PSYCHOLOGICAL STRESS, STRESS REACTIVITY AND BLOOD GLUCOSE METABOLIZATION DURING PREGNANCY

A Dissertation
Submitted to the Graduate Faculty
of the
North Dakota State University
of Agriculture and Applied Science

By

Anna Marie Strahm

In Partial Fulfillment of the Requirements
for the Degree of
DOCTOR OF PHILOSOPHY

Major Department:
Psychology

July 2020

Fargo, North Dakota

North Dakota State University
Graduate School

Title

PSYCHOLOGICAL STRESS, STRESS REACTIVITY AND BLOOD GLUCOSE METABOLIZATION DURING PREGNANCY

By

Anna Marie Strahm

The Supervisory Committee certifies that this ***disquisition*** complies with North Dakota State University's regulations and meets the accepted standards for the degree of

DOCTOR OF PHILOSOPHY

SUPERVISORY COMMITTEE:

Clayton Hilmert
Chair

Leah Irish

Linda Langley

Lawrence Reynolds

Approved:

July 13, 2020
Date

Mark Nawrot
Department Chair

ABSTRACT

Gestational diabetes mellitus impacts between 3-10% of pregnancies, and increases the risk of pregnancy complications and lifelong health effects for mother and child (Bellamy, Casas, Hingorani, & Williams, 2009; Ross, 2006; Ryser Rüetschi et al., 2016). About half of cases occur without an evident risk factor (American College of Obstetricians and Gynecologists (ACOG), 1994; Dode & Santos, 2009). The present study was designed to examine possible psychophysiological connections linking psychological stress and stress reactivity, the magnitude of an individual's response to stress, to blood sugar metabolization during mid-pregnancy between 24-28 weeks gestation. Participants were recruited from Sanford Health in Fargo, where patients underwent routine Oral Glucose Tolerance Testing (OGTT) a diagnostic assessment in which higher results indicate less blood sugar metabolization. They also completed a Virtual Trier Social Stress Task while psychological and physiological markers of stress reactivity were assessed. Additionally, maternal stress and stress reactivity were assessed using psychosocial questionnaires. There was support for proposed psychophysiological connections, including models in which positive associations between OGTT and maternal stress and anxiety were moderated by psychological stress reactivity. Results suggest that both the presence of stress and a women's responses to that stress are influential over blood glucose metabolization during pregnancy. Continuing research in this area may have implications for improving outcomes of women at higher risk of GDM and other adverse pregnancy and perinatal outcomes.

ACKNOWLEDGMENTS

Foremost, Dr Clayton Hilmert, thank you for seeing weakness as potential areas of growths, and strengths as areas to encourage. You have an ability to see where people are and help them develop individually for their benefit. I am not sure where I would be or who I would be today without your mentorship.

To Dr. Leah Irish you were an inspiration when I started here, a seemingly impossible demonstration of academic perfection. Since then you have shown me the humanity of what we do and made it clear that capitalizing on what you can do is of peak importance for success. I am grateful for your input on this project and other projects I have worked on NDSU, thank you to my second mentor.

Thank you, Dr. Larry Reynolds, you provided research inspiration from the first day I watched your talk about placental development in ruminants. Your continued encouragement regarding maternal and offspring health, including sending on important new papers in the area, adds fuel to my persistence.

To Dr. Linda Langley, your perspective of lifelong development and approach to your students has always impressed me. Thank you for your feedback and opinions over the last four years. In this particular project you asked questions which prompted the analysis of a measure which had significant results, thank you.

There are many others that deserve my heartfelt thanks beyond those acknowledged by name here. My role models, family, and friends all helped support me throughout my time in graduate school. They continually reminded me that “things are only impossible until they’re not.” I am grateful for all of you, thank you.

Furthermore, I am grateful for study support and consultations with Siri Thaden, Janelle Brandon, and Sanford Health and OBGYN clinic practitioners and staff. This research was supported by a College of Graduate and Interdisciplinary Studies Doctoral Dissertation Fellowship from North Dakota State University and by a Sanford Health – North Dakota State University Research Seed Grant.

DEDICATION

For Dr Kati.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

ACOG	American College of Obstetricians and Gynecologists.
OGTT	Oral Glucose Tolerance Test.
GDM	Gestational Diabetes Mellitus.
WHO	World Health Organization.
HPA	Hypothalamic-Pituitary-Adrenal.
HR	Heart Rate.
BP	Blood Pressure.
DBP	Diastolic Blood Pressure.
SBP	Systolic Blood Pressure.
NDSU	North Dakota State University.
OB/GYN	Obstetrician and Gynecology.
SES	Socioeconomic Status.
ASA24®	Automated Self-Administered Recall System.
HEI	Healthy Eating Index.
USDA	United States Department of Agriculture.
PSS	Perceived Stress Scale.
STAI	State Trait Anxiety Inventory.
PA	Pregnancy Anxiety.
LEL	Life Event List.
PSRS	Perceived Stress Reactivity Scale.
SOC	Sense of Coherence.
TSST	Trier Social Stressor Task.
V-TSST	Virtual Trier Social Stressor Task.

3D.....Three Dimensional.

SACL .....Stress and Arousal Checklist.

µg/dL.....Microgram per Deciliter.

AUC .....Area Under the Curve.

mg/dL.....Milligram per Deciliter.

BMI .....Body Mass Index.

IBM .....International Business Machine.

SPSS.....Statistical Package for the Social Science.

CGM .....Continuous Glucose Monitoring.

Kg/M^2 .....Kilograms per Meters Squared.

1. PSYCHOLOGICAL STRESS, STRESS REACTIVITY AND BLOOD GLUCOSE METABOLIZATION DURING PREGNANCY

Despite investing 17.2% of the U.S. gross domestic product in health care costs during 2016, the highest rate of investment worldwide, the U.S. still experiences a higher rate of infant mortality, 5.8 per 1,000 live births, than comparable international peers (Organization for Economic Co-operation and Development, 2017). Technology and medical interventions designed to reduce the rate of infant mortality, combined with changes in treatment approaches, have accounted for a modest decrease in perinatal morbidity and mortality since 2000 (ACOG, 2009, 2014; WHO, 2011). Clearly, factors outside of medical care contribute to these high rates of adverse perinatal health outcomes.

Domestically, Gestational Diabetes Mellitus (GDM) affects 3% to 10% of pregnancies and is associated with a variety of risk factors including being overweight, increased age, a family history of Type 2 diabetes, and being of minority descent (Chu et al., 2007; Hunt & Schuller, 2007; Ross, 2006; Ryser Rüetschi et al., 2016). However, approximately 50% of cases occur with no evident risk factor (ACOG, 1994; Dode & Santos, 2009). The pathophysiology of GDM is not clear, and research that focuses on biopsychosocial factors related to the development of GDM is lacking.

Biopsychosocial research on non-pregnant populations has identified stress as a risk factor for diabetes (e.g. Siddiqui, Madhu, Sharma, & Desai, 2015). Similarly, the effects of stress may contribute to the formation and progression of GDM. This study examined how maternal stress and stress reactivity are associated with the results of a diagnostic Oral Glucose Tolerance Test (OGTT). The OGTT is routinely used to determine how well blood sugar is metabolized.

Higher values on the OGTT indicate poorer blood sugar metabolization, a cardinal symptom of GDM.

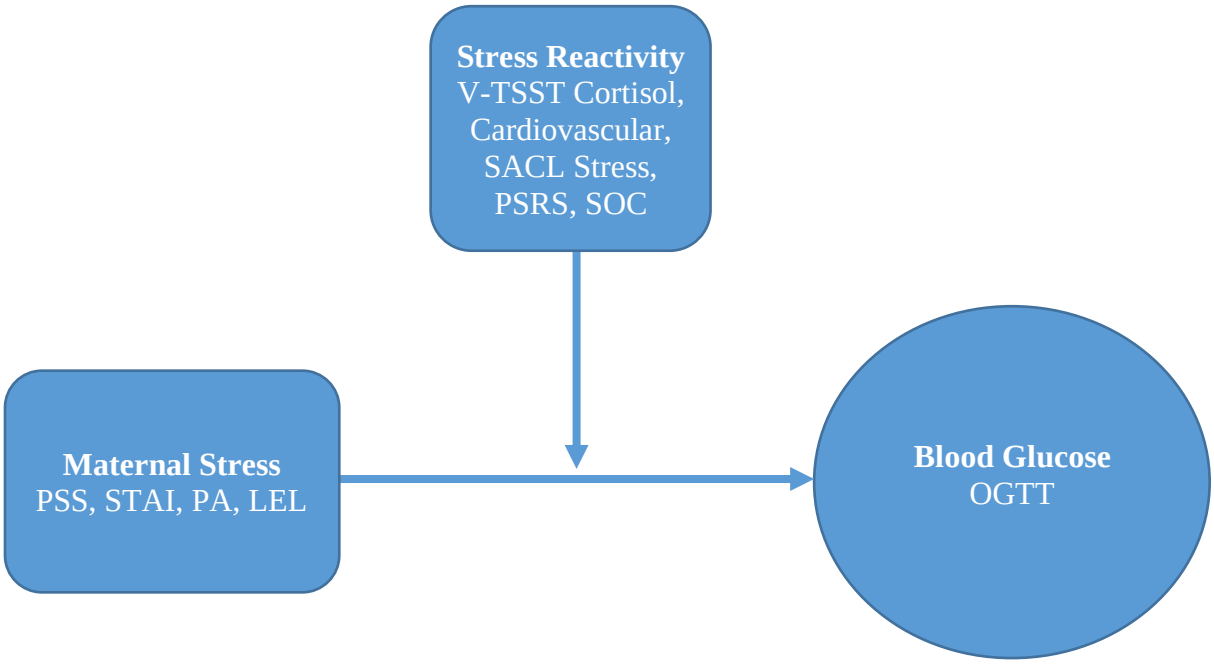

Figure 1. Moderated Model of Maternal Stress, Stress Reactivity, and Blood Glucose.

1.1. Gestational Diabetes Mellitus

Gestational Diabetes Mellitus is the inadequate ability to metabolize caloric intake due to insulin resistance during pregnancy. Without the insulin necessary to process the amount of glucose released into the blood stream, high levels of blood sugar build up. A mild increase in baseline blood sugar during the second trimester of pregnancy is normative, presumably to facilitate fetal growth. However, some women are unable to produce the 1.5-2.5 times more insulin necessary to manage this increase in blood sugar and develop GDM (Carr & Gabbe, 1998). GDM increases the risk of various pregnancy complications, including maternal risk of preeclampsia, complications during delivery, and neonatal macrosomia and dysmaturation (e.g., respiratory distress), all risk factors for infant mortality and metabolic morbidities (Black, Sacks, Xiang, & Lawrence, 2010; O'Sullivan, Charles, Mahan, & Dandrow, 1973; Ross, 2006).

The detrimental effects of GDM during pregnancy can have life-long impacts on both mothers and their children. Women who are diagnosed with GDM during pregnancy are more likely to have complications in future pregnancies (Getahun, Fassett, & Jacobsen, 2010; Moses, 1996), be diagnosed with post-natal depression (Kozhimannil, Pereira, & Harlow, 2009), metabolic syndrome (Lauenborg et al., 2005) and develop Type II diabetes within 5-years (Bellamy et al., 2009; Kim, 2014). Children born to women diagnosed with GDM have higher risk of infant mortality, and metabolic morbidities such as childhood obesity and diabetes (Clausen et al., 2009; Ross, 2006; Ryser Rüetschi et al., 2016).

Approximately 7% of all pregnancies have complications related to diabetes, and around the world GDM rates are rising above 10%-14% (Hunt & Schuller, 2007; Ryser Rüetschi et al., 2016). Given these increasing rates and the current obesity epidemic, a major risk factor for GDM (Chu et al., 2007), improving our ability to predict which women can benefit from GDM-related interventions and improving these interventions is important for reducing rates of infant mortality and adverse perinatal outcomes.

1.2. Stress and Diabetes

Research on GDM and diabetes in non-pregnant populations has shown that there are a number of shared risk factors (Hunt & Schuller, 2007; Ross, 2006; Ryser Rüetschi et al., 2016). These include being overweight (Chan, Rimm, Colditz, Stampfer, & Willett, 1994; Chu et al., 2007; Colditz, Willett, Rotnitzky, & Manson, 1995), a family history of diabetes (Wilson et al., 2007), genotype (Lyssenko et al., 2008), and being of minority descent (Haffner, 1998). However, many women develop diabetes and GDM in the absence of these known risk factors. Therefore, research has begun to focus on psychosocial risk factors for diabetes.

In non-pregnant populations, research has linked stress to higher glucose levels and has documented an association between stress and diabetes in adults (Faulenbach et al., 2012; Siddiqui et al., 2015). Also, stress exacerbates the severity of diabetic symptoms, which can increase the risk of diabetes-related complications (Surwit, Schneider, & Feinglos, 1992). Longitudinal research has demonstrated a relationship between work stress, stressful life events and distress, and the development of type 2 diabetes in adults (Agardh et al., 2003; Eriksson, van den Donk, Hilding, & Ostenson, 2013). Current research suggests that stress may be impacting blood glucose through neuroendocrine mechanisms, particularly the hypothalamic-pituitary-adrenal (HPA) axis.

In response to psychological and physical stress, the HPA axis activates, facilitating behavioral responses to a threat by mobilizing energy, increasing heart rate (HR) and raising blood pressure (BP). As part of this process, cortisol is released by the adrenal cortex. Once in the blood stream, one way cortisol makes energy available is by increasing insulin resistance, thereby inhibiting glucose storage and raising blood sugar levels. Research has shown that over time cortisol can disrupt the functioning of the insulin producing cells of the pancreas. When this occurs, an insufficient amount of insulin is released, complicating the body's ability to effectively store glucose, and eventually leading to Type II, 'insulin resistant' diabetes (Djurhuus et al., 2002; McEwen, 2015; Plat et al., 1996). Chronic high levels of cortisol and sustained high levels of blood sugar can lead to vascular damage from oxidative stress (Monnier et al., 2006), and irreversible damage to insulin producing β-cells of the pancreas (WHO, 1999). The amount of damage to the pancreas can eventually prevent the production of insulin, leading to a diagnosis of Type I 'insulin dependent' diabetes (WHO, 1999). Similarly, during pregnancy, it is

possible that the extent to which a women experiences stress and releases cortisol in response to that stress, puts her at risk of developing GDM.

1.2.1. Stress Reactivity

The extent to which an individual physiologically responds to stress, or *stress reactivity*, may determine one's risk of developing GDM. Stress reactivity varies depending on many factors (Meaney, 2001). Individuals with greater stress reactivity release more cortisol and have greater increases in HR and BP during a stressful event (Sapolsky, 2004). Research on individual differences in stress reactivity have been associated with genotype (Wu, Snieder, & de Geus, 2010), maternal caregiving behavior (Hane & Fox, 2006), childhood experiences (Lovallo, 2013), self-identified race (Anderson, McNeilly, & Myers, 1993), personality (Contrada & Krantz, 1988), social support (Heinrichs, Baumgartner, Kirschbaum, & Ehlert, 2003), and sleep deprivation (Minkel et al., 2014) among other biopsychosocial factors. The magnitude of cortisol release, HR and BP increases have been associated with higher levels of stress, and a sensitivity to stressful events (Low, Salomon, & Matthews, 2009; Miller, Chen, & Zhou, 2007; Schlotz, Yim, Zoccola, Jansen, & Schulz, 2011; Smyth et al., 1998). Multiple studies have shown that there is moderate test-retest reliability in cortisol, HR and BP reactivity to stress, suggesting that this is a relatively stable trait (Dickerson & Kemeny, 2004; Federenko, Nagamine, Hellhammer, Wadhwa, & Wüst, 2004; Goodman, Janson, & Wolf, 2017; C. Kirschbaum et al., 1995; Schommer, Hellhammer, & Kirschbaum, 2003; Susman, Dorn, Inoff-Germain, Nottelmann, & Chrousos, 1997). Stress reactivity can help identify those at greater risk for developing diabetes and diabetes-related complications in non-pregnant populations (Madhu, Siddiqui, Desai, Sharma, & Bansal, 2019; Steptoe et al., 2014; Surwit et al., 1992) and possibly, GDM.

