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The Temporal Dynamics of Emotional Responding: Implications for Well-Being and Health From the MIDUS Neuroscience Project

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Abstract and Keywords

Findings are reviewed from the Midlife in the United States (MIDUS) Neuroscience Project demonstrating the value in examining the temporal dynamics of responses to brief emotional provocation for understanding linkages among emotional response styles and factors contributing to health and well-being. Findings from functional magnetic resonance imaging (fMRI) as well as electromyographic recordings (EMG) of the facial muscles to objectively measure emotional responses demonstrate that the temporal dynamics of emotional responses to affective stimuli are associated with aging, personality, psychopathology, stress exposure, biomarkers, and well-being. These findings suggest that variation in health and well-being are differentially predicted by specific temporal parameters of the emotional response. By examining temporal dynamics in response to affective stimuli, a better understanding is gained of the brain–behavior associations underlying emotion and how emotions “get under the skin” to impact well-being and health across the life span.

Keywords: emotion, health, well-being, affective stimuli, aging, personality, psychopathology, stress exposure, biomarkers, positive emotional responses

Introduction: Bringing Affective Neuroscience to MIDUS

Besides collecting standard neuroimaging measures, the MIDUS Neuroscience Project assays variation in emotional responses by studying both psychophysiological and imaging measures in response to the presentation of unpleasant, neutral, and pleasant stimuli. These measures, when combined with the breadth of data collected across the MIDUS enterprise, allow for the investigation of how the temporal course of emotional responses covaries with trajectories in aging, health, and well-being across individuals. The laboratory-based neuroscience assessments in the context of a national longitudinal study of aging provide a unique neuroscientific dataset: In addition to the broad age range, the sample studied is far more representative of the American population than most neuroimaging studies, with a wide range of sociodemographic diversity and backgrounds. Moreover, approximately one third of the sample is African Americans, a relative rarity in cognitive and affective neuroscience research. The Neuroscience laboratory data can be linked to the multitude of measures collected in the other MIDUS projects at the MIDUS 1, MIDUS 2, and MIDUS 3 longitudinal assessments. In addition, the ongoing MIDUS 3 Neuroscience data collection is bringing back the same participants who were studied roughly 10 years ago by the Neuroscience Project at (p. 356) MIDUS 2. These longitudinal data will allow *causal* inferences on the role that individual differences in the time course of emotional responding play in aging, health, and well-being processes.

In this chapter, we describe findings demonstrating associations between the temporal dynamics of emotional responses to affective stimuli with aging, personality, psychopathology, stress exposure, biomarkers, and well-being. First, a brief introduction to the participant sample studied by the Neuroscience Project is provided. Then, the theoretical framework and hypotheses central to its design are introduced. Finally, prior to delving into the findings, a brief background in the psychophysiological and affective neuroscience methods employed for objectively measuring emotional responses is provided to build a foundation for understanding the relevance of the findings. The chapter concludes with consideration of future directions for affective neuroscience in MIDUS.

The MIDUS Neuroscience Samples

The Neuroscience Project was initiated at MIDUS 2, the second longitudinal follow-up of the original MIDUS sample from 2004 to 2009, and studied 331 respondents. More recently, the Neuroscience Project completed data collection on the MIDUS Refresher from 2012 to 2016 with a total of 138 respondents. Those MIDUS Refresher data are currently being processed, analyzed, and prepared for public sharing, while simultaneously the longitudinal follow-up of the original neuroscience baseline sample has begun (as part of MIDUS 3). Therefore, this chapter focuses on the previously published findings from the MIDUS 2 Neuroscience Project's data. The MIDUS 2 Neuroscience respondents also completed data collection for two earlier projects: the MIDUS survey assessments and the biomarker assessments. The sample included 223 participants from the core longitudinal subsample as well as 108 participants from the Milwaukee subsample of African Americans added to MIDUS as of the second wave of MIDUS data collection. All 331 respondents participated in a psychophysiology session, and 74 of those same respondents participated in a neuroimaging session.

