelum_6_R	1716	33.5	-66.5	-22.5
Cerebelum_Crus1_L	938	-44.5	-58.5	-28.5
Angular_R	705	59.5	-50.5	33.5
Frontal_Mid_R	462	41.5	9.5	51.5
Caudate_L	376	-12.5	13.5	7.5
Temporal_Mid_R	348	49.5	-36.5	-2.5
Caudate_R	222	11.5	17.5	5.5
Young X Old				
Frontal_Sup_R	723	21	83	37
Frontal_Sup_R	581	21	36	53
Frontal_Sup_R	481	47	71	69
Frontal_Sup_R	341	16	45	39
Frontal_Sup_R	271	24	70	65

Supp Table 3.3: Look Negative > Look Neutral

		MNI Coordinates		
Label	Voxels	X	Y	Z
Old > Young				
Cerebelum_6_L	314	-22.5	-64.5	-26.5
Cerebelum_6_R	311	35.5	-46.5	-26.5
Young + Old				
Supp_Motor_Area_L	14033	-2.5	15.5	61.5
Frontal_Inf_Orb_R	1991	45.5	31.5	-10.5
Cerebelum_6_R	1716	33.5	-66.5	-22.5
Cerebelum_Crus1_L	938	-44.5	-58.5	-28.5
Angular_R	705	59.5	-50.5	33.5
Frontal_Mid_R	462	41.5	9.5	51.5
Caudate_L	376	-12.5	13.5	7.5
Temporal_Mid_R	348	49.5	-36.5	-2.5
Caudate_R	222	11.5	17.5	5.5

Appendix C: Study 3

Supp Table 4.1: Enhance Positive > Look Positive

		MNI Coordinates		
Label	Voxels	X	Y	Z
Young > Old				
Supp_Motor_Area_R	590	1.5	19.5	65.5
Frontal_Sup_Medial_L	568	-4.5	53.5	45.5
Frontal_Sup_Medial_L	373	-0.5	59.5	3.5
Temporal_Pole_Sup_L	327	-52.5	15.5	-14.5
Temporal_Mid_L	168	-62.5	-52.5	9.5
Frontal_Sup_Medial_L	159	-2.5	41.5	27.5
Young + Old				
Frontal_Inf_Tri_L	18493	-52.5	19.5	-2.5
Insula_R	2293	45.5	11.5	-0.5
Precuneus_L	843	-6.5	-74.5	61.5
Temporal_Mid_R	230	41.5	-54.5	21.5
Temporal_Mid_R	227	47.5	-34.5	-4.5
Precentral_R	200	47.5	3.5	45.5
Cingulum_Mid_L	194	-2.5	-10.5	37.5
Precentral_L	175	-32.5	-24.5	59.5
Frontal_Sup_Medial_L	143	-10.5	65.5	17.5
Occipital_Mid_L	133	-14.5	-98.5	1.5

Young X Old

Frontal_Sup_R	463	27	35	58
Frontal_Inf_Tri_R	321	64	33	28

Supp Table 4.2: Minimize Positive > Look Positive

		MNI Coordinates		
Label	Voxels	X	Y	Z
Young > Old				
Supp_Motor_Area_L	2222	-4.5	23.5	61.5
Frontal_Inf_Tri_L	2017	-52.5	19.5	-0.5
Temporal_Mid_L	312	-60.5	-60.5	17.5
Frontal_Mid_L	240	-40.5	17.5	53.5
Temporal_Pole_Sup_R	188	39.5	25.5	-22.5
Angular_L	135	-50.5	-68.5	33.5
Old > Young				
SupraMarginal_R	157	67.5	-30.5	35.5
Young + Old				
Frontal_Inf_Orb_L	9570	-52.5	21.5	-2.5
SupraMarginal_L	3991	-62.5	-56.5	31.5
Cerebelum_Crus1_R	3784	25.5	-76.5	-26.5
Insula_R	1477	33.5	27.5	-4.5
Parietal_Inf_R	539	49.5	-46.5	41.5
Frontal_Mid_R	248	41.5	9.5	51.5
Temporal_Mid_R	183	53.5	-34.5	-0.5
Young X Old				

Frontal_Sup_R	592	18	41	61
Frontal_Inf_Tri_R	564	66	38	23
Frontal_Sup_R	370	23	89	37
Frontal_Sup_R	336	29	70	63

Supp Table 4.3: Positive Reactivity: Look Positive > Look Neutral

		MNI Coordinates		
Label	Voxels	X	Y	Z
Young + Old				
Precuneus_L	7615	-6.5	-56.5	49.5
Temporal_Mid_R	3630	51.5	-76.5	7.5
Temporal_Mid_R	1323	63.5	-2.5	-18.5
Frontal_Sup_Medial_R	1065	7.5	59.5	23.5
Temporal_Pole_Sup_L	386	-38.5	19.5	-26.5
Lingual_R	348	19.5	-48.5	-0.5
Hippocampus_R	156	19.5	-4.5	-14.5
Fusiform_L	152	-42.5	-54.5	-20.5
Cingulum_Ant_L	136	-0.5	35.5	7.5
Young X Old				
Frontal_Inf_Oper_R	1114	75	29	42
Frontal_Mid_R	890	49	37	55
Frontal_Sup_R	262	21	30	48