1.3. Stress and Pregnancy

Stress during pregnancy increases risks to the pregnancy and to the antenatal health of mother and child. Adverse outcomes associated with prenatal stress include preeclampsia (Zhang et al., 2013), premature delivery, lower birth weight at term (Dunkel Schetter, 2011), and increased rates of medical interventions including medical induction and cesarean (Saunders, Lobel, Veloso, & Meyer, 2006). Therefore, there is a growing body of literature focusing on how stress and pregnancy-related outcomes are associated, and this research has identified a number of important factors relevant to the current project.

Stress which occurs earlier in pregnancy appears to have a greater impact on pregnancy outcomes. For example, pregnant women who were earlier in their pregnancies during a major flood or earthquake had lower birthweight babies and shorter gestation, than those who were later in pregnancy (Glynn, Wadhwa, Dunkel-Schetter, Chicz-Demet, & Sandman, 2001; Hilmert, Kvasnicka-Gates, Teoh, Bresin, & Fiebiger, 2016). Additionally, later in pregnancy maternal perceptions of stress change. For instance, those who experienced an stressful events earlier in pregnancy rated those experiences as more distressing (Glynn, Dunkel Schetter, Wadhwa, & Sandman, 2004; Glynn et al., 2001). It is possible that the effects of stress on prenatal blood sugar metabolization is most evident earlier in pregnancy. This would be consistent with research linking stress and cortisol during pregnancy.

1.3.1. Stress Related Cortisol during Pregnancy

Cortisol levels during pregnancy have been associated with stressful events, psychological stress, anxiety and depression (Obel et al., 2005; Pluess, Bolten, Pirke, & Hellhammer, 2010; Pluess et al., 2012). Also, there is a distinct pattern of cortisol sensitivity to stress over the course of pregnancy. Earlier during pregnancy, waking cortisol is positively

associated with anxiety. As pregnancy progresses, this association diminishes (Pluess et al., 2010). Consistent with this, stress reactivity as measured through cortisol, HR, and BP reactivity to stress is greater earlier in pregnancy (Entringer et al., 2010). This early cortisol sensitivity to stress and anxiety may indicate that earlier in gestation, pregnancy is more vulnerable to the effects of stress and anxiety (Glynn et al., 2001). Consistent with this, Sandman et al. (2006) found associations between higher levels of cortisol in early pregnancy and preterm delivery. In the present study I focus on mid-pregnancy measures of stress, reactivity, and blood sugar metabolization to coincide with the gestational timing of the routinely prescribed OGTT. This is an important first step in understanding how these factors interact and are associated during pregnancy and ultimately in how they are related to pregnancy health.

1.4. Stress and Gestational Diabetes Miletus

Thus far, few studies have reported a connection between psychosocial measures of stress and the formation of GDM. In two studies, more stressful pregnancy-related life events (e.g., financial difficulty) were reported in women who had been diagnosed with GDM when compared to those without GDM (Hosler, Nayak, & Radigan, 2011; Spirito et al., 1991).Both of the studies used retrospective methods, and recollections of stress may have been affected by the experience of GDM (Daniells et al., 2003). Horsch et al. (2016) conducted a prospective study of stress and GDM-related variables. They found associations between psychosocial variables assessed at a single time point in pregnancy, between 24-30 weeks gestation, and fasting glucose levels. However, they did not find an association between psychosocial variables and OGTT results. This lack of an association between stress and OGTT results, an acute test of glucose metabolization, may be because Horsch et al. (2016) did not consider individual differences in stress reactivity. Women with greater stress reactivity may have more difficulty metabolizing a

high dose of glucose than those with lower stress reactivity, especially when experiencing stress during pregnancy. Therefore, the present study measured both maternal stress and stress reactivity to examine this possibility.

1.5. Overview and Hypothesis

The present study was designed to examine two possible biopsychosocial mechanisms linking the experience of maternal stress to blood sugar metabolization: perceptions of stress and stress reactivity. There is a relatively well-established literature linking maternal stress to various facets of pregnancy health, including the development of GDM (Zhang et al., 2013), preeclampsia (Klonoff-Cohen, Cross, & Pieper, 1996), multiple adverse pregnancy outcomes, and infant mortality (Dunkel Schetter, 2011; Dunkel Schetter & Glynn, 2011). Understanding the mechanisms by which stress "gets under the skin" and influences the regulation of blood sugar metabolization could afford new targets of intervention to help reduce incidence of GDM and the adverse effects GDM has on pregnancy outcomes.

Participants were recruited from Sanford Health in Fargo, where, as part of standard prenatal care, patients are routinely referred to undergo an OGTT during a 24-28 week prenatal visit. To assess maternal stress and stress reactivity during pregnancy participants completed self-report measures prior to 28 weeks gestation. In addition, participants completed the in-lab Virtual Trier Social Stress Task at NDSU between 24-28 weeks gestation while psychophysiological markers of stress reactivity were tracked. The resulting data set was used to examine associations between maternal stress, stress reactivity, and blood sugar metabolization.

It was hypothesized that maternal stress would predict prenatal blood sugar metabolization, and this association would be moderated by stress reactivity (Figure 1). Specifically, it was anticipated that higher scores on Perceived Stress Scale, Pregnancy Anxiety,

State Trait Anxiety Inventory, and Life Events List measures would predict higher OGTT results. In addition, these associations would be moderated by Perceived Stress Reactivity Scale scores and Sense of Coherence, a measure of a person's ability to cope with stress, and psychophysiological reactivity during the Virtual Trier Social Stress Task. Psychological stress during the task was measured by the Stress and Arousal Checklist, and physiological reactivity by cortisol, HR, systolic blood pressure (SBP) and diastolic blood pressure (DBP). In particular, participants who reported higher levels of environmental stress who also had high stress reactivity were anticipated to have less effective blood sugar metabolization (higher OGTT results), while participants with other combinations of stress and stress reactivity were anticipated to have more effective blood sugar metabolization (lower OGTT results).

2. METHODS

2.1. Participants

In cooperation with members of the Sanford Health OB/GYN department participants were recruited via brochures with short descriptions of the requirements of the study, compensation for completing the study and contact information for the lab. Inclusion criteria consisted of being at least 18 years old, having a singleton, intrauterine pregnancy, without a history of cardiac and endocrine disease, prior diabetes or GDM diagnoses. Women who had been diagnosed with diabetes or GDM in a past pregnancy were excluded to focus on the associations between maternal stress, stress reactivity and blood sugar metabolization without this risk factor present. Women with a history of diabetes may have their ability to metabolize sugar compromised for reasons not present in women without such a history. Women who expressed interest in the study by using the contact information on the advertisements and study brochures, or women who left a request for contact card at the clinic during or after a prenatal visit, were contacted by phone or email. Once inclusion/exclusion criteria (above) were established, the participant provided demographic and contact information including an email address. Beginning at their 21st week of gestation each participant was contacted to schedule a visit between their estimated 24-28th week of gestation, at the Mind, Body and Baby Lab at NDSU. After a participant reported her delivery via email or voice message, she was thanked for her participation, compensated with $200, and offered opportunities to find out more about the study results in the future.

Of the 103 recruited 2 participants decided not to take the prescribed OGTT. Out of the remaining 101 participants, OGTT results were available for 77 of these participants at the time of data analysis. An additional participant was excluded from analysis as they took the OGTT

prior to enrolling in the study. It is possible that their questionnaire data regarding maternal stress includes environmental stressors which occurred after their OGTT. Subsequently, this questionnaire data could not be used to predict the OGTT results. A series of T-tests and Chi-squared tests comparing those excluded here on available demographic and study variables to those included in analyses revealed no significant differences between groups (*ps* > .05). Therefore, questionnaire-based analyses reported here include 76 participants. One participant discontinued the in-lab task due to an unrelated personal issue, and 2 were excluded from lab participation due a resting BP exceeding the predetermined high limit (140/90). Analyses involving in-lab physiological and psychological reactivity included the remaining 73 who completed the lab. Full cardiovascular reactivity data was available for 59 of these participants due to equipment malfunction.

2.2. Procedure

Participants were consented for participation and completed psychosocial measures and demographic questionnaires prior to 28 weeks gestation online. These measures included standardized questionnaires such as the Sense of Coherence Scale and the Perceived Stress Reactivity Scale (see Measures below) as well as providing 24hours of dietary intake in order to calculate nutritional quality using the Healthy Eating Index. Participants completed these assessments online, using NDSU's Qualtrics online survey hosting service, which provides a secure method of assessment. Although it was available, none of our participants elected to complete the questionnaires by mail, home-visit, or at NDSU. A 90-minute lab session at the Mind, Body and Baby Lab was scheduled to occur for each participant between 11am and 6pm at 24-28 weeks gestation. During this lab session participants signed a Sanford Health medical record release of information form and completed a standardized stressor task while data

regarding participants' stress reactivity were gathered. Stress reactivity included measures of cortisol reactivity, cardiovascular reactivity (HR, SBP and DBP), as well as a psychosocial measurement of stress and arousal. Reminder emails were sent and phone calls were made periodically to ensure compliance with all procedures. A Sanford Health OneChart Link (electronic medical record) was used to retrieve OGTT test results after participants had delivered their baby. Procedure and protocol were approved by the Institutional Review Board of North Dakota State University.

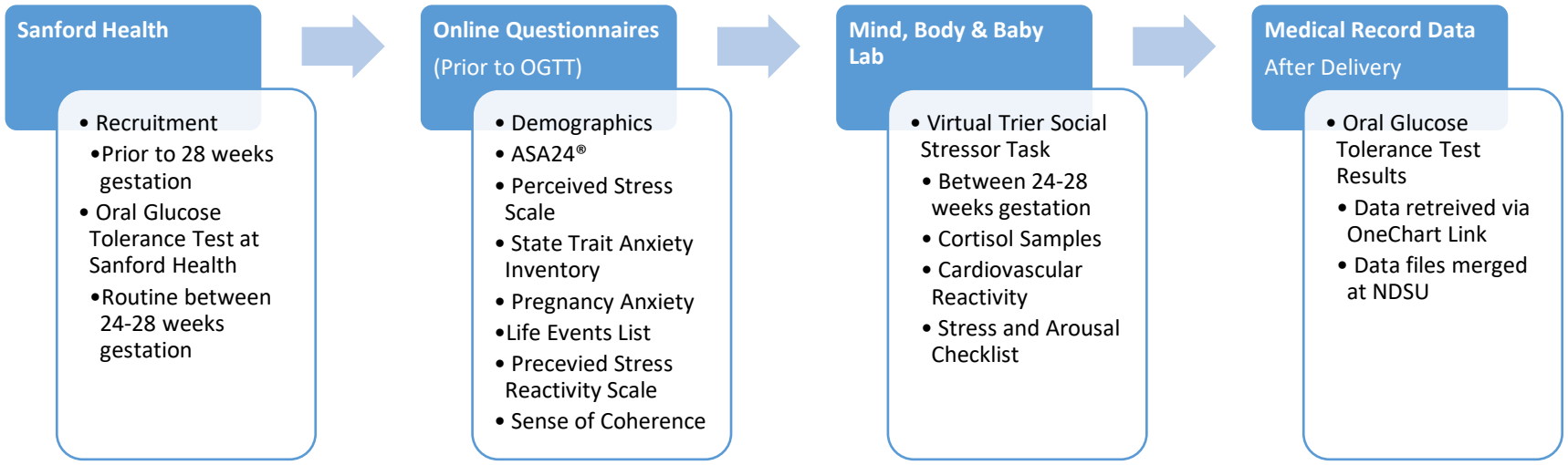

Figure 2. Study Outline.

2.3. Measures

2.3.1. Demographics and Background

Demographic data which has been associated with GDM including age, socioeconomic status (SES) as income divided by number of people in the household and education completed, ethnicity, and race were collected as part of the questionnaires. Medical records were used to determine each participant's family history of diabetes and body mass index assessed at their OGTT appointment (ACOG, 2013; Ryser Rüetschi et al., 2016). Age during pregnancy, biological sex of the baby identified at birth, number of prior pregnancies, access to prenatal care, and general health during pregnancies were also assessed via medical record.

2.3.2. Healthy Eating Index (HEI) 2015

This assessment was computed using dietary information self-reported on the ASA24® Dietary Assessment Tool. The ASA24® dietary diary measure was used to record nutritional intake, asking subjects to recall the last 24hours of food consumption. This measure was developed and is maintained by the National Institutes of Health and is a reliable measure of food intake. It included questions which assess food, drink and supplement consumption and whether or not the past 24-hour period was typical of their consumption. Information regarding the breakdown of nutritional consumption including macronutrient (e.g. protein), micronutrient (e.g. folic acid), and non-nutrients (e.g. caffeine) was provided by the ASA24® website to the researcher (Kipnis et al., 2003; Moshfegh et al., 2008). This information was processed using the HEI scoring guide which provides a measure of dietary quality, in which higher scores meet or exceed dietary guidelines set by the USDA. All participants fell below the national average (Krebs-Smith et al., 2018; Reedy et al., 2018).

2.4. Psychosocial Measures

2.4.1. Perceived Stress Scale (PSS)

This ten-item measure assessed how often the participant felt stressed or lacking in control during the past month. Participants provided ratings from 1 (never) to 5 (very often) (Cohen, Kamarck, & Mermelstein, 1983). This scale was reliable within our sample with a Cronbach's $\alpha = .82$, which is consistent with other studies of pregnant women with Cronbach's alphas ranging from $\alpha = .81$-$.84$ (Hilmert et al., 2008; Wadhwa, Sandman, Porto, Dunkel-Schetter, & Garite, 1993). Higher summed scores indicated a greater amount of maternal perceived stress.

2.4.2. State Trait Anxiety Inventory (STAI)

Participants completed the brief 10-item version of the STAI. This questionnaire asks questions regarding anxiety in the last few days on a scale from 1 (not at all) to 4 (very much) (Spielberger, 1985). This scale was reliable within our sample with a Cronbach's $\alpha = .92$, which was similar to past pregnancy studies with Cronbach's alphas ranging from $\alpha = .84$-$.90$ (Hilmert et al., 2008). Higher average scores on the STAI indicated greater maternal general anxiety.

2.4.3. Pregnancy Anxiety (PA)

Ten items assessing anxiety associated with pregnancy were administered. For this measure, a participant rated how confident she was on a scale from 1 = "not at all" to 4 = "very much" of having a normal labor, delivery, and childbirth. She also rated how fearful she was about being harmed during delivery, and how concerned she was about her baby's health and that the baby might not be normal. Additionally, on a scale from 1 = "never" to 4 = "almost all of the time," the participant rated how often she was concerned or worried about losing her baby, how her baby was growing in utero, having a difficult labor and delivery, developing medical

problems during pregnancy, and taking care of a new baby (Rini, Dunkel-Schetter, Wadhwa, & Sandman, 1999). This scale was reliable within our sample, Cronbach's $\alpha = .87$, similar to past pregnancy studies with Cronbach's alphas ranging from $\alpha = .75$-$.85$ (Hilmert et al., 2008). Higher average scores on this scale indicated greater maternal pregnancy specific anxiety.

2.4.4. Life Event List (LEL)

The LEL contains 67 items pertaining to the occurrence and impact of stressful life experiences, both positive and negative, which may have happened to the participant or another person close to the participant in the past 12 months. For each event participants selected whether the event happened, who the event happened to and the impact of the event which was calculated into an index (Cohen, Tyrrell, & Smith, 1993). Higher scores on this index indicated a greater amount of stressful life events.

2.4.5. Perceived Stress Reactivity Scale (PSRS)

This online assessment consisted of 23-items which assessed perceptions of stress reactivity across five subscales including: prolonged reactivity, reactivity to work overload, reactivity to social conflicts, reactivity to failure, and reactivity to social evaluation. It is designed to assess an individual's perception of the magnitude of their reactions to stressors occurring in their environment. An aggregated total derived from the subscales was used. This scale was reliable within our sample, Cronbach's $\alpha = .89$, and was consistent with the Cronbach's alpha for the measure $\alpha = .89$ (Schlotz et al., 2011). Higher scores indicated that the participant perceived the magnitude of her reaction to stressful events to be greater.