Aims and Hypotheses of the Neuroscience Project

The primary aims of the MIDUS Neuroscience Project have been to characterize individual differences in affective style (Davidson, 1992) using psychophysiological and neuroimaging measures and to test which aspects of these central and peripheral measures are associated with the comprehensive array of health, cognitive, psychological, social, and life challenge factors assessed in the other MIDUS projects. In other words, the primary focus of the MIDUS Neuroscience Project has been to characterize the biological and physiological processes giving rise to individual differences in emotional response styles. The core assumption is that psychosocial and demographic factors get under the skin and impact core aspects of behavior related to health and well-being by modulating emotional circuits in the brain. These aims have been addressed by examining whether and how the health tolls and benefits exerted by some psychosocial factors impact individual differences in reactivity to, and recovery from, emotional provocations. It is the prevailing hypothesis of this project that the central and peripheral bodily responses to these emotional provocations are the mediating mechanisms that link emotional response styles to mental and physical health.

The central hypotheses underlying this project emerge from the perspective of affective neuroscience, which considers emotions essential to inform and guide adaptive behavior. Poorly regulated or context-inappropriate emotions may impair functioning and leave an individual vulnerable to psychopathology and stress-related disorders. The notion of affective chronometry (Davidson, 1998) complements this perspective and suggests that measuring different temporal dynamic parameters of an individual's emotional responses can reveal the mechanisms by which individual differences in health and well-being emerge. The emotional response styles believed to be most healthful for the MIDUS population, in accordance with Western cultural norms and idealized emotional goals (Miyamoto, Ma, & Petermann, 2014; Miyamoto & Ryff, 2011), are a faster recovery from negative provocation, longer sustaining of responses (or “slower recovery” or “savoring”) to positive provocation, and less attenuation (i.e., less habituation) of responses to repeated positive provocations.

Psychophysiological Measures of the Neuroscience Project: Background

Facial electromyography (EMG) features strongly in the MIDUS Neuroscience Project. This is because facial EMG has a long history of use by affective psychophysiologists to objectively infer an individual’s emotional responses. For over (p. 357) 30 years, facial muscle activity has been a gold standard measure for making inferences about a person’s emotional responses to affective stimuli and current affective state. Several facial EMG measures are valence sensitive, such that their activity differentiates responses to unpleasant, neutral, or pleasant stimuli reflecting negative, neutral, and positive emotional responses, respectively. Importantly, these valence-sensitive facial EMG measures allow for the measurement of emotion without interrupting an individual’s experience to ask him or her about the experience and are also free from many demand characteristics that can bias self-report (Bradley & Lang, 2007; Tassinary, Cacioppo, & Vanman, 2007). Critically, individual differences in emotional responding and regulation as measured by EMG are reliable over time (Lee, Shackman, Jackson, & Davidson, 2009). In the MIDUS 2 data acquisition, two different facial EMG measures were acquired during the emotional response paradigm: EMG from the orbicularis occuli muscle was recorded for derivation of the eye-blink startle reflex magnitude (EBR) in response to acoustic startle probes (or loud bursts of white noise), and continuous EMG was recorded from the corrugator supercilli muscle, which is involved in pulling the eyebrows down and together to furrow the brow and form a frown.

The magnitude of the EBR has been shown to be modulated by emotion or attention, depending on whether the startle probe appears before, during, or after an affect-provoking stimulus (for review, see Taubitz, Robinson, & Larson, 2013). Converging evidence from studies using animals and humans suggests that the magnitude of the startle reflex is influenced by the current motivational and affective state of the participant, such that eye-blinks to acoustic startle probes are potentiated by aversive/defensive motivational states and attenuated by appetitive states (Filion, Dawson, & Schell, 1998; Grillon & Baas, 2003; Lang, 1995; Lang, Bradley, & Cuthbert, 1998). In other words, the magnitude of an eye-blink in response to loud noise probes tend to be larger when the individual is feeling more negative and smaller when the individual is feeling more positive. Moreover, the neurobiological substrates of startle modulation have been relatively well established using fear-potentiated startle paradigms in animals; these paradigms have established the importance of the amygdala for the modulation of startle EBR magnitude (for review, see Koch, 1999).