2.4.6. Sense of Coherence (SOC)

The SOC scale measured the participant's ability to cope with stressors (Antonovsky, 1993). It is composed of three sub scales addressing comprehensibility, manageability, and

meaningfulness. Previous research has demonstrated a negative association between the SOC and Type II diabetes diagnoses in the general population (Madhu et al., 2019; Siddiqui et al., 2015). Also, SOC tends to be negatively associated with stress reactivity (Antonovsky, 1993), and has been used as a measure of coping with stressors in pregnant populations (Guardino & Dunkel Schetter, 2014). The short form of the scale, SOC-9 has been used in pregnant populations previously, Cronbach's $\alpha = .81$ (Ferguson, Davis, Browne, & Taylor, 2015). Our sample using the SOC-9 showed similar reliability, Cronbach's $\alpha = .80$. Summed total score from this measure was used for analysis, with higher scores representing greater perceived ability to cope with stress.

2.5. In-Lab Task

2.5.1. Trier Social Stressor Task (TSST)

To explore the role of physiological stress reactivity participants each scheduled a 90-minute visit to the Mind, Body and Baby Lab at NDSU to complete the "virtual" TSST (V-TSST). Ideally, this occurred between the 24-28th gestational week of a pregnancy (see Figure 2), however, gestational age was tested as a possible control variable for analyses of the stress reactivity data, as previous research has reported blunting of stress responses as pregnancy progresses (Glynn, Christenfeld, & Gerin, 1997; Glynn et al., 2004). Additionally, visit scheduling was restricted to occur between 11am-6pm, in order to minimize the effects of diurnal rhythm on baseline cortisol and cortisol reactivity (Dickerson & Kemeny, 2004).

The TSST has been used by many researchers and has been shown to reliably elicit psychophysiological stress responses in the lab (Goodman et al., 2017; Clemens Kirschbaum, Pirke, & Hellhammer, 1993). Reactivity to the TSST has been shown to be consistent with

reactivity to stressful situations outside the lab and relatively stable over time (Treiber et al., 2003).

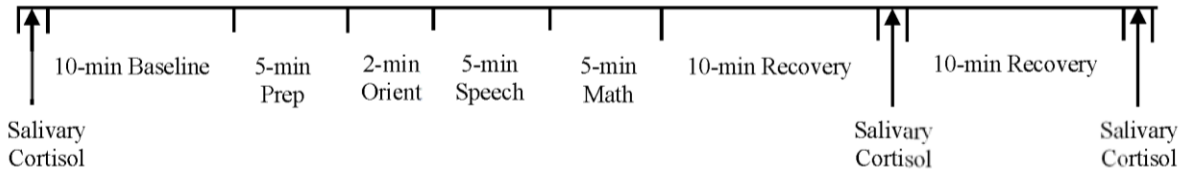

Figure 3. Laboratory Session Timeline.

The virtual reality version of the TSST was developed for use by the Mind, Body and Baby Lab. Specifically, the V-TSST is a speech and math task performed in front of an audience of 200 pre-recorded evaluators who were trained to respond to a participant's performance in a non-positive manner. Additionally, participants were told that recordings of their performances would be analyzed by experts, in order to enhance the evaluative nature of the situation. Based on past research with the TSST, participants were first asked to relax for a 10-minute baseline to allow for orienting to the room (See Figure 3 for the Session Timeline). After the baseline, participants were asked to prepare a 5-minute speech about why audience members should hire them for a job. Then the participant was fitted with an Oculus headset which provided an immersive 3D experience. For the first 2-minutes of wearing the headset the participant viewed an empty auditorium in order to orient themselves to the virtual experience. After this "virtual orienting" the 200-person audience appeared in the auditorium and the participant gave her 5-minute speech and then performed oral arithmetic in front of the audience for 5 minutes. Saliva samples were taken at the beginning of the session and after the tasks to assess cortisol reactivity. Heart rate, SBP and DBP were tracked during the entire session, as measures of cardiovascular reactivity. To assess the subjective experience during the task stress and arousal were measured using the Stress and Arousal Checklist immediately following the task.

2.5.2. Cortisol Reactivity

To measure cortisol, saliva samples were collected using Salivettes (Sarstedt, Germany), which are manufactured to allow for simple, safe saliva collection. The Salivette is one of the first devices designed for measuring salivary cortisol. It contains a tube and a small cotton dental roll that participants were asked to lightly chew on and hold between their cheek and gums for 2-3 minutes for each sample collection. Three Salivettes were collected during the laboratory session (see Figure 3). Saliva samples were collected prior to a resting baseline, 20 minutes after the initiation of the speech of the TSST, and 30-35 minutes after. According to recommendations made in the literature, this provided resting baseline, peak, and early recovery levels of cortisol, respectively (Dickerson & Kemeny, 2004).This protocol has been used previously by the Hilmert Lab (Eisenberger, Taylor, Gable, Hilmert, & Lieberman, 2007; Hilmert, Christenfeld, & Kulik, 2002; Hilmert, Kulik, & Christenfeld, 2002; Hilmert, Teoh, & Roy, 2013; Ode, Hilmert, Zielke, & Robinson, 2010; Robinson, Ode, & Hilmert, 2011, 2014; Taylor et al., 2008; Taylor et al., 2006) and others with a variety of non-pregnant and pregnant (Deligiannidis et al., 2016; Entringer et al., 2010) populations to assess a cortisol stress-response in the laboratory. Saliva samples were shipped to Salimetrics (Carlsbad, CA) for cortisol assays in duplicate. The µg/dL difference between baseline and 20 minutes after the initiation of the V-TSST and cortisol area under the curve (AUC) for the entire session were used to indicate cortisol reactivity.

2.5.3. Cardiovascular Measurement

A Finometer Pro® (Finapres, Netherlands) was used to record continuous HR, SBP and DBP for the duration of the lab timeline (see Figure 3). The Finometer Pro® records beat-to-beat cardiovascular measurements through a pressurized finger cuff placed on the middle finger of the non-dominant hand (Jansen et al., 2001; Schutte, Huisman, van Rooyen, Oosthuizen, & Jerling,

2003). The difference between the average of the last 5-minutes of baseline and the average of the 5-minute speech were used to indicate cardiovascular reactivity in HR, SBP and DBP.

2.5.4. Stress and Arousal Checklist (SACL)

To measure the subjective experience of stress and arousal during the task participants completed the SACL immediately following V-TSST. Participants were asked to reflect on whether they experienced 20 emotions (e.g., calm, lively) during the task using a 4-item scale ranging from "definitely no" to "definitely yes." In our sample the SACL Stress sub-scale met reliability criteria, Cronbach's $\alpha = .91$, the Arousal subscale did not, Cronbach's $\alpha = .56$. Previous literature reports the Stress subscale with similar reliability, Cronbach's $\alpha = .86$, however our arousal subscale was lower than anticipated by prior research, Cronbach's $\alpha = .74$ (King, Burrows, & Stanley, 1983). During pregnancy measuring arousal can be challenging, as physical tiredness may confound a measure designed for the general population. This has been seen in prior research on pregnant women in the workplace where energetic arousal is significantly lower than in non-pregnant workers (Morris, Toms, Easthope, & Biddulph, 1998). For these reasons the SACL Arousal subscale was not included in the following analyses.

2.6. Medical Record Based Data

2.6.1. Oral Glucose Tolerance Test (OGTT)

The OGTT is the most common method for diagnosing GDM. At Sanford Health, an OGTT is routinely prescribed for all pregnant women which follows the current American College of Obstetricians and Gynecologists (ACOG) guidelines suggesting initial screening between 24-28 weeks of pregnancy (ACOG, 2013). At the time of this study Sanford Health provided the following instructions to patients, via their preferred contact method (e.g. Sanford MyChart, print out):

'In the middle of your pregnancy (about 24-28 weeks) you will have a 1-hour gestational diabetes-screening test. This test involves drinking a special sweetened orange drink. (You may eat and drink prior to this test. It is best to avoid anything high in sugar.) One hour after this, your blood sugar will be tested. If the results are high, your doctor may order a second test called a 3-hour glucose tolerance test.'

During testing the patient orally consumes a mixture of hydrolyzed dextrose in solution. After 1 hour a blood sample is taken in order to assess blood glucose metabolism. The thresholds for diagnosing GDM varies by medical practitioner/clinic, however Sanford Health flags anything at or above 135mg/dL as high. Current ACOG guidelines recommend that a 1-hour OGTT result of 140 mg/dL satisfies criteria for diagnosis. If there is an unclear result (e.g. patient failed to followed instructions), a follow up 2 or 3 hour version of the OGTT is used to verify blood sugar metabolization prior to diagnosis (ACOG, 2013).

For the purposes of the proposed study, the initial 1-hour OGTT results were used, regardless of diagnosis threshold. That is, the hypotheses were predicated on the idea that blood sugar metabolization is a continuous variable, and to understand the influence of stress on blood glucose levels, differences in OGTT results ranging from sub-clinical to clinical levels were considered. During data extraction from medical records, the results of patients' OGTT were recorded and merged into the NDSU de-identified data file for analysis.

3. DATA ANALYSIS

All study analyses were conducted using IBM SPSS Statistics for Windows Version 25.0. Missing Data. For study measures assessed by questionnaire less than 1.4% of the data were missing due to participants not answering a question, and less than .4% for any individual item. A study variable not completed, (e.g. participant did not complete V-TSST thus has no HR reactivity data) was omitted from analyses. To test our hypothesized model (Figure 1) separate hierarchical linear regression analyses were conducted using measures of maternal stress and stress reactivity, to predict OGTT results.

4. RESULTS

4.1. Preliminary Analyses

In order to check for possible confounding variables preliminary analyses were conducted to assess associations between study variables and known risk factors or demographics. A series of one-way ANOVAs, and T-tests were used to see if demographic (gestational ages at the time of V-TSST and OGTT, time of day that V-TSST occurred, HEI score), known risk factors (maternal age, parity, BMI, and SES), study predictor variables (STAI, PA, PSS, LEL, PSRS, SOC, SACL Stress scores, Cortisol Reactivity, Cortisol AUC, HR reactivity, SBP reactivity, DBP reactivity) and the dependent variable (OGTT results) differed by self-identified race (Latino, American Indian/Alaska Native, Asian, Native Hawaiian or Other Pacific Islander, Black or African American, White/Caucasian, or other), family history of diabetes (2 categories: none, at least 1 biological parent or grandparent), and biological sex of the baby (2 categories: male or female identified at birth). Bivariate correlations were then conducted between all continuous variables. Study variables that were significantly different between categorical groups or were significantly associated with predictor variables or the dependent variable were included in the primary analyses as control variables in step 1 of hierarchical regressions.

Additionally, to verify that the V-TSST elicited physiological reactivity, repeated measures ANOVAs with LSD comparisons were used to examine changes in cortisol, HR, SBP and DBP over the course of the laboratory session.

Table 1

Study Variables

	N	Mean	SD	%
Maternal Age	76	30.3	(4.5)	
18 - 25	9			11.8
25 - 35	55			71.5
35 <	12			15.6
Number of Prior Pregnancies	76	1.1	(1.1)	
0	29			38.2
1	24			31.6
2	14			18.4
3 ≤	9			11.8
BMI Kg/M^2	75	29.2	(4.4)	
< 25	16			21.3
25 to 29.9	27			35.3
30 to 49.9	32			41.7
50 < *	0			0.0
Family History of Diabetes	76			
None	40			53.3
Parent	10			13.3
Grandparent	25			33.3
Race & Ethnicity	76			
Latino/Hispanic	2			2.6
Black	2			2.6
American Native	3			3.9
Asian	3			3.9
White	66			86.8
Education	75			
High School or GED	8			10.7
Technical or Vocational School	1			1.3
Some college but no degree	4			5.3
Associate Degree	9			12.0
Bachelor's Degree	31			41.3
Graduate degree	21			28.0
Other not listed above	1			1.3
Household Size	76			
2	30			39.5
3	29			38.2
4	16			21.1
5	1			1.3

Note. * Indicates high risk pregnancy due to obesity.

Table 1. Study Variables (Continued).

	N	Mean	SD	%
Household Income	76	$97,631	($45,866)	
Less than $10,000	1			1.3
$10,000 - $19,999	3			3.9
$20,000 - $29,999	6			7.9
$30,000 - $39,999	3			3.9
$40,000 - $49,999	2			2.6
$50,000 - $59,999	6			7.9
$60,000 - $69,999	3			3.9
$70,000 - $79,999	6			7.9
$80,000 - $89,999	10			13.2
$90,000 - $99,999	8			10.5
$100,000 - $149,999	24			31.6
More than $150,000	4			5.3
Healthy Eating Index Score*	69	35.2	(9.6)	
Gestational Age at Questionnaires	76	168.8 days	(23.0 days)	
< 24 weeks	9			11.7
24-28 weeks	67			88.3
Lab Reactivity				
Cortisol	73	.1	(.2)	
Cortisol AUC	73	2.3	(4.3)	
Heart Rate	59	14.5	(12.1)	
Systolic Blood Pressure	59	40.1	(19.2)	
Diastolic Blood Pressure	59	22.0	(11.5)	
SACL Stress	73	27.0	(7.1)	
Gestational Age at Lab	76	177.7 days	(9.5 days)	
24-28 weeks	75			98.7
29 ≤ weeks	1			1.3
Glucose mg/dL	76	113.8	(27.1)	
< 135	61			80.3
135 ≤	15			19.7
Gestational Age at OGTT	76	195.2 days	(11.3 days)	
24-28 weeks	55			72.4
29 ≤ weeks	21			27.6

Note. * 1 participant met or exceeded the national average HEI=59.

4.1.1. Demographics

Participants were representative of the greater Fargo-Moorhead area, the majority were white (86.8%), non-Hispanic (97.4%) and held a bachelor's degree (41.3%). For the parameters

of demographic and study variables see Table 1. There were significant differences between racial groups for maternal age ($F(4,71) = 2.974$, $p < .05$) cortisol reactivity ($F(4,68) = 3.726$, $p < .01$) and cortisol AUC ($F(4,68) = 3.804$, $p < .01$). Asian women were (*ps* < .05) older than Black women (M = 10.8 years, SE = 3.95), American Native women (M = 9.35 years, SE = 3.53), and white women (M = 6.5 years, SE = 2.6). Asian women were higher in cortisol reactivity and cortisol AUC (*ps* < .05) than Black women (reactivity M = .47 µg/dL, SE = .17; AUC M = 9.8, SE = 3.66), Latina women (reactivity M = .43 µg/dL, SE = .17; AUC M = 8.76, SE = 3.66), and white women (reactivity M = .33 µg/dL, SE = .11; AUC M = 6.74, SE = 2.37). American Native women were higher in both cortisol reactivity and cortisol AUC than Black women (reactivity M = .36 µg/dL, SE = .17; AUC M = 8.59, SE = 3.66) and white women (reactivity M = .22 µg/dL, SE = .11; AUC M = 5.53, SE = 2.37). Furthermore, American Native women were higher in cortisol AUC than Latina women (M = 7.54, SE = 3.66). There were no other significant differences between different racial or ethnic groups (*ps* > .05). Also, family history of diabetes and sex of the baby were not significantly associated with the study variables (*ps* > .05).

Maternal age was positively associated with parity ($r = .327$, $p < .01$) and SES ($r = .320$, $p < .01$). Parity was not associated with any additional study variables (*ps* >.05). SES was negatively associated with PSS ($r = -.357$, $p < .01$), LEL ($r = -.254$, $p < .05$), and SOC ($r = -.264$, $p < .05$), and positively associated with HR reactivity ($r = .259$, $p < .05$). HEI was not significantly associated with any of the study variables (*ps* >.05). There were no other significant associations between study variables and demographic or relevant background control variables with any other study variable (*ps* > .05).

Table 2

Correlations of Study Variables

												Lab Reactivity						
	Age	Parity	SES	BMI	HEI	STAI	PA	PSS	LEL	PSRS	SOC	Cort.	AUC	HR	SBP	DBP	Stress	GA
Parity	.327**																	
N	76																	
SES	.320**	-.162																
N	76	76																
BMI	-.024	.142	.000															
N	75	75	75															
HEI	-.134	-.153	.089	-.114														
N	69	69	69	68														
STAI	-.190	-.022	-.180	.097	.052													
N	75	75	75	74	68													
PA	-.002	-.042	-.004	.009	.133	.505**												
N	75	75	75	74	68	75												
PSS	-.196	.118	-.357**	.029	-.043	.734**	.461**											
N	75	75	75	74	68	75	75											
LEL	-.204	-.023	-.254*	.099	.026	.184	.105	.396**										
N	75	75	75	74	68	74	74	74										
PSRS	-.182	-.022	-.084	.002	.029	.678**	.618**	.695**	.301**									
N	75	75	75	74	68	75	75	75	74									
SOC	-.154	.049	-.264*	.095	-.012	.551**	.572**	.706**	.404**	.734**								
N	73	73	73	72	66	73	73	73	72	73								
Lab Reactivity																		
Cort.	.011	-.098	.185	.154	.022	-.011	.046	.112	.099	-.116	.014							
N	73	73	73	72	66	72	72	72	72	72	70							
AUC	.012	-.088	.172	.162	-.002	-.028	.041	.113	.111	-.123	.000	.997**						
N	73	73	73	72	66	72	72	72	72	72	70	73						
HR	.147	-.132	.259*	-.193	-.041	-.161	-.029	-.135	-.114	-.147	-.232	.505**	.513**					
N	59	59	59	58	53	58	58	58	58	58	56	59	59					
SBP	.202	-.112	.094	-.097	-.103	-.065	-.083	-.106	-.077	-.253	-.191	.322*	.320*	.321*				
N	59	59	59	58	53	58	58	58	58	58	56	59	59	59				
DBP	.154	-.104	.098	-.110	-.127	-.154	-.070	-.123	-.070	-.284*	-.244	.317*	.325*	.390**	.926**			
N	59	59	59	58	53	58	58	58	58	58	56	59	59	59	59			
Stress	-.178	.017	-.186	-.007	.029	.242*	.240*	.262*	.087	.349**	.264*	.130	.140	.089	.195	.120		
N	73	73	73	72	66	72	72	72	72	72	70	73	73	59	59	59		
GA	-.071	.140	.088	-.003	.078	.034	-.083	.072	-.142	.014	.056	.002	-.007	.107	-.038	.002	-.011	
N	76	76	76	75	69	75	75	75	75	75	73	73	73	59	59	59	73	
OGTT	.165	-.214	.032	-.045	.091	.176	.205	.050	.006	.159	.194	.010	.008	.031	-.086	-.138	.091	-.177
N	76	76	76	75	69	75	75	75	75	75	73	73	73	59	59	59	73	76

Note. * $p < .05$, ** $p < .01$. Cort. = Cortisol Reactivity, AUC = Cortisol AUC, Stress = SACL Stress, GA = GA at time of OGTT, OGTT = OGTT results.

4.1.2. Study Measures

STAI, PA, PSS, PSRS, and SOC were all positively associated with each other (.301 < *r* < .734, *ps* <.01) and to SACL Stress (.240 < *r* < .349, *ps* < .05). Additionally, LEL was positively associated with PSS (*r* = .396, *p* < .01), PSRS (*r* = .301, *p* < .01), and SOC (*r* = .404, *p* < .01). PSRS was negatively associated with DBP (*r* = -.284, *p* < .05). Cortisol reactivity, AUC cortisol, HR, SBP and DBP, were positively associated with each other (.317 < *r* < .997, *ps* <.05). For full correlations between study variables see Table 2. The first cortisol sample from each lab session was negatively correlated with time of day that session occurred (*r* = -.260, *p* < .05), which follows the natural pattern of the diurnal rhythm of cortisol. However, cortisol reactivity was not significantly associated with time of day (*p* >.05). Therefore, time of day was not included in primary analyses involving cortisol reactivity.

4.1.3. V-TSST Verification

Use of the V-TSST to elicit a reliable stress response with non-pregnant participants has been validated elsewhere (Strahm, Rued, Bagne, & Hilmert, in preparation). As this is the first study using this protocol with a sample of pregnant women, an analysis of data regarding the participant response to the V-TSST is presented here. Between baseline and 20 minutes after the initiation of the speech task, the average increase in cortisol was .108 µg/dL (SD = .201). Repeated measures analyses showed that this was a significant increase in cortisol (*SE* = .024, p <.01). This is similar to responses seen in non-pregnant participants (.149 µg/dL, SD = .200, *SE* = .043, *p* < .01) (Strahm, Rued, et. al., in preparation). For full results of V-TSST segment comparisons for cortisol see Figure 4.

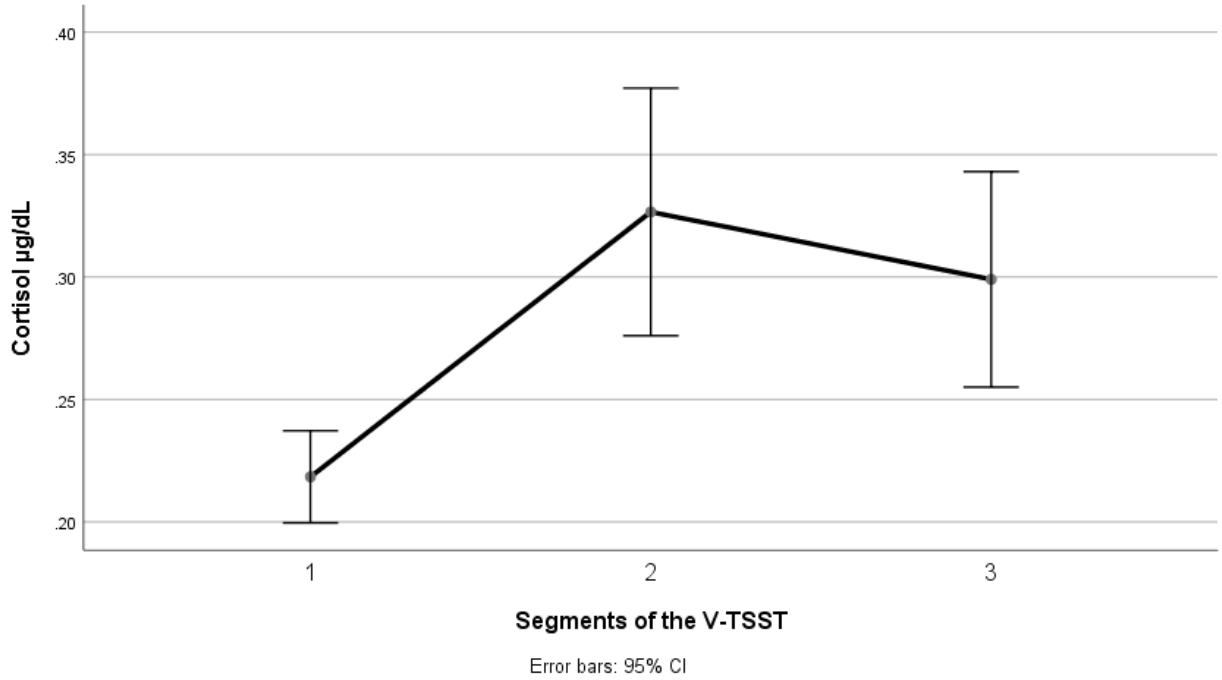

Figure 4. Estimated Marginal Means of Cortisol during the V-TSST.
Note. Segments of the V-TSST: 1 = Prior to baseline of the V-TSST, 2 = 20 minutes after the initiation of the speech for the V-TSST, and 3 = 30-35 minutes after the initiation of the speech for the V-TSST. Mauchly's Test of Sphericity was significant $X^2(2)=63.149$ $p < .01$, Greenhouse-Geisser ($\varepsilon = .629$) correction was used. $F(1.259,90.617)=17.965$, $p < .01$ $\eta p^2 = .200$. Cortisol at baseline was lower than both cortisol 20 minutes after the initiation of the TSST by an average of .108 µg/dL (SE = .024, $p < .01$) and cortisol 30-35 minutes after the initiation of the V-TSST by an average of .081 µg/dL (SE = .020, $p < .01$). Additionally, cortisol 20 minutes after the initiation of the V-TSST was higher by than cortisol 30-35 minutes after the initiation of the V-TSST at an average of .028 µg/dL (SE = .010, $p < .01$).

Cardiovascular reactivity as HR, SBP, and DBP was indicated by the difference between the average of the last 5-minutes of baseline and the average of the 5-minute speech which included the peak in reactivity for participants. The average increases between baseline to speech task were as follows, HR increased 14.53 beats per minute (SD = 12.08), SBP increased 40.07 mmHg (SD = 19.19), and DBP increased 22.05 mmHg (SD = 11.53). Once again, repeated measures analyses showed that these were significant increases (HR: *SE* = 1.968; SBP: *SE* = 2.631; DBP: *SE* = 1.521, *ps* < .01). This is similar to responses seen in non-pregnant participants (HR: 14.83 beats per minute, SD = 12.49, *SE* = 2.21; SBP: 35.30 mmHg, SD = 24.41, *SE* = 4.32;

DBP: 21.57 mmHg, SD = 18.25, *SE* = 3.23; *ps* < .01) (Strahm, Rued, et. al., in preparation). For the full results of V-TSST segment comparisons see Figures 5-7 for estimated marginal means and Tables 3-5 for mean differences. Psychological stress response assessed using the SACL Stress subscale (M = 27.00, SD = 7.07) was also similar to responses of non-pregnant participants (M = 29.9, SD = 6.85) in a previous study (Strahm, Rued, et. al., in preparation).

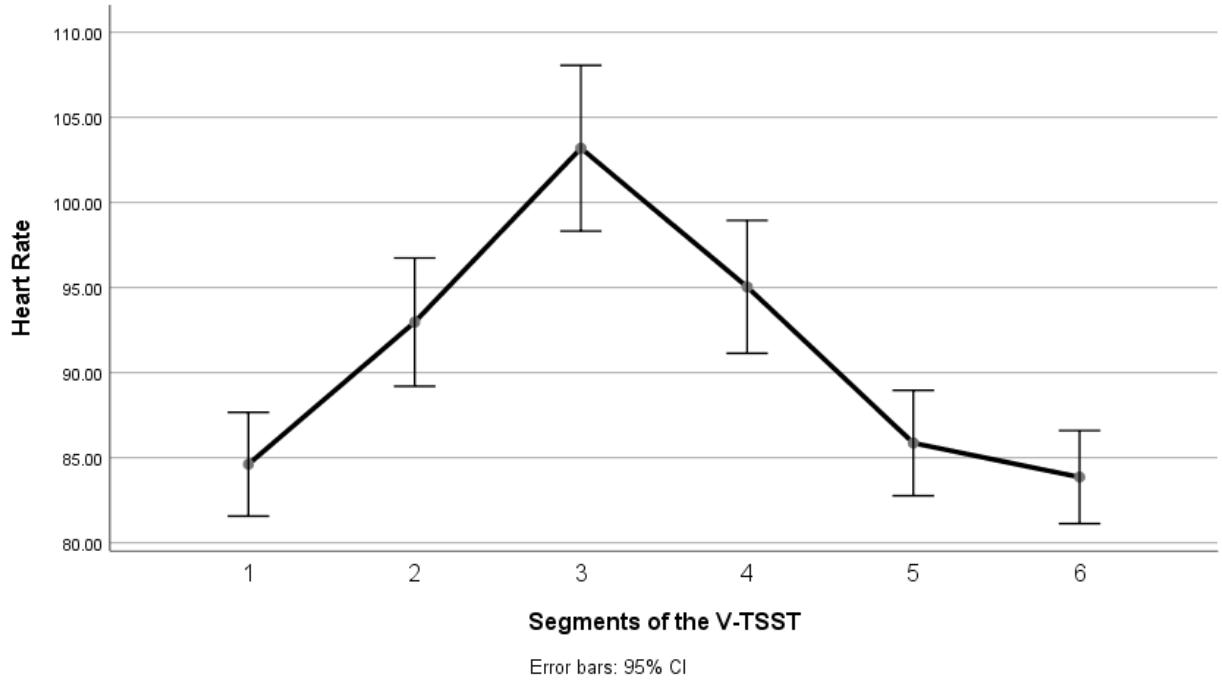

Figure 5. Estimated Marginal Means of Heart Rate during the V-TSST.
Note. Heart Rate is in beats per minute. Segments of the V-TSST: 1 = Baseline, 2 = Speech Preparation, 3 = Speech, 4 = Math, 5 = 1st 10 minute Recovery, 6 = 2nd 10 minute Recovery. Mauchly's Test of Sphericity was significant $X^2(14)=158.962$ $p < .01$, Greenhouse-Geisser ($\varepsilon = .405$) correction was used. $F(2.026,99.296)=70.439$, $p < .01$, $\eta p^2 = .590$. All time points were significantly different from each other ($p < .01$). All time points were significantly different from each other ($p < .01$) with the exceptions of segment 1 which was not significantly different from either segment 5 or 6; and segment 2 which was not different from segment 4. For a table of mean differences see Table 3.

Table 3

Mean Differences for Heart Rate between V-TSST Segments

	M	(SE)	M	(SE)	M	(SE)	M	(SE)	M	(SE)
Segment	1		2		3		4		5	
2	-8.349*	(1.327)								
3	-18.568*	(1.968)	-9.163*	(1.317)						
4	-10.422*	(1.333)	-1.744	(1.013)	8.145*	(1.119)				
5	-1.245	(.667)	7.154*	(1.086)	17.323*	(1.670)	9.178*	(1.019)		
6	.756	(.604)	9.255*	(1.268)	19.324*	(1.866)	11.178*	(1.252)	2.001*	(.503)

Note. *p <.01. Heart rate is in beats per minute. Segments of the V-TSST: 1 = Baseline, 2 = Speech Preparation, 3 = Speech, 4 = Math, 5 = 1st 10 minute Recovery, 6 = 2nd 10 minute Recovery. Mauchly's Test of Sphericity was significant $X^2(14)=158.962$ $p < .01$, Greenhouse-Geisser ($\varepsilon = .405$) correction was used. $F(2.026,99.296)=70.439$, $p < .01$, $\eta p^2 = .590$. All time points were significantly different from each other (p <.01) with the exceptions of segment 1 which was not significantly different from either segment 5 or 6; and segment 2 which was not different from segment 4. Estimated marginal means are shown in Figure 5.

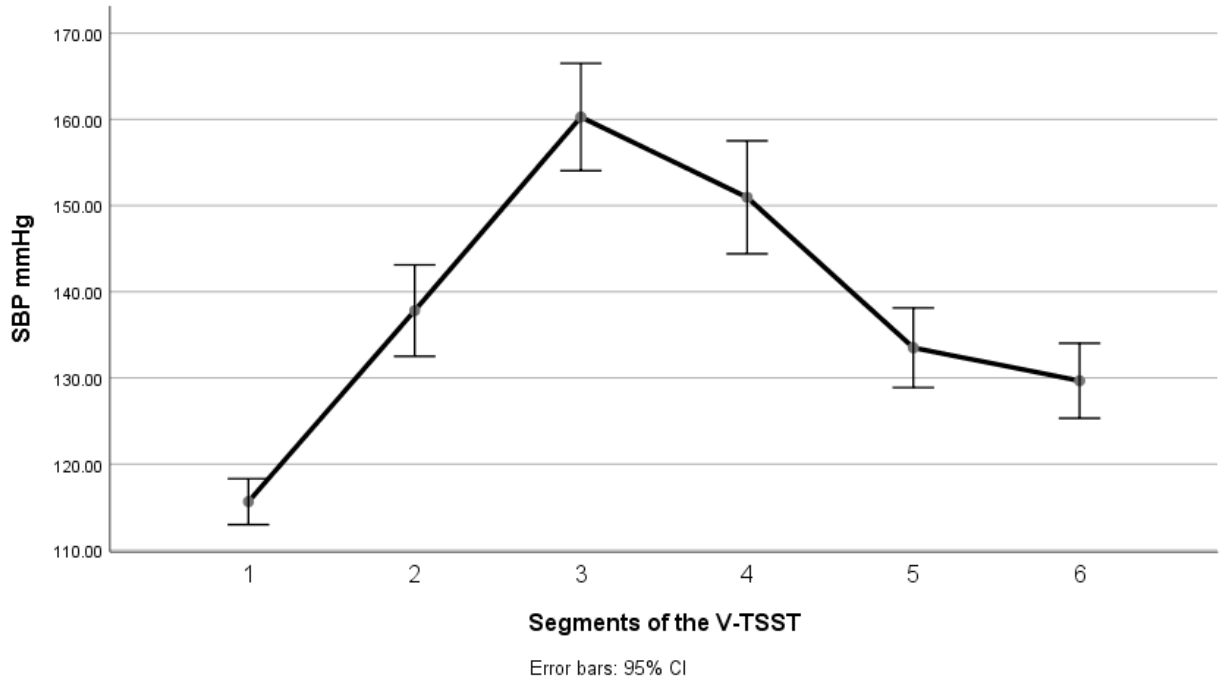

Figure 6. Estimated Marginal Means of SBP during the V-TSST.
Note. Segments of the V-TSST: 1 = Baseline, 2 = Speech Preparation, 3 = Speech, 4 = Math, 5 = 1st 10 minute Recovery, 6 = 2nd 10 minute Recovery. Mauchly's Test of Sphericity was significant $X^2(14)=99.834$ $p < .01$, Greenhouse-Geisser ($\varepsilon = .589$) correction was used. $F(2.943,144.224)=117.055$, $p < .01$ $\eta p^2 = .705$. All time points were significantly different from each other (p <.01). For a table of mean differences see Table 4.