Similar to EBR, corrugator muscle activity distinguishes the valence of emotional experience such that pleasant stimuli elicit less corrugator activity, and unpleasant stimuli elicit more corrugator activity than neutral stimuli. In fact, the magnitude of corrugator activity correlates linearly with participants' individual pleasantness ratings of the stimuli (Cacioppo, Petty, Losch, & Kim, 1986; Lang, Greenwald, Bradley, & Hamm, 1993; Larsen, Norris, & Cacioppo, 2003; Tan et al., 2011), with greater corrugator activity for more negative stimuli and less corrugator activity for more positive stimuli. The modulation of corrugator EMG by negative emotion shows excellent test-retest stability (which appears to be superior to that of EBR responses to acoustic startle probes; Lee et al., 2009; Manber, Allen, Burton, & Kaszniak, 2000; Tan et al., 2011). Simultaneous recording of corrugator during functional magnetic resonance imaging (fMRI) reveals significantly greater corrugator and amygdala activity to negative compared to neutral pictures (Heller, Greischar, Honor, Anderle, & Davidson, 2011). Moreover, intracerebral stimulation of the human amygdala elicits changes in corrugator EMG and corresponding changes in subjective emotional experience (Lanteaume, Khalfa, Regis, Marquis, Chauvel, & Bartolomei, 2006). Collectively, these findings illustrate the utility of unobtrusive EBR and corrugator EMG measurements of emotional responses and underscore the rationale for examining them in MIDUS as peripheral measures of individual differences in affective style. Whereas brain imaging is not an option for those MIDUS participants who suffer from claustrophobia, have had extensive dental work, or have other contraindications for magnetic resonance imaging, facial EMG measures have no such constraints on their use and yet provide objective measures of emotional responses. Moreover, existing evidence suggests that the neural bases underlying the affective modulation of these EMG metrics are brain regions, such as the amygdala, known to play important roles in the early stages of emotional processing and are impacted by top-down emotion regulatory processes.

Focus on Reactivity to, Recovery from, and Change Across Emotional Provocations

In the MIDUS 2 data, as well as other studies of affective chronometry, differentiating *reactivity* in response to an emotional stimulus from *recovery* after the stimulus offsets, as well as the *change* in responses across repeated trials of the same type, has (p. 358) been particularly relevant to explore the interactions between emotional responses, age, mood, psychosocial stress, personality, well-being, and real-world affect (Heller et al., 2009, 2013; Javaras et al., 2012; Lapate et al., 2014; Schaefer et al., 2013; Schuyler et al., 2014; van Reekum et al., 2011). *Reactivity* is defined as the processes occurring during the period immediately in response to an affectively salient stimulus, whereas *recovery* refers to processes that occur following offset of the affective stimulus. To probe individual differences in emotional reactivity and recovery in MIDUS 2, psychophysiological and neural measures are examined during the presentation of affectively valenced (positive and negative) and neutral pictures, as well as during a post-picture period. The logic of this strategy is that continued activation during the recovery period following a negative stimulus is indicative of poor regulation of the negative emotion, whereas continued activity after positive picture offset reflects better sustaining of the positive emotional response. In addition to examining *averaged* reactivity and recovery measures obtained from multiple trials of the same picture valence type, the *change* in responses across repeated trials of the same valence type is computed, providing measures of response decreases or increases across repeated provocations, which may reflect habituation-like processes. We employed the latter approach, examining the change in responses across repeated trials of the same valence, to our MIDUS brain-imaging datasets, as discussed later in this chapter.

Importantly, the hypothesized regulatory processes that influence the temporal parameters of the emotional response may be conscious and effortful or may proceed automatically and outside of conscious awareness. Of note, while tracking subjective feeling states over time has provided valuable insights in the role of temporal dynamics in psychopathology and well-being (see, e.g., a recent review by Trull, Lane, Koval, & Ebner-Priemer, 2015), these likely reflect regulatory processes that are conscious, are prone to biases in reporting, and can even influence or disrupt the very object of inquiry by altering the emotional experience being assessed (Kassam & Mendes, 2013). In contrast, psychophysiological and neural measures have the advantage of capturing the output of both conscious and unconscious regulatory processes, with high temporal resolution, but are restricted to observations made in a laboratory setting.

As yet, the relationship between self-reported dynamics and temporal processes captured by neuroscientific measures remains understudied, although recent findings suggest they are related. For example, the sustained engagement in the laboratory of brain regions responsive to reward was shown to predict the duration of predominantly young adult, college-aged participants' longer real-world positive emotional responses to reward (obtained via experience sampling; Heller et al., 2015). This finding suggests that the neural processes measured experimentally over very brief timescales of milliseconds and seconds share common pathways with, and are indicative of, affective responses unfolding over minutes and hours, giving rise to emotions and moods. Of note, the MIDUS study provides the opportunity to replicate and extend this finding in a sample that is considerably more age, ethnic, and socioeconomically diverse.

Experimental Protocol Design

In the MIDUS study, the neural and psychophysiological measures were acquired in two experimental sessions held on two consecutive days: one psychophysiology and one neuroimaging session. At the MIDUS 2 data collection, 331 respondents participated in the psychophysiology session, with a subgroup of 74 respondents participating in the neuroimaging session. In both sessions, affective picture-viewing tasks were used as emotional provocations to measure the temporal dynamics of emotion with facial EMG in the psychophysiological session and fMRI measures in the neuroimaging session. The two sessions utilized different sets of affective pictures selected from the International

Affective Picture System (IAPS; Lang, Bradley, & Cuthbert, 2008), which were carefully valence and arousal matched, such that the negative and positive valence sets did not differ on ratings of arousal, and the picture sets were matched across the two sessions with similar ratings for each valence category.

The paradigm used to assess emotional response styles in the psychophysiology lab employed 30 positive, 30 negative, and 30 neutral pictures presented in a quasi-randomized sequence. Each trial started with a fixation cross presented 1 s before each picture. A picture was then presented for 4 s, and during the initial 500 ms of picture presentation, a color border (purple or yellow) surrounded the picture. The participants' task was to identify the color border as quickly as possible with a button press. Besides providing measures of reaction time and accuracy for each image valence, this task maintains participant engagement and attention. Startle probes (50 ms, 105 dB, white noise bursts (p. 359) with rapid onset times) were presented over headphones at three time points across the trials (one probe/trial, probe time randomized across trials to maintain an average interprobe interval of ~16 s): the first probe during the picture presentation (2,900 ms following onset), the second probe at 400 ms following picture offset (4,400 ms after picture onset), and the third probe 1.9 s following picture offset (5,900 ms following picture onset). Each image valence category had a total of nine probes at each of the three time points, resulting in three unprobed trials for each valence category. The intertrial interval (ITI) was 14–18 s. Corrugator EMG was recorded continuously throughout the psychophysiology paradigm, was baseline corrected by subtracting the EMG from the 1-s fixation period, and then was averaged across time epochs of interest. Most commonly, 4-s averages were used for these epochs, including the 4-s reactivity epoch to the picture presentation, an early recovery epoch corresponding to 0–4 s after picture offset, and a late recovery epoch corresponding to 4–8 s after picture offset. For additional methodological details, please see van Reekum and colleagues (2011).

A similar emotional response task as the one used in the psychophysiological protocol was also utilized in the fMRI acquisition at MIDUS 2. Participants viewed 60 positive, 60 neutral, and 60 negative images for 4 s each over the course of five functional scan runs in a quasi-random order with a variable intertrial interval (4–16 s). On 120 of the trials, a neutral male face was presented for 500 ms at either 1 or 3 s after the offset of the affective picture. The participants' task was to categorize the valence of the picture (negative, neutral, or positive) as quickly as possible with a button press on a response pad. In the MIDUS 2 study, 74 respondents participated in the neuroimaging session.