Table 4

Mean Differences for SBP between V-TSST Segments

	M	(SE)	M	(SE)	M	(SE)	M	(SE)	M	(SE)
Segment	1		2		3		4		5	
2	-22.170*	(2.173)								
3	-44.639*	(2.631)	-22.469*	(1.829)						
4	-35.317*	(2.852)	-13.147*	(2.241)	9.321*	(1.378)				
5	-17.859*	(1.924)	4.311*	(1.939)	26.780*	(1.998)	17.458*	(1.908)		
6	-14.029*	(1.923)	8.141*	(2.079)	30.610*	(2.323)	21.289*	(2.219)	3.830*	(.891)

Note. *p <.01. SBP is in mmHg. Segments of the V-TSST: 1 = Baseline, 2 = Speech Preparation, 3 = Speech, 4 = Math, 5 = 1st 10 minute Recovery, 6 = 2nd 10 minute Recovery. Mauchly's Test of Sphericity was significant $X^2(14)=99.834$ $p < .01$, Greenhouse-Geisser ($\varepsilon = .589$) correction was used. $F(2.943,144.224)=117.055$, $p < .01$ $\eta p^2 = .705$. All time points were significantly different from each other (p <.01). Estimated marginal means are shown in Figure 6.

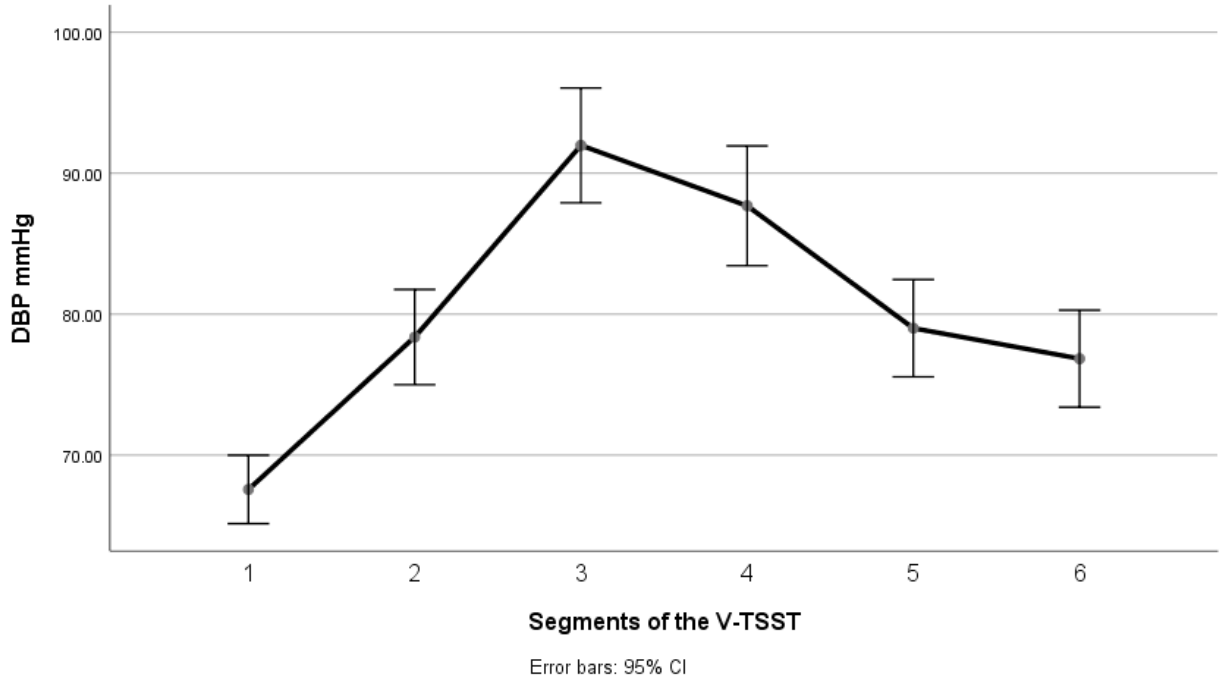

Figure 7. Estimated Marginal Means of DBP during the V-TSST
Note. Segments of the V-TSST: 1 = Baseline, 2 = Speech Preparation, 3 = Speech, 4 = Math, 5 = 1st 10 minute Recovery, 6 = 2nd 10 minute Recovery. Mauchly's Test of Sphericity was significant $X^2(14)=129.033$ $p < .01$, Greenhouse-Geisser ($\varepsilon = .537$) correction was used. $F(2.685,131.545)=110.245$, $p < .01$ $\eta p^2 = .692$. All time points were significantly different from each other (p <.01) with the exceptions of segment 2 which was not significantly different from either 5 or 6. For a table of mean differences see Table 5.

Table 5

Mean differences for DBP between V-TSST Segments

	M	(SE)	M	(SE)	M	(SE)	M	(SE)	M	(SE)
Segment	1		2		3		4		5	
2	-10.805*	(1.096)								
3	-24.404*	(1.521)	-13.599*	(.930)						
4	-20.121*	(1.652)	-9.316*	(1.148)	4.283*	(.664)				
5	-11.436*	(1.157)	-.631	(1.082)	12.968*	(1.100)	8.685*	(1.110)		
6	-9.276*	(1.238)	1.530	(1.201)	15.129*	(1.251)	10.845*	(1.262)	2.161*	(.449)

Note. *p <.01. DBP is in mmHg. Segments of the V-TSST: 1 = Baseline, 2 = Speech Preparation, 3 = Speech, 4 = Math, 5 = 1st 10 minute Recovery, 6 = 2nd 10 minute Recovery. Mauchly's Test of Sphericity was significant $X^2(14)=129.033$ $p < .01$, Greenhouse-Geisser ($\varepsilon = .537$) correction was used. $F(2.685,131.545)=110.245$, $p < .01$ $\eta p^2 = .692$. All time points were significantly different from each other (p <.01) with the exceptions of segment 2 which was not significantly different from either 5 or 6. Estimated marginal means are shown in Figure 7.

In a prior study with pregnant women by de Weerth, Gispen-de wied, Jansen, and Buitelaar (2007) measures of physiological reactivity, including cortisol and SBP, were diminished during lab sessions of the TSST which occurred earlier (9:30am) in the day, when compared to participant reactivity in the afternoon (1pm). In this study, physiological reactivity measures were not associated (with and without maternal age, SES and race entered as control variables; *ps* > .10) with the time of day their lab occurred (between 11am-6pm). This lack of association is consistent with other prior research on time of day and TSST use in non-pregnant populations (Dickerson & Kemeny, 2004; Goodman et al., 2017). Therefore, time of day is not included in primary analyses.

Based on these preliminary analyses, maternal age and SES were entered as control variables in all primary analyses. Furthermore, race was entered as a control variable for all models which included cortisol reactivity and cortisol AUC.

4.2. Primary Analyses

Separate hierarchical linear regression analyses were conducted to test the hypothesized model (Figure 1) using measures of maternal stress including PSS, PA, STAI, and LEL in combination with measures of stress reactivity, SOC, PSRS, cortisol reactivity, cortisol AUC, cardiovascular reactivity as HR, SBP, DBP, and SACL Stress to predict OGTT results. All predictor and control variables were standardized prior to regression analyses. For all analyses in step 1, maternal age and SES were entered as control variables. Specific to cortisol reactivity and cortisol AUC analyses, race was also entered in step 1. In step 2 the set of stress (e.g. PSS scores) and stress reactivity (e.g. cortisol reactivity) variables were entered individually. In step 3 the interaction of the proposed set of stress and stress reactivity variables was entered. Next, to further explore the relationships between predictors in the models that resulted in significant interactions, simple slope analyses were conducted using the same values from each model to predict unstandardized OGTT results as the outcome variable.

Table 6

PA predicting OGTT Results (N = 75)

		β	SE	Beta	t	*p*	95% CI	
1	Constant	-.010	.116		-.090	.928	-.241	.220
	SES	-.024	.122	-.024	-.198	.844	-.268	.219
	Maternal Age	.154	.124	.152	1.235	.221	-.094	.402
2	Constant	-.010	.114		-.091	.927	-.238	.217
	SES	-.023	.120	-.023	-.194	.846	-.263	.217
	Maternal Age	.154	.123	.152	1.256	.213	-.091	.399
	PA	.205	.115	.205	1.789	.078	-.024	.434

Note. For full model, R=.252, R^2=.063, ΔR^2=.024.

Table 7

STAI predicting OGTT Results (N = 75)

		β	SE	Beta	t	*p*	95% CI	
1	Constant	-.010	.116		-.090	.928	-.241	.220
	SES	-.024	.122	-.024	-.198	.844	-.268	.219
	Maternal Age	.154	.124	.152	1.235	.221	-.094	.402
2	Constant	-.009	.114		-.083	.934	-.237	.218
	SES	.004	.121	.004	.034	.973	-.238	.246
	Maternal Age	.186	.124	.183	1.497	.139	-.062	.433
	STAI	.211	.118	.211	1.791	.078	-.024	.446

Note. For full model, R=.252, R^2=.064, ΔR^2=.024.

Table 8

SOC predicting OGTT Results (N = 73)

		β	SE	Beta	t	*p*	95% CI	
1	Constant	-.042	.114		-.370	.712	-.270	.185
	SES	-.072	.120	-.074	-.596	.553	-.312	.168
	Maternal Age	.148	.122	.151	1.218	.227	-.094	.390
2	Constant	-.040	.113		-.355	.724	-.264	.185
	SES	-.022	.122	-.023	-.183	.856	-.265	.221
	Maternal Age	.165	.120	.168	1.374	.174	-.075	.405
	SOC	.208	.118	.214	1.763	.082	-.027	.442

Note. For full model, R=.252, R^2=.064, ΔR^2=.023.

Full results are listed in Tables 6-8. While there were no statistically significant main effects on OGTT results (*ps* > .05), there were 3 marginally significant associations, PA (β = .205, *p* = .078, ΔR^2 = .024), STAI (β = .211, *p* = .078, ΔR^2 = .024), and SOC (β = .208, *p* = .082, ΔR^2 = .023) were positively associated with OGTT, suggesting that greater stress and greater ability to cope with stress were associated with less blood sugar metabolization. In addition these analyses resulted in 4 interactions that met traditional criteria of significance (*p* < .05), two of which included SACL Stress as the measure of stress reactivity and two other models in which LEL was the measure of maternal stress.

Table 9

Interaction of STAI and SACL Stress Predicting OGTT Results (N = 72)

		B	SE	Beta	t	*p*	95% CI	
1	Constant	-.028	.115		-.240	.811	-.257	.202
	SES	-.072	.121	-.074	-.592	.556	-.314	.170
	Maternal Age	.165	.122	.169	1.351	.181	-.079	.410
2	Constant	-.028	.114		-.250	.804	-.256	.199
	SES	-.036	.122	-.037	-.291	.772	-.279	.208
	Maternal Age	.201	.123	.205	1.634	.107	-.045	.446
	SACL Stress	.084	.120	.087	.705	.484	-.155	.323
	STAI	.178	.118	.185	1.500	.138	-.059	.414
3	Constant	-.122	.112		-1.084	.282	-.346	.103
	SES	-.022	.115	-.023	-.195	.846	-.253	.208
	Maternal Age	.276	.119	.282	2.317	.024*	.038	.513
	SACL Stress	.153	.116	.158	1.327	.189	-.077	.384
	STAI	.095	.115	.099	.825	.412	-.135	.326
	Interaction	.397	.134	.355	2.964	.004**	.130	.665

Note. *$p < .05$, **$p < .01$. For full model, R=.426, R^2=.181, ΔR^2=.119.

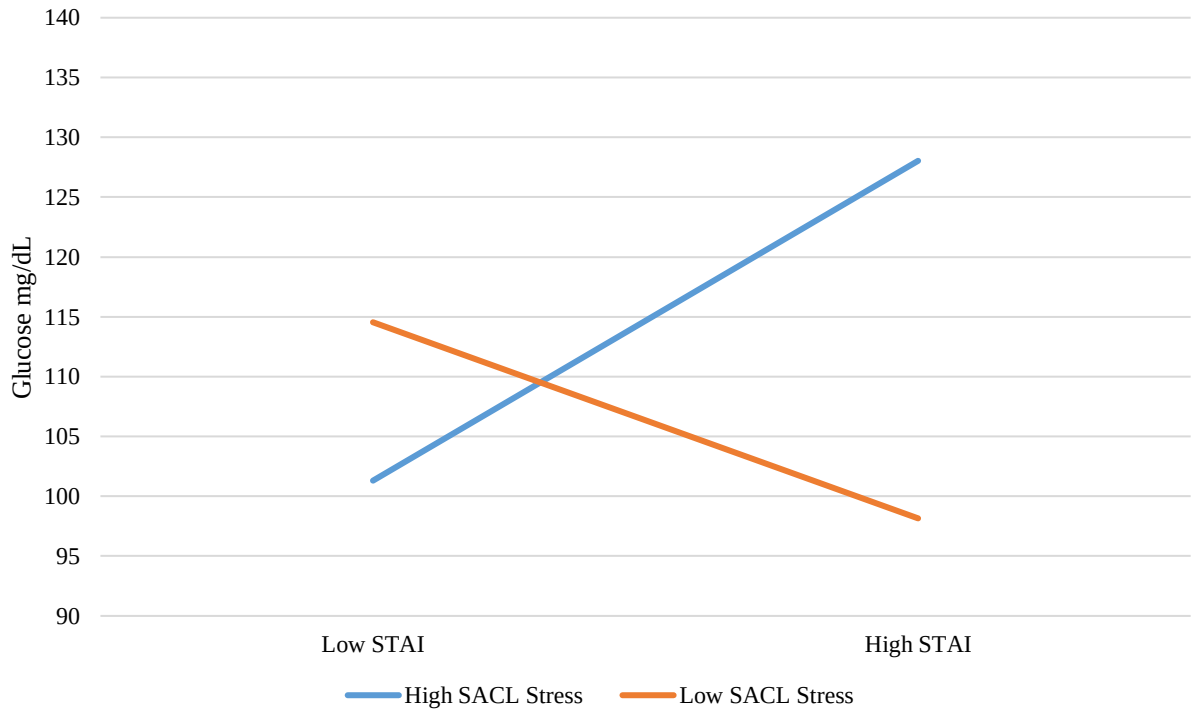

Figure 8. Predicted Values of STAI and SACL Stress Effects on OGTT.
Note. Interaction β = .397, $p < .01$.

In the regression involving STAI and SACL Stress maternal age was a predictor of OGTT results ($\beta = .276$, $p < .05$), suggesting that older women had worse blood sugar metabolization. In addition, the association between STAI scores and OGTT results was moderated by SACL Stress scores ($\beta = .397$, $p < .01$, $\Delta R^2 = .119$). See Table 9 for full results, and Figure 8 for the predicted values. For women with greater psychological stress response to the V-TSST, SACL Stress scores at 1SD (M = 26.959, SD = 7.070) above the mean, there was a significant positive relationship between STAI scores and OGTT results (*B* = 13.365, *SE* = 4.190, *t* = 3.189, *p* < .01). There was no such association for women with a smaller psychological stress response to the V-TSST, SACL Stress scores at 1SD below the mean (*B* = -8.195, *SE* = 5.340, *t* = -1.535, *p* = .13).

Further analyses revealed there was a positive relationship between SACL Stress scores and OGTT results for women with higher anxiety, STAI scores at 1SD (M = 18.347, SD = 6.057) above the mean (*B* = 14.942, *SE* = 5.260, *t* = 2.841, *p* < .01) but not for those with less anxiety, STAI scores at 1SD below the mean (*B* = -6.618, *SE* = 4.297, *t* = -1.540, *p* = .13). These results indicate that for women with greater psychological response to stress, for every 1SD increase in STAI scores, OGTT results increased by 13.365 mg/dL. Similarly, for women with greater anxiety, for every 1SD increase in SACL Stress scores, OGTT results increased by 14.942 mg/dL. Women with a combination of greater stress responses and greater anxiety had poorer blood sugar metabolization than those with greater stress responses and less anxiety or those with lower stress responses and greater anxiety. These findings support the hypothesis that a combination of high environmental stress and high stress reactivity may be detrimental to blood sugar metabolization. There were no other significant predictors of OGTT results in this analysis.

Table 10

Interaction of PSS and SACL Stress Predicting OGTT Results (N = 72)

		B	SE	Beta	t	*p*	95% CI	
1	Constant	-.028	.115		-.240	.811	-.257	.202
	SES	-.072	.121	-.074	-.592	.556	-.314	.170
	Maternal Age	.165	.122	.169	1.351	.181	-.079	.410
2	Constant	-.028	.116		-.238	.812	-.258	.203
	SES	-.035	.128	-.036	-.271	.787	-.291	.222
	Maternal Age	.184	.124	.188	1.483	.143	-.064	.432
	SACL Stress	.108	.121	.111	.887	.378	-.135	.350
	PSS	.067	.125	.069	.531	.597	-.184	.317
3	Constant	-.099	.117		-.847	.400	-.333	.135
	SES	.003	.126	.003	.024	.981	-.249	.255
	Maternal Age	.256	.125	.262	2.048	.045*	.006	.506
	SACL Stress	.104	.118	.107	.880	.382	-.132	.340
	PSS	.102	.123	.106	.826	.412	-.144	.348
	Interaction	.286	.131	.270	2.187	.032*	.025	.548

Note. *$p < .05$. For full model, R=.331, R^2=.110, ΔR^2=.042.

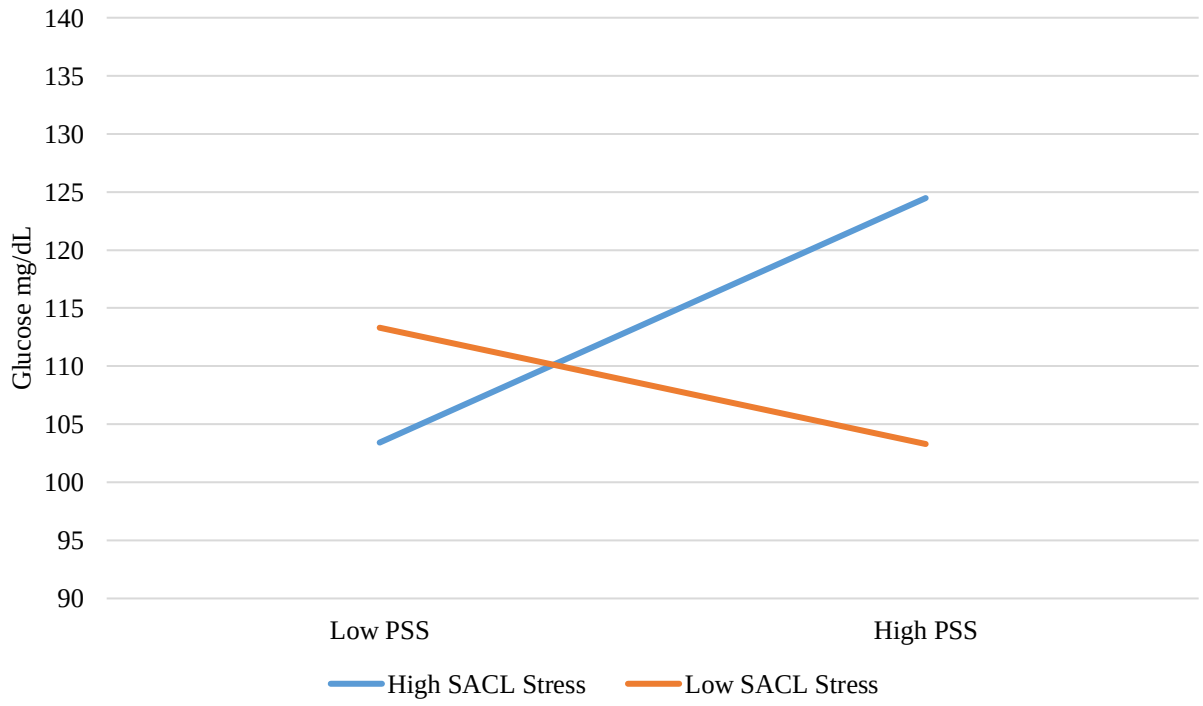

Figure 9. Predicted Values of PSS and SACL Stress Effects on OGTT.
Note. Interaction β = .286, $p < .05$.

In the analysis involving PSS and SACL Stress maternal age was a significant predictor of OGTT results ($\beta = .256$, $p < .05$). Also, the association between PSS scores and OGTT results was moderated by SACL Stress scores ($\beta = .286$, $p < .05$, $\Delta R^2 = .042$). See Table 10 for full results, and Figure 9 for the predicted values. For women with greater psychological stress response to the V-TSST, SACL Stress scores at 1SD above the mean, there was a significant positive relationship between PSS scores and OGTT results ($B = 10.525$, $SE = 5.182$, $t = 2.031$, $p < .05$). This was not the case for women with a smaller psychological stress response to the V-TSST, SACL Stress scores at 1SD below the mean ($B = -5.007$, $SE = 4.547$, $t = -1.101$, $p = .28$).

Further analyses revealed there was a positive relationship between SACL Stress scores and OGTT results for those with greater perceived stress, PSS scores (M = 27.693, SD = 6.000) at 1SD above the mean ($B = 10.588$, $SE = 4.750$, $t = 2.229$, $p < .05$) but not for those with less perceived stress, PSS scores at 1SD below the mean ($B = -4.944$, $SE = 4.817$, $t = -1.026$, $p = .31$). These results indicate that for women with greater stress reactivity, for every 1SD increase in PSS scores, OGTT results increased by 10.525 mg/dL. Similarly, women with greater perceived stress, for every 1 SD increase in SACL Stress scores, OGTT results increased by 10.588 mg/dL. Women with a combination of greater stress responses and greater perceived stress had poorer blood sugar metabolization, than women with greater stress responses and less perceived stress or women with lower stress responses and greater perceived stress. These findings support the primary hypothesis. There were no other statistically significant relationships in this model.

Table 11

Interaction of LEL and SOC Predicting OGTT Results (N = 72)

		B	SE	Beta	t	*p*	95% CI	
1	Constant	-.039	.116		-.335	.739	-.270	.192
	SES	-.071	.121	-.074	-.589	.558	-.313	.170
	Maternal Age	.150	.123	.153	1.224	.225	-.095	.395
2	Constant	-.040	.115		-.345	.731	-.269	.190
	SES	-.031	.125	-.032	-.252	.802	-.280	.217
	Maternal Age	.156	.123	.159	1.271	.208	-.089	.402
	SOC	.231	.128	.236	1.798	.077	-.025	.487
	LEL	-.068	.130	-.070	-.526	.600	-.328	.191
3	Constant	.065	.123		.530	.598	-.180	.310
	SES	-.044	.122	-.046	-.364	.717	-.287	.199
	Maternal Age	.138	.120	.140	1.144	.257	-.103	.378
	SOC	.259	.126	.265	2.060	.043*	.008	.511
	LEL	-.070	.127	-.072	-.554	.581	-.324	.183
	Interaction	-.269	.129	-.244	-2.088	.041*	-.526	-.012

Note. *$p < .05$. For full model, R=.354, R^2=.125, ΔR^2=.059.

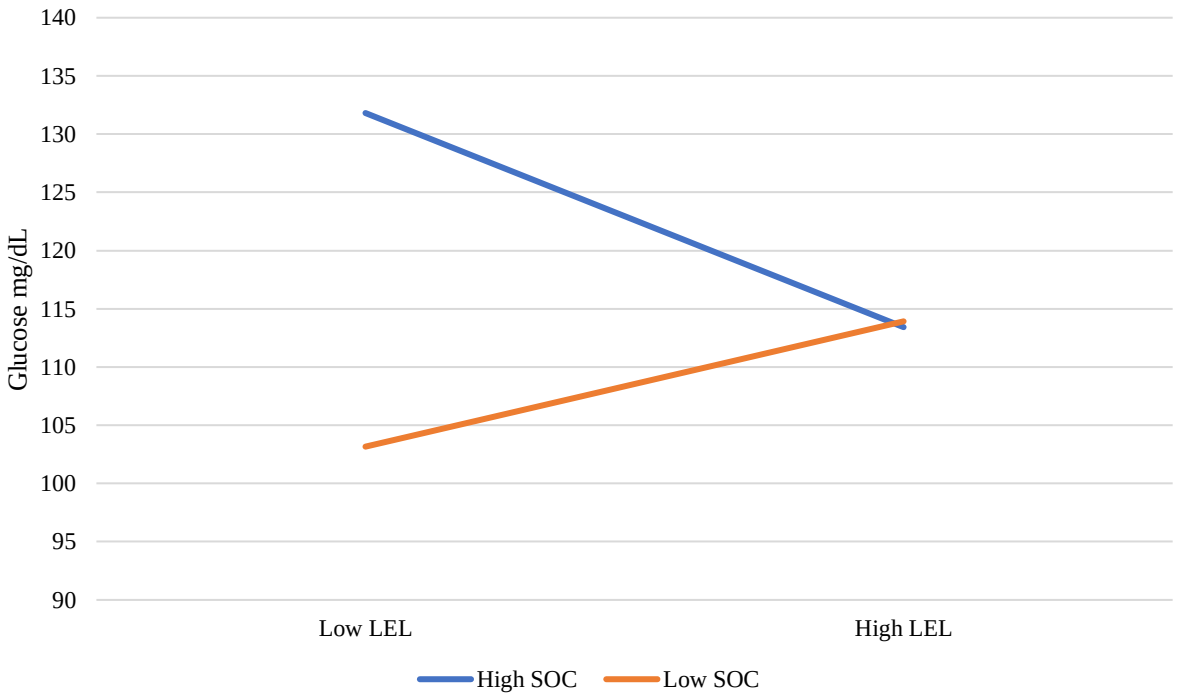

Figure 10. Predicted Values of LEL and SOC Effects on OGTT.
Note. Interaction β = -.269, $p < .05$.

In the analysis involving LEL and SOC predicting OGTT results SOC predicted OGTT results ($\beta = .259$, $p < .05$). In addition, SOC interacted with LEL scores to predict OGTT results ($\beta = -.269$, $p < .05$, $\Delta R^2 = .059$). Full results for this model are in Table 11 and the predicted values are modeled in Figure 10. For women with greater ability to cope with stress, 1SD above the mean of SOC (SD = 10.12, M = 38.658), there was a marginally significant negative relationship between maternal stressful life events and blood glucose metabolization ($B = -9.195$, $SE = 4.921$, $t = -1.869$, $p = .07$), however there wasn't a relationship for women with poorer ability to cope, 1SD below the mean of SOC ($B = 5.380$, $SE = 4.886$, $t = 1.101$, $p = .28$).

Further analysis of this model showed that for those women with more stressful life events, 1SD scores above the mean of LEL (SD = 1.532, M = 3.387), there was no relationship between SOC scores and OGTT results ($B = -.250$, $SE = 4.610$, $t = -.054$, $p = .96$) however there was a positive relationship between SOC and OGTT for those with less stressful life events, 1SD below the mean of LEL ($B = 14.324$, $SE = 5.144$, $t = 2.785$, $p < .01$). These results indicate that for women with fewer stressful life events, LEL scores 1SD below the mean, every 1SD increase in SOC scores was associated with a 14.324 mg/dL increase in OGTT results. Simplified, women with fewer stressful life events and lower ability to cope had better blood sugar metabolization than those with better ability to cope. This interaction appears to be in the opposite direction of that hypothesized. There were no other significant predictors of blood sugar metabolization in this analysis.

Table 12

Interaction of LEL and HR Reactivity Predicting OGTT Results (N = 58)

		B	SE	Beta	t	*p*	95% CI	
1	Constant	.068	.133		.511	.612	-.199	.336
	SES	-.082	.148	-.082	-.556	.581	-.379	.215
	Maternal Age	.151	.142	.156	1.059	.294	-.134	.436
2	Constant	.068	.135		.508	.614	-.202	.339
	SES	-.064	.156	-.064	-.413	.681	-.377	.248
	Maternal Age	.170	.146	.176	1.166	.249	-.122	.462
	HR reactivity	.034	.140	.034	.245	.807	-.246	.315
	LEL	.124	.135	.130	.917	.363	-.147	.395
3	Constant	.039	.132		.294	.770	-.226	.303
	SES	.057	.163	.057	.349	.728	-.270	.384
	Maternal Age	.166	.142	.172	1.173	.246	-.118	.450
	HR reactivity	.012	.136	.012	.091	.928	-.261	.286
	LEL	.204	.137	.214	1.485	.144	-.072	.479
	Interaction	-.258	.128	-.292	-2.020	.049*	-.514	-.002

Note. *$p < .05$. For full model, R=.326, R^2=.106, ΔR^2=.020.

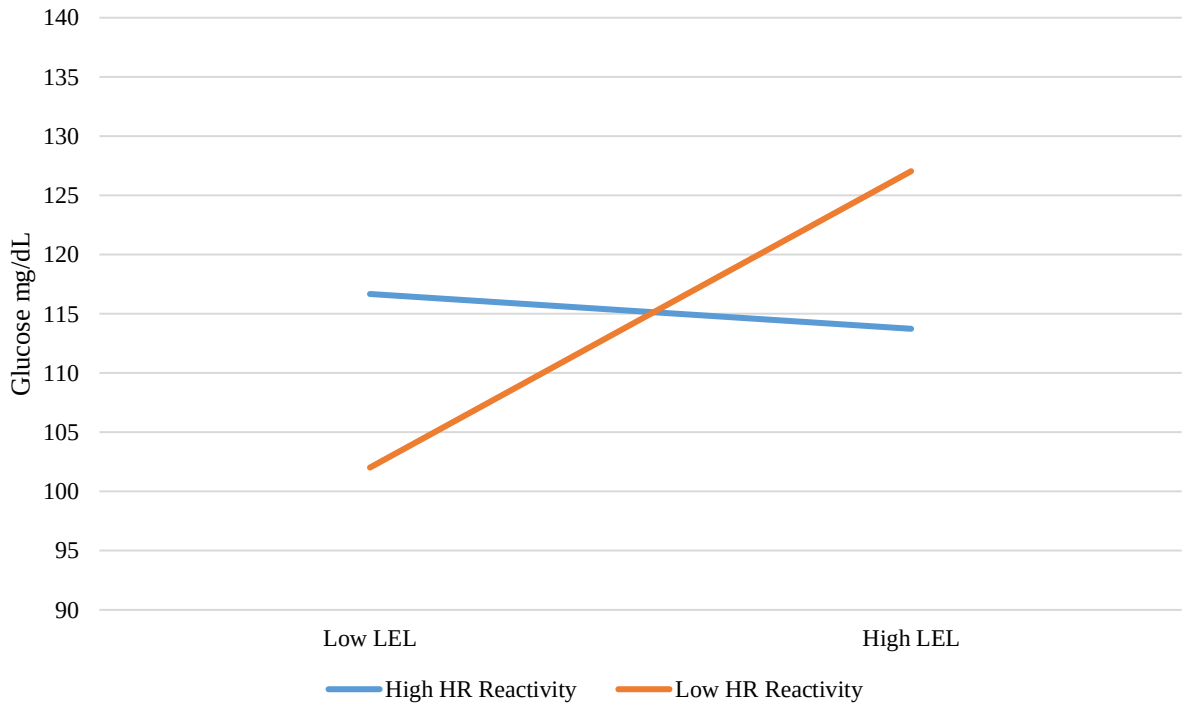

Figure 11. Predicted Values of LEL and HR Effects on OGTT.
Note. Interaction β = -.258, $p < .05$.