Findings from the MIDUS Neuroscience Project

Aging and the Positivity Effect

Given the nature of the MIDUS study's focus on aging, the first examination of the MIDUS 2 psychophysiological data explored the possible interaction between emotional valence and aging, under the overarching hypotheses of the age-related positivity effect (Mather & Carstensen, 2005). The positivity effect in aging refers to the finding that older adults appear to focus their attention and memory more on positive and less on negative stimuli. This effect has been suggested as a mechanism by which emotion regulation appears to improve in aging: As individuals age into their 70s, older individuals typically report higher levels of positive and lower levels of negative affect than their younger peers (Carstensen et al., 2011; Gruenewald, Mroczek, Ryff, & Singer, 2008). However, this positivity effect has not been found universally across different paradigms: Whereas the positivity effect is present in studies assessing attention for, and memory of, positive and negative information, studies that constrain the processing of emotional stimuli with a task, such as requiring explicit judgments or evaluations of emotion-relevant information, do not systematically demonstrate age effects (Reed, Chan, & Mikels, 2014). The color border identification task and picture valence categorization tasks employed in the MIDUS paradigms to maintain attention on the task may fall under such a definition.

Indeed, the MIDUS 2 sample did not show a standard positivity effect in psychophysiological responding. The most robust age effect for eye-blink startle and facial EMG was found in the initial reactivity response to *neutral* stimuli (van Reekum et al., 2011) and not to positive or negative images. Increasing age was associated with both lower corrugator EMG and EBR reactivity to neutral stimuli, suggesting a more positive psychophysiological response to neutral stimuli with age. This more positive psychophysiological response to neutral stimuli was further supported in that older participants tended to rate the neutral stimuli more positively than younger participants. It is worth pointing out that most studies testing the age-related positivity effect compare a younger versus older age group, whereas the MIDUS sample features a continuous adult age range, allowing linear explorations of the effect of age. Also of note, the specific content of neutral images varies greatly, including images of faces, abstract art, landscape scenes, and inanimate objects. Moreover, these neutral images are consistently rated less emotionally arousing than either the negative or the positive images.

Both the psychophysiological and self-reported measures in the MIDUS 2 sample converged to indicate that responses to the arousing negative and positive stimuli do not vary as much with age as do responses to neutral stimuli. Responses to these low-arousal, affectively neutral stimuli appeared to be appraised more positively with older age across both modalities. As described, studies of the ratings and response to negative and positive stimuli do not consistently see an aging-related positivity effect when the processing of the emotional stimuli is constrained with an experimentally suggested goal (p. 360) or task (Reed et al., 2014), so the MIDUS 2 data are not an anomaly in the aging and emotional literature. Still, the aging-related effect that was observed in the MIDUS 2 data suggests that incorporating arousal level of the stimulus into studies examining the positivity effect in aging will be essential to disentangle the processes underlying potential affective changes across the life course. Moreover, the addition of measures assessing memory for the affective images, which were incorporated into the subsequent MIDUS Neuroscience Project's data acquisitions (e.g., MIDUS Refresher, MIDUS 3), will allow the comparison of age-related variation in ratings, responses, and later memory for differently valenced stimuli. This will allow for determining if an age-related positivity effect is observed for memory even if it is not observed in stimulus ratings or in psychophysiological responses to the stimuli. Finally, exactly how this finding of age-related positivity *to neutral stimuli* is associated with adaptive emotional responding in daily life and better health outcomes is an area of active exploration within MIDUS. It will be critically informative to follow up this finding in the MIDUS 3 assessment when these same participants return for a follow-up assessment to test whether exhibiting larger positivity effects is beneficial or detrimental to functioning 10 years later.

Personality and Differences in Emotional Recovery

Just as older age is associated with more optimal levels of relative positive to negative affect (Carstensen et al., 2011; Gruenewald et al., 2008), personality profiles are also associated with more optimal levels of negative and positive emotion. For example, greater conscientiousness is associated with lower levels of negative affect (Fayard, Roberts, Robins, & Watson, 2012) and lower rates of depression and anxiety (Kotov, Gamez, Schmidt, & Watson, 2010). However, a mechanistic account explaining this association between personality profiles and mental health outcomes was lacking. Therefore, under the hypothesis that conscientiousness may decrease negative affect via more effective emotion regulation (in particular, due to better self-regulatory and control capacities), the effects of self-reported conscientiousness on recovery from negative provocation was tested (Javaras et al., 2012). Indeed, those who had higher levels of self-reported conscientiousness showed quicker recovery from negative stimuli as indexed by lower corrugator EMG after the image was no longer on the screen. Interestingly, this effect was specific to the recovery period: Individual differences in conscientiousness were not related to corrugator EMG magnitude differences in the initial *reactivity* to negative, neutral, or positive emotional stimuli. The association between conscientiousness and speed of recovery from negative images remained even when controlling for factors such as gender, the time between the personality assessment and the psychophysiology assessment, as well as other personality factors, including neuroticism, extraversion, openness, and agreeableness.