In a separate analysis LEL scores interacted with HR reactivity to predict OGTT results (β = -.258, $p < .05$, $\Delta R^2 = .020$). Full results for this analysis are in Table 12 and the predicted values are modeled in Figure 11. For women with HR reactivity that was relatively high at 26.6 beats per minute higher than baseline, 1SD higher than the mean, there was not a significant relationship between LEL and OGTT results (B = -1.469, SE = 4.288, t = -.343, p = .73), however there was a significant positive relationship for those with relatively low HR reactivity at 2.5 beats per minute higher than baseline, 1SD below the mean (B = 12.510, SE = 5.763, t = 2.171, $p < .05$).

Further analyses did not reveal a significant relationship between HR reactivity and OGTT results for those with more stressful life events, LEL scores at 1SD above the mean (B = -6.652, SE = 5.263, t = -1.264, p = .21), or fewer stressful life events, LEL scores at 1SD below the mean (B = 7.326, SE = 4.862, t = 1.507, p = .14). These results indicate that for women with lower HR reactivity, 2.5 beats per minute higher than baseline, for every 1SD increase in LEL scores, OGTT results increased by 12.510 mg/dL. That is, among women with lower HR reactivity those with fewer stressful life events had better blood sugar metabolization, while those with more stressful life events had worse blood sugar metabolization. This interaction appears to be in the opposite of the proposed direction. There were no other significant predictors of blood sugar metabolization in this analysis.

There were no other significant stress by stress reactivity interactions predicting OGTT results (all ps>.05).

4.3. Exploratory Analyses

Stress reactivity Racial and ethnic minorities were underrepresented in this sample, therefore comparisons between racial groups using the proposed model cannot be made. For

exploratory purposes the primary analyses were reanalyzed using only participants who identified as white. This ostensibly reduced variance that may have been caused by the inclusion of various racial and ethnic participants in the analyses of this relatively small sample. The interactions of STAI and SACL Stress ($\beta = .429$, $p < .05$, $\Delta R^2 = .090$), PSS and SACL Stress ($\beta = .305$, $p < .05$, $\Delta R^2 = .048$), and LEL and SOC ($\beta = -.275$, $p < .05$, $\Delta R^2 = .051$) were similarly significant to results using the full sample. However, the interaction of LEL and HR reactivity while in the same direction was no longer significant ($\beta = -.267$, $p = .15$, $\Delta R^2 = -.038$).

Additionally, for white participants, PA scores interacted with SACL Stress scores to predict OGTT results ($\beta = .214$, $p < .05$, $\Delta R^2 = .071$). In this model PA was a significant predictor of OGTT results ($\beta = .285$, $p < .05$). Full results for this analysis are in Table 13 and the predicted values are modeled in Figure 12. For women with SACL Stress scores at 1SD (M = 26.905, SD = 7.022) above the mean, there was a significant positive relationship between PA scores and OGTT results ($B = 13.603$, $SE = 5.016$, $t = 2.712$, $p < .01$). There was no such association for women with a smaller psychological stress response to the V-TSST, SACL Stress scores at 1SD below the mean ($B = 1.947$, $SE = 3.796$, $t = .513$, $p = .61$).

Further analyses revealed there was trend towards a positive relationship between SACL Stress scores and OGTT results for women with higher anxiety, PA scores at 1SD (M = 17.769, SD = 5.126) above the mean ($B = 7.519$, $SE = 3.858$, $t = 1.949$, $p = .06$) but not for those with less anxiety, PA scores at 1SD below the mean ($B = -4.138$, $SE = 5.094$, $t = -.812$, $p = .42$). These results indicate that for women with greater psychological response to stress, for every 1SD increase in PA scores, OGTT results increased by 13.603 mg/dL. Women with a combination of greater stress responses and greater pregnancy anxiety had poorer blood sugar metabolization than those with greater stress responses and less anxiety. These findings support

the hypothesis that a combination of high environmental stress and high stress reactivity may be detrimental to blood sugar metabolization. There were no other significant predictors of OGTT results in this analysis.

There were no other significant stress by stress reactivity interactions predicting OGTT results for white participants (all *p*s>.05).

Table 13

Interaction of PA and SACL Stress Predicting OGTT Results (N = 62)

		B	SE	Beta	t	*p*	95% CI	
1	Constant	-.035	.125		-.280	.780	-.286	.215
	SES	.008	.133	.008	.061	.952	-.258	.274
	Maternal Age	.051	.135	.052	.374	.710	-.220	.322
2	Constant	-.034	.122		-.279	.781	-.278	.210
	SES	.016	.130	.017	.126	.900	-.244	.277
	Maternal Age	.066	.133	.067	.495	.623	-.200	.331
	SACL Stress	.134	.126	.138	1.059	.294	-.119	.387
	PA	.215	.123	.226	1.747	.086	-.031	.462
3	Constant	-.069	.120		-.574	.568	-.309	.172
	SES	.036	.127	.038	.284	.778	-.218	.290
	Maternal Age	.138	.134	.141	1.031	.307	-.130	.406
	SACL Stress	.062	.128	.064	.484	.630	-.195	.318
	PA	.285	.125	.299	2.285	.026*	.035	.535
	Interaction	.214	.105	.284	2.034	.047*	.003	.424

Note. *$p < .05$. For full model, R=.384, R^2=.147, ΔR^2=.071.

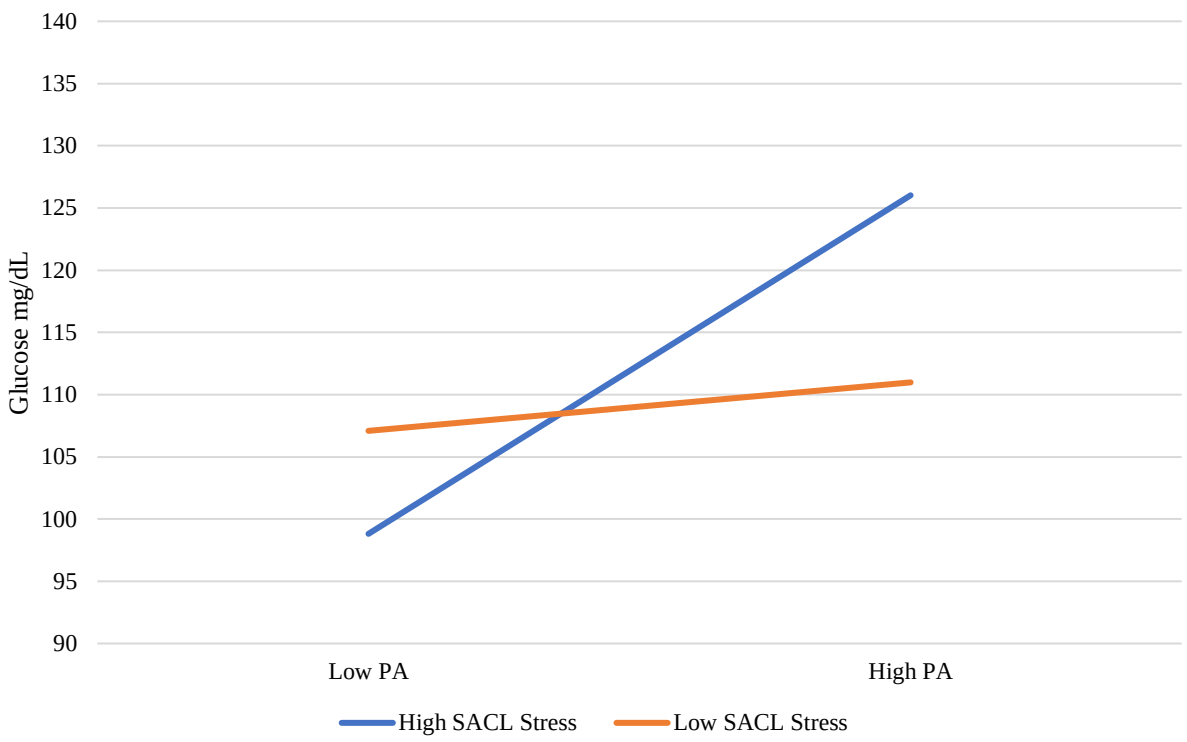

Figure 12. Predicted Values of PA and SACL Stress Effects on OGTT.
Note. Interaction β = .214, $p < .05$.

5. DISCUSSION

Stress reactivity was anticipated to moderate an association between prenatal blood sugar metabolization and environmental stress (Figure 1). Specifically, it was hypothesized that a combination of high environmental stress and high stress reactivity would hinder blood sugar metabolization relative to other combinations of stress and stress reactivity. There was some evidence for this hypothesis, however the results were not ubiquitous. Two regression analyses revealed stress by stress-reactivity interactions predicting OGTT results in the proposed direction.

Associations between maternal anxiety and blood sugar metabolization, and perceived stress and blood sugar metabolization were both moderated by psychological stress during the V-TSST. For women with higher psychological stress reactivity, environmental anxiety over the last few days was positively associated with OGTT results. For those with lower psychological stress reactivity the association between anxiety and OGTT was mitigated. Similarly, those with higher psychological stress reactivity and higher maternal perceived stress over the last month had less blood sugar metabolization than those with high reactivity and low perceived stress, those with low reactivity and high perceived stress, and those with both low reactivity and low stress. These results suggest that there is a psychophysiological connection between maternal stress, stress reactivity and blood sugar metabolization, as a combination of higher anxiety or perceived stress and higher psychological stress response was associated with a decreased ability to metabolize blood sugar efficiently during pregnancy.

However, there were contradictory results involving the measure of stressful life events. In this study stressful life events in the past 12 months interacted with SOC to predict OGTT results. SOC is a measure that indicates one's self perception of her ability to cope with stress

and has been found to be negatively associated with stress reactivity (Antonovsky, 1993). Therefore, it was anticipated that for women with high LEL scores there would be a negative association between SOC and OGTT, and a weaker association for women with low LEL scores. However, for women who reported fewer stressful life events in the past 12 months, sense of coherence was positively related to OGTT results. For women with relatively high LEL scores, SOC was unrelated to OGTT. In other words, these findings seem to suggest that a better perceived ability to cope is related to worse blood sugar metabolism for individuals who have not had as many stressful life events in the past 12 months.

Although past research has shown that SOC is negatively associated with self-perceptions of stress reactivity (Antonovsky, 1993) and psychological distress and heart rate reactivity during stress eliciting lab tasks (McSherry & Holm, 1994), it is possible that higher SOC is not always associated with lower reactivity (Kristenson, Olsson, & Kucinskiene, 2005). In the present study self-perceptions of reactivity (i.e., PSRS) and SACL Stress scores were both positively correlated with SOC. Perhaps higher SOC is associated with greater willingness to engage in stressful events (Van der Colff & Rothmann, 2009; Vogt, Hakanen, Jenny, & Bauer, 2016) and therefore, also with higher physiological reactivity (Hilmert & Kvasnicka, 2010). If this is the case, then the interpretation of results would be that high SOC or high reactivity combined with a low LEL score was associated with the highest OGTT results. A conclusion that is still not consistent with hypotheses. Consideration of another result involving LEL may be helpful.

The association between maternal stressful life events and blood sugar metabolization was moderated by cardiovascular reactivity as measured by HR. For women with lower HR reactivity, there was a positive association between LEL scores and OGTT results. For women with relatively high HR reactivity LEL was unrelated to OGTT. These findings suggest that a

lower HR reactivity is related to worse blood sugar metabolism depending on how many stressful life events have been experienced in the past 12 months. It may be that women with a combination of high LEL scores and low HR reactivity experience a lack of engagement in stressful tasks (Teoh & Hilmert, 2018; Tomaka, Blascovich, Kibler, & Ernst, 1997). However, data concerning task engagement were not collected in the current study.

It is also possible that the LEL measure, which asked about stressful life experiences over the last 12 months, primarily assessed stress experienced prior to pregnancy. This is possible as the questionnaire only accounted for 6 months of pregnancy on average and a number of the events on this questionnaire may be less likely to occur during pregnancy due to current pregnancy status (e.g., having a stillbirth, abortion, had a child). Major stressors that occurred six or more months prior to the OGTT may have effects on physiology and stress reactivity that differ from the effects of more immediate stressors over the past few days or weeks. In fact, major life stressors may have more chronic effects, leading to blunted cardiovascular reactivity due to a downregulation of stress reactivity in response to chronic or traumatic stress (Lovallo, Farag, Sorocco, Cohoon, & Vincent, 2012; Phillips, Carroll, Ring, Sweeting, & West, 2005). If this is the case, then we might see that a combination of high LEL scores and low (possibly blunted) laboratory reactivity, here, HR reactivity, is associated with compromised blood sugar metabolization. To address this possibility, future research should assess chronic stressors and delineate between proximal and more distal life stressors as they may have disparate associations with stress reactivity and blood sugar metabolization during pregnancy.

Revisiting the results involving LEL and SOC (figure 10), if high LEL is associated with blunted physiological stress responding, then we would expect SOC to be associated with OGTT results under conditions of low LEL scores (“reactive” reactivity), but not under conditions of

high LEL scores (blunted reactivity). In addition, if SOC is positively associated with physiological reactivity rather than negatively (see discussion above), then a combination of low LEL and high SOC would be associated with higher OGTT results than all other combinations of these variables, as was found in the present study results. These interpretations are highly speculative, as LEL was not associated with a blunting of stress reactivity in the lab (e.g., there was not a negative correlation between LEL and cardiovascular reactivity), and we have no direct evidence that SOC was associated with higher reactivity (e.g., a positive correlation between SOC and cardiovascular reactivity). However, it is possible that the limitations of this study (see below) affected the ability to detect such associations and future research may benefit from closer examination of these relationships.

It is notable that in this study psychological reactivity but not cortisol reactivity interacted with environmental stress measures to predict OGTT results. Cortisol is known to inhibit glucose storage (Djurhuus et al., 2002; McEwen, 2015; Plat et al., 1996) and women with high baseline cortisol or a combination of high cortisol stress-reactivity and high environmental stress were expected to have diminished blood sugar metabolization. The direction of the association between baseline cortisol and OGTT results was consistent with this ($r = .106$, partial correlation controlling for maternal age, SES and race) but this association and interactions with environmental stress did not approach statistical significance ($ps > .10$). Instead the significant findings with psychological reactivity suggests other physiological mechanisms associated with stress, such as the immune system, may influence blood sugar metabolization during pregnancy. The magnitude of immunoreactivity experienced in responses to stress during pregnancy contributes to possible dysregulation of the immune system which can be detrimental to maternal health and fetal health and development (Christian, 2012a, 2012b). This is a speculative

connection however, as data collection focused on cortisol reactivity and did not include measures of immune reactivity in the present study.