Javaras and colleagues (2012) also examined whether the relationship between conscientiousness and recovery from negative images was moderated by age. When examining age effects, the relationship between conscientiousness and greater recovery from negative stimuli was observed only in younger and middle-aged (< 0 and 50–65 years old), but not older (> 65 years old) participants. This suggests that conscientiousness may play a greater role in emotion regulation in the years prior to retirement. This finding of better recovery from negative emotional provocation in people with higher levels of conscientiousness is consistent with findings of less anger and less aggressive behavior in more conscientious individuals when responding to a frustrating experience (Jensen-Campbell, Knack, Waldrip, & Campbell, 2007) and may at least partially explain why high conscientiousness is associated with lower risk of mental and physical health disorders linked to stress and negative events, such as depression (Kotov et al., 2010) and obesity (Chapman, Fiscella, Duberstein, Coletta, & Kawachi, 2009). Finally, MIDUS 3 will allow us to reexamine this finding in the same middle-aged participants when they are 10 years older. Importantly, we can then determine whether the observed lack of a conscientiousness effect in the older participants at MIDUS 2 was the result of a cohort or generational difference or whether the effect of conscientiousness on emotional recovery disappears after age 65, indicating that conscientiousness is more important for emotion regulation processes earlier in adulthood, perhaps when balancing work and family life.

Purposeful Life Engagement and Emotion Regulation

A sense of purpose in life is one of the factors of psychological well-being that is most associated with positive long-term outcomes (see Ryff, Heller, Schaefer, van Reekum, & Davidson, 2016, for (p. 361) review). Emotion regulation skill is a hypothesized mechanism through which greater purpose in life may be protective and may promote resilience (McKnight & Kashdan, 2009; Ryff et al., 2016). For example, having a strong meaning and sense of purpose might motivate faster or more effective reappraisal of stressful situations to deal with them more productively. Alternatively, better emotion regulation, as reflected in faster recovery from negative events, may allow a person to achieve or maintain a greater sense of purpose in life.

Whether purpose in life relates to better emotional recovery after negative emotional provocation was tested in the MIDUS 2 sample. Individuals reporting a higher purpose in life showed evidence for better emotional recovery from acute negative emotional provocation 2 years later, as indicated by reduced EBR (Schaefer et al., 2013). Specifically, those reporting a greater purpose in life recovered more rapidly from negative stimuli, as indexed by a smaller startle-induced eye-blink after the negative picture disappeared. Importantly, the relationship between purpose in life and more rapid recovery from negative stimuli was independent of other parameters of the temporal course of emotion, remaining significant after statistically controlling for the initial reactivity to the negative picture, the participant's general emotional state, and demographics such as age and gender. Thus, these results support the idea that purpose in life may promote resilience and protect against the harmful effects of stressful events by enhancing emotion-regulatory capacity. From the standpoint of psychological well-being, it is noteworthy that purpose in life was a unique predictor of negative emotional recovery relative to other facets of well-being; that is, purpose in life predicted better emotional recovery even when controlling for the other five psychological well-being factors that comprise the multidimensional measure of psychological well-being (i.e., autonomy, environmental mastery, personal growth, positive relations with others, and self-acceptance; Ryff, 1989; Ryff & Keyes, 1995).

Long-Term Marital Strain and Prolonged Positive Emotion

In addition to aging, well-being, and personality factors, the impact of stress on emotional reactivity and recovery processes has been examined in the MIDUS 2 data. Given the importance of interpersonal relationships, especially close, intimate relationships, on daily life, marital strain can be a significant stressor and can have a toxic effect on mental health. In fact, marriage impacts mental health more than other social relationships, and marital stress is associated with a higher incidence of psychopathology, especially major depression (see Lapate et al., 2014, for review).

Taking advantage of the unique opportunities that arise from blending longitudinal aging research with lab-based affective neuroscience, the psychophysiological emotional response data were combined with marital quality information spanning nearly a decade. Based on the idea that marital relations may interact with emotional reactivity and recovery processes, relations between marital strain and emotional responses in MIDUS 2 participants who were in the same relationship from MIDUS 1 were assessed. Thus, among those who had been married for a minimum of 9 years (the time difference between MIDUS 1 and MIDUS 2), associations between prolonged marital stress and the temporal dynamics of negative and positive emotional responses were examined.

Those who reported higher levels of marital strain across the two assessments exhibited briefer responses to positive stimuli as indexed by corrugator EMG. Notably, (and similar to the results described in Javaras et al., 2012, and Schaefer et al., 2013) this effect was not observed in the initial reactivity to pleasant stimuli but was only observed in the time period after the positively valenced image disappeared. Moreover, this association between marital strain and less persistent positive emotional responses remained even when controlling for the participants' initial depression symptomatology at MIDUS 1. In addition, the decreased persistence of positive affect (as assessed by a faster return to baseline of corrugator EMG) statistically mediated the relationship between marital strain and the participants' depressive symptoms at MIDUS 2. These findings held across age and gender, thereby demonstrating an important link between psychosocial stress and emotional responses. These results suggest that one potential mechanism for how marital stress exerts a toxic toll on health and well-being is by impacting the temporal course of responding to positive life events, resulting in less persistent positive emotional responses. The experience of positive emotions has been hypothesized to be psychologically protective, promoting resilience to stress and enhancing flourishing (Fredrickson, 2001, 2004; Fredrickson & Branigan, 2005). Therefore, the association between marital strain and shortened positive emotional responses, and mediation of the relationship between marital strain (p. 362) and depressive symptomatology by the shortened positive emotional responses, suggested a mechanism through which marital strain may contribute to the development of depression.

Neural Mechanisms Underlying Positive Emotional Styles

Given the hypothesized importance of the experience of positive emotion for health and well-being, specifically promoting resilience to stress and enhancing flourishing (Fredrickson, 2001, 2004; Fredrickson & Branigan, 2005), the neural mechanisms underlying emotional styles characterized by more persistent positive emotional responses over time are beginning to be delineated. In a prior study of 27 depressed individuals between the ages of 19 and 53 years old (mean age 31 years), the inability to repeatedly engage or activate brain circuitry implicated in reward-related processes (i.e., the ventral striatum) to pleasant, positive pictures (intermixed with negative and neutral pictures) was associated with depressive symptomatology (Heller et al., 2009). This finding was revealed not by the magnitude of the initial reactivity or the persistence of emotional experience within a trial, but rather by examining another variant of the temporal dynamics of emotion that captures a habituation-related process. Specifically, instead of looking at activity averaged across trials, the change or relative lack of change in activity *across* trials was investigated. Given the strong negative associations between depression and eudaimonic psychological well-being (Nierenberg et al., 2010; Ryff, 1989; Ryff & Keyes, 1995) and the MIDUS emphasis on well-being, these findings were followed up in the MIDUS 2 data by examining whether repeated engagement of reward circuitry across trials might also be associated with well-being in a healthy sample—a unique opportunity provided by the MIDUS data.

Indeed, higher levels of well-being were associated with *more sustained* engagement of brain activity in response to positive pictures in two brain regions: the striatum (extending into the ventral striatum, which includes portions of both the caudate nucleus and nucleus accumbens), as well as the right dorsal lateral prefrontal cortex (DLPFC) (Heller et al., 2013). Notably, these associations remained significant when controlling for variability in time between the well-being assessment and the neuroimaging session, age, or even trait positive affect. Thus, this result extended the original finding in a depressed sample to a healthy sample, indicating that more sustained engagement of brain reward circuitry (i.e., less habituation of brain reward circuitry) across repeated presentations of positively valenced stimuli is indicative not only of the absence of depression, but also of eudaimonic well-being.

Moreover, this sustained striatal activity was associated with diurnal fluctuations in the stress hormone cortisol, specifically the total daily cortisol output, computed as the area under the curve with respect to ground (Pruessner, Kirschbaum, Meinlschmid, & Hellhammer, 2003). Individuals who showed the most consistent activity in the striatum and DLPFC in response to appetitive images (i.e., no attenuation over subsequent pleasant image presentations) had the lowest diurnal cortisol output. In addition, the temporal consistency of activity in both these regions mediated the relationship between cortisol and well-being. Again, these findings were specific to the *change* in the response, as activity in the DLPFC and striatum in response to positive images averaged across time did not show these relationships. This suggests a possible neurobiological mechanism by which eudaimonic well-being may influence health is through a more consistent response to positive emotional provocation over time, as well as lower overall cortisol levels. It will be interesting to extend this finding and test whether individual differences in consistency of engagement of reward-related brain circuitry is associated with measures of physical health previously associated with higher cortisol output, such as atherosclerosis of the carotid arteries (Dekker et al., 2008), a measure of ischemic heart disease.

Summary of Advances Afforded by MIDUS

By examining different aspects of the temporal dynamics of emotional responding across the MIDUS Neuroscience Project sample, robust interactions between emotional responses and age, personality, psychosocial stress, and well-being have been revealed (Heller et al., 2013; Javaras et al., 2012; Lapate et al., 2014; Schaefer et al., 2013; van Reekum et al., 2011). These findings suggest that higher levels of conscientiousness and purpose in life are protective by facilitating better recovery from negative provocation. Conversely, marital strain may have toxic effects on health by shortening positive emotional responses and increasing vulnerability to depressive symptomatology. Similarly, depression is associated with attenuation (habituation) of responses to positive stimuli across repeated trials, whereas eudaimonic well-being is associated with more consistent (p. 363) responses to repeated positive stimuli. In sum, findings from the Neuroscience Project suggest the experience of stress, personality traits, and other personal attributes and factors may affect health and well-being by influencing different emotional response parameters, whether by facilitating faster recovery from negative emotions or greater savoring of positive emotions. Of note, many of the present findings would have been missed if emotional responses had been examined as a static output over the course of several seconds. By probing emotion as the dynamic system that it is has afforded critical insight into how a person may adaptively respond to the slings and arrows, as well as boons and joys, of everyday life. This work is ongoing, and there is much more to come.

Future Directions in Affective Neuroscience in MIDUS

When data from the MIDUS Refresher sample are combined with the MIDUS 2 sample, the greater power of the larger sample will allow for explorations of the impact of other sociodemographic factors and life course changes on the temporal dynamics of emotion. In particular, the larger sample size will allow probing of potential subgroup differences, such as gender, race, education, or socioeconomic status, in the impact of temporal dynamics of emotional responses on predicting health and well-being. These analyses may shed important light on how poverty or the experience of discrimination may influence or interact with emotional responses to affect health and well-being. Moreover, the addition of the ongoing MIDUS 3 Neuroscience assessment will provide two longitudinal assessments of both psychophysiological and neural measures of emotional reactivity and recovery. These longitudinal measures obtained roughly a decade apart will provide a unique and important opportunity to robustly test the *causal* implications of individual differences in the temporal dynamics of emotion and their import, paving the way for a deeper and biologically guided mechanistic understanding of individual differences in emotional processes, their brain–behavior associations, and how emotions get under the skin to impact well-being and health across the life span.

For example, does the aging-related finding of more positive appraisals and responses to neutral stimuli predict flourishing or better mental and physical health outcomes over the 10 years between MIDUS 2 and MIDUS 3? Or, might the positivity effect of appraisal of neutral stimuli over age depend on sociodemographic or life circumstances? And, what implications do these effects have on resilience to stress, cognition, health, or other metrics of functioning and life success? Are the relations between conscientiousness and recovery from negative emotion still observed only in people 65 and younger at MIDUS 3? And if so, what may drive the change in the relationship between conscientiousness and emotional recovery during later life? For example, might it reflect the change in responsibilities and shift in priorities that may happen when a person retires? Finally, which aspects of positive emotional responses—the reactivity to positive events, the sustaining of emotional responses, or the continued strong response of the positive emotional response system across repeated positive events—are most predictive of future health and well-being? These and many more questions will be available for investigation via the increased Neuroscience Project sample and repeated longitudinal assessments.

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