There were limitations to this study. The sample size was relatively small. Improving the size of the sample would further clarify the veracity of the models tested. A sample size of 100 was planned, and although 145 originally signed up, 76 participants had useable data across all study portions for the proposed analyses. This small sample size may have affected our ability to find significant associations. Additionally, our sample consisted mostly of white women which may limit the generalizability of these findings. Specifically, discriminated racial minorities tend to report greater stress, and have greater stress reactivity during pregnancy (Christian, 2012a). Also, African Americans have been shown to have stronger associations between BP and psychosocial stress during pregnancy (Hilmert et al., 2014; Hilmert et al., 2008; Strahm, Hilmert, et al., in preparation). Therefore, the hypothesized associations may be stronger in this population. When primary analyses were run with white women only, the association between stressful life events and blood sugar metabolization was not moderated by HR reactivity as seen in the full sample. For white participants there was an association between pregnancy specific anxiety and blood sugar metabolization moderated by psychological stress response that was consistent with the hypothesis. However, it is not entirely clear why this result only emerged when racial and ethnic minority participants were excluded. Future research should consider racial and ethnic differences in how stress and stress reactivity predict blood sugar metabolization with a larger, more diverse sample.

It is possible that a single measure of stress reactivity at 24-28 weeks gestation is not optimal for detecting reactivity by environmental stress effects on a single measure of blood sugar metabolization in the same time period. Physiological adaptations during mid pregnancy in

both cardiovascular (Christian, 2012a) and endocrine systems (Akinloye, Obikoya, Jegede, Oparinde, & Arowojolu, 2013) have been implicated in the dampening of stress reactivity as pregnancy progresses (Entringer et al., 2010). The V-TSST was conducted between 24-28 weeks to coincide with time in which participants would routinely complete the OGTT (ACOG, 2013). However, reactivity prior to this and perhaps prior to pregnancy may have been more likely to interact with environmental stress during pregnancy to predict blood sugar metabolization. Alternatively, reactivity at 24-28 weeks gestation may be more likely to interact with environmental stress to predict blood sugar metabolization in the 3rd trimester, the period in which GDM usually develops.

It is also possible that focusing on only one measure of blood sugar metabolization at 24-28 weeks limited our ability to detect associations between stress and OGTT results. That is, blood sugar concentrations fluctuate over the course of the day, and associations between blood sugar and stress in healthy individuals may be better detected using continuous glucose monitoring (CGM). Furthermore, CGM in combination with daily dietary information collected through the ASA24® for the days that glucose is recorded, would provide a more in-depth look at day to day blood sugar metabolization. Similarly, finer grained measurement of stress may improve detection of stress associations with blood sugar metabolization. Ecological momentary assessment of stress could be used to gather in vivo recordings of stress and self-reported stress reactivity for those days.

This study provided novel insights into the interactions between maternal stress, stress reactivity and prenatal blood sugar metabolization. Although some results supported the hypothesized effect, that a combination of high environmental stress and high stress reactivity would hinder blood sugar metabolization, other results were not as clear. As is often the case,

these mixed results have raised more questions for future research, which may benefit from assessing reactivity earlier in pregnancy and stress and blood sugar at multiple timepoints during pregnancy. In general, the current results suggest that environmental stress and stress reactivity interact to influence blood sugar metabolization. Assessment of stress reactivity during pregnancy may be a helpful diagnostic tool for determining risk of developing GDM. It is possible that this would be especially true for already at-risk populations (e.g., obese women, older women, women with a history of diabetes, minority women). With more obese women and older women having pregnancies world-wide, this may be an important next step in mitigating the adverse effects of GDM.

REFERENCES

ACOG. (1994). *Precis V: An update in obstetrics and gynecology*: Washington DC: ACOG.

ACOG. (2009). *Ultrasonography in pregnancy*: Washington DC: ACOG.

ACOG. (2013). Practice Bulletin No. 137 Gestational Diabetes Mellitus. *Obstet Gynecol, 122*(2), 406-416. doi:10.1097/01.AOG.0000433006.09219.fl

ACOG. (2014). Safe prevention of the primary cesarean delivery. Obstetric Care Consensus No. 1. *Obstet Gynecol, 123*, 693-711.

Agardh, E. E., Ahlbom, A., Andersson, T., Efendic, S., Grill, V., Hallqvist, J., . . . Ostenson, C. G. (2003). Work stress and low sense of coherence is associated with type 2 diabetes in middle-aged Swedish women. *Diabetes Care, 26*(3), 719-724.

Akinloye, O., Obikoya, O., Jegede, A., Oparinde, D., & Arowojolu, A. (2013). Cortisol plays central role in biochemical changes during pregnancy. *International Journal of Medicine and Biomedical Research, 2*(1), 3-12.

American College of Obstetricians and Gynecologists (ACOG). (1994). *Precis V: An update in obstetrics and gynecology*: Amer College of Obstetricians & Gynecologists.

Anderson, N. B., McNeilly, M., & Myers, H. F. (1993). A biopsychosocial model of race differences in vascular reactivity. In J. Blascovich, E. S. Katkin (Eds.), *Cardiovasuclar reactivity to psychosological stress and disease*. (pp. 83-108) American Psychological Associtaion.

Antonovsky, A. (1993). The structure and properties of the sense of coherence scale. *Social Science & Medicine, 36*(6), 725-733.

Bellamy, L., Casas, J.-P., Hingorani, A. D., & Williams, D. (2009). Type 2 diabetes mellitus after gestational diabetes: a systematic review and meta-analysis. *The Lancet, 373*(9677), 1773-1779.

Black, M. H., Sacks, D. A., Xiang, A. H., & Lawrence, J. M. (2010). Clinical outcomes of pregnancies complicated by mild gestational diabetes mellitus differ by combinations of abnormal oral glucose tolerance test values. *Diabetes Care, 33*. doi:10.2337/dc10-1445

Carr, D. B., & Gabbe, S. (1998). Gestational diabetes: detection, management, and implications. *Clinical Diabetes, 16*(1), 4.

Chan, J. M., Rimm, E. B., Colditz, G. A., Stampfer, M. J., & Willett, W. C. (1994). Obesity, fat distribution, and weight gain as risk factors for clinical diabetes in men. *Diabetes Care, 17*(9), 961-969.

Christian, L. M. (2012a). Physiological reactivity to psychological stress in human pregnancy: Current knowledge and future directions. *Progress in Neurobiology, 99*(2), 106-116. doi:Doi 10.1016/J.Pneurobio.2012.07.003

Christian, L. M. (2012b). Psychoneuroimmunology in pregnancy: immune pathways linking stress with maternal health, adverse birth outcomes, and fetal development. *Neuroscience & Biobehavioral Reviews, 36*(1), 350-361.

Chu, S. Y., Callaghan, W. M., Kim, S. Y., Schmid, C. H., Lau, J., England, L. J., & Dietz, P. M. (2007). Maternal obesity and risk of gestational diabetes mellitus. *Diabetes Care, 30*(8), 2070-2076.

Clausen, T. D., Mathiesen, E. R., Hansen, T., Pedersen, O., Jensen, D. M., Lauenborg, J., . . . Damm, P. (2009). Overweight and the metabolic syndrome in adult offspring of women

with diet-treated gestational diabetes mellitus or type 1 diabetes. *The Journal of Clinical Endocrinology & Metabolism, 94*(7), 2464-2470.

Cohen, S., Kamarck, T., & Mermelstein, R. (1983). A global measure of perceived stress. *Journal of Health & Social Behavior, 24*(4), 385-396.

Cohen, S., Tyrrell, D. A., & Smith, A. P. (1993). Negative life events, perceived stress, negative affect, and susceptibility to the common cold. *J Pers Soc Psychol, 64*(1), 131-140.

Colditz, G. A., Willett, W. C., Rotnitzky, A., & Manson, J. E. (1995). Weight gain as a risk factor for clinical diabetes mellitus in women. *Annals of internal medicine, 122*(7), 481-486.

Contrada, R. J., & Krantz, D. S. (1988). Stress, reactivity, and Type A behavior: Current status and future directions. *Annals of Behavioral Medicine, 10*(2), 64-70.

Daniells, S., Grenyer, B. F., Davis, W. S., Coleman, K. J., Burgess, J.-A. P., & Moses, R. G. (2003). Gestational diabetes mellitus: is a diagnosis associated with an increase in maternal anxiety and stress in the short and intermediate term? *Diabetes Care, 26*(2), 385-389.

de Weerth, C., Gispen-de wied, C. C., Jansen, L. M., & Buitelaar, J. K. (2007). Cardiovascular and cortisol responses to a psychological stressor during pregnancy. *Acta obstetricia et gynecologica Scandinavica, 86*(10), 1181-1192.

Deligiannidis, K. M., Kroll-Desrosiers, A. R., Svenson, A., Jaitly, N., Barton, B. A., Hall, J. E., & Rothschild, A. J. (2016). Cortisol response to the Trier Social Stress Test in pregnant women at risk for postpartum depression. *Arch Womens Ment Health, 19*(5), 789-797.

Dickerson, S. S., & Kemeny, M. E. (2004). Acute Stressors and Cortisol Responses: A Theoretical Integration and Synthesis of Laboratory Research. *Psychological Bulletin, 130*(3), 355-391.

Djurhuus, C. B., Gravholt, C. H., Nielsen, S., Mengel, A., Christiansen, J. S., Schmitz, O. E., & Møller, N. (2002). Effects of cortisol on lipolysis and regional interstitial glycerol levels in humans. *American Journal of Physiology-Endocrinology and Metabolism, 283*(1), E172-E177. doi:10.1152/ajpendo.00544.2001

Dode, M. A. S. d. O., & Santos, I. S. d. (2009). Non classical risk factors for gestational diabetes mellitus: a systematic review of the literature. *Cadernos De Saude Publica, 25*, S341-S359.

Dunkel Schetter, C. (2011). Psychological science on pregnancy: stress processes, biopsychosocial models, and emerging research issues. *Annual review of psychology, 62*, 531-558.

Dunkel Schetter, C., & Glynn, L. M. (2011). Stress in pregnancy: Empirical evidence and theoretical issues to guide interdisciplinary research. In R. J. Contrada & A. Baum (Eds.), *The handbook of stress science: Biology, psychology, and health.* (pp. 321-347). New York, NY: Springer Publishing Co.

Eisenberger, N. I., Taylor, S. E., Gable, S. L., Hilmert, C. J., & Lieberman, M. D. (2007). Neural pathways link social support to attenuated neuroendocrine stress responses. *Neuroimage, 35*(4), 1601-1612. doi:S1053-8119(07)00085-7 [pii]10.1016/j.neuroimage.2007.01.038

Entringer, S., Buss, C., Shirtcliff, E. A., Cammack, A. L., Yim, I. S., Chicz-DeMet, A., . . . Wadhwa, P. D. (2010). Attenuation of maternal psychophysiological stress responses and

the maternal cortisol awakening response over the course of human pregnancy. *Stress, 13*(3), 258-268.

Eriksson, A. K., van den Donk, M., Hilding, A., & Ostenson, C. G. (2013). Work stress, sense of coherence, and risk of type 2 diabetes in a prospective study of middle-aged Swedish men and women. *Diabetes Care, 36*(9), 2683-2689. doi:10.2337/dc12-1738

Faulenbach, M., Uthoff, H., Schwegler, K., Spinas, G., Schmid, C., & Wiesli, P. (2012). Effect of psychological stress on glucose control in patients with type 2 diabetes. *Diabetic Medicine, 29*(1), 128-131.

Federenko, I. S., Nagamine, M., Hellhammer, D. H., Wadhwa, P. D., & Wüst, S. (2004). The Heritability of Hypothalamus Pituitary Adrenal Axis Responses to Psychosocial Stress Is Context Dependent. *The Journal of Clinical Endocrinology & Metabolism, 89*(12), 6244-6250. doi:10.1210/jc.2004-0981

Ferguson, S., Davis, D., Browne, J., & Taylor, J. (2015). Examining the validity and reliability of Antonovsky's Sense of Coherence Scale in a population of pregnant Australian women. *Evaluation & the health professions, 38*(2), 280-289.

Getahun, D., Fassett, M. J., & Jacobsen, S. J. (2010). Gestational diabetes: risk of recurrence in subsequent pregnancies. *American Journal of Obstetrics and Gynecology, 203*(5), 467. e461-467. e466.

Glynn, L. M., Christenfeld, N., & Gerin, W. (1997). Implications of alternative methods of computing blood pressure means. *Blood Press Monit, 2*(4), 175-178.

Glynn, L. M., Dunkel Schetter, C., Wadhwa, P. D., & Sandman, C. A. (2004). Pregnancy affects appraisal of negative life events. *J Psychosom Res, 56*(1), 47-52.

Glynn, L. M., Wadhwa, P. D., Dunkel-Schetter, C., Chicz-Demet, A., & Sandman, C. A. (2001). When stress happens matters: effects of earthquake timing on stress responsivity in pregnancy. *Am J Obstet Gynecol, 184*(4), 637-642.

Goodman, W. K., Janson, J., & Wolf, J. M. (2017). Meta-analytical assessment of the effects of protocol variations on cortisol responses to the Trier Social Stress Test. *Psychoneuroendocrinology, 80*, 26-35.

Guardino, C. M., & Dunkel Schetter, C. (2014). Understanding Pregnancy Anxiety. *Zero to Three, 34*(4), 12-21.

Haffner, S. M. (1998). Epidemiology of type 2 diabetes: risk factors. *Diabetes Care, 21*(Supplement 3), C3-C6.

Hane, A. A., & Fox, N. A. (2006). Ordinary variations in maternal caregiving influence human infants' stress reactivity. *Psychological Science, 17*(6), 550-556.

Heinrichs, M., Baumgartner, T., Kirschbaum, C., & Ehlert, U. (2003). Social support and oxytocin interact to suppress cortisol and subjective responses to psychosocial stress. *Biological Psychiatry, 54*(12), 1389-1398.

Hilmert, C. J., Christenfeld, N., & Kulik, J. A. (2002). Audience status moderates the effects of social support and self-efficacy on cardiovascular reactivity during public speaking. *Annals of Behavioral Medicine, 24*(2), 122-131.

Hilmert, C. J., Dominguez, T. P., Schetter, C. D., Srinivas, S. K., Glynn, L. M., Hobel, C. J., & Sandman, C. A. (2014). Lifetime racism and blood pressure changes during pregnancy: Implications for fetal growth. *Health Psychol, 33*(1), 43-51. doi:10.1037/a0031160

Hilmert, C. J., Kulik, J. A., & Christenfeld, N. (2002). The varied impact of social support on cardiovascular reactivity. *Basic and Applied Social Psychology, 24*(3), 229-240.

Hilmert, C. J., Kvasnicka-Gates, L., Teoh, A. N., Bresin, K., & Fiebiger, S. (2016). Major flood related strains and pregnancy outcomes. *Health Psychology, 35*(11), 1189.

Hilmert, C. J., Schetter, C. D., Dominguez, T. P., Abdou, C., Hobel, C. J., Glynn, L., & Sandman, C. (2008). Stress and blood pressure during pregnancy: Racial differences and associations with birthweight. *Psychosomatic Medicine, 70*(1), 57-64. doi:10.1097/PSY.0b013e31815c6d96

Hilmert, C. J., Teoh, A. N., & Roy, M. M. (2013). Effort and negative affect interact to predict cardiovascular responses to stress. *Psychol Health, 29*(1), 64-80. doi:10.1080/08870446.2013.825917

Horsch, A., Kang, J. S., Vial, Y., Ehlert, U., Borghini, A., Marques-Vidal, P., . . . Puder, J. J. (2016). Stress exposure and psychological stress responses are related to glucose concentrations during pregnancy. *British Journal of Health Psychology*, *21*(3), 712-729.

Hosler, A. S., Nayak, S. G., & Radigan, A. M. (2011). Stressful events, smoking exposure and other maternal risk factors associated with gestational diabetes mellitus. *Paediatric and perinatal epidemiology*, *25*(6), 566-574.

Hunt, K. J., & Schuller, K. L. (2007). The increasing prevalence of diabetes in pregnancy. *Obstetrics and Gynecology Clinics, 34*(2), 173-199.

Jansen, J., Schreuder, J., Mulier, J. P., Smith, N., Settels, J., & Wesseling, K. (2001). A comparison of cardiac output derived from the arterial pressure wave against thermodilution in cardiac surgery patients. *British journal of anaesthesia, 87*(2), 212-222.

Kim, C. (2014). Maternal outcomes and follow-up after gestational diabetes mellitus. *Diabetic Medicine, 31*(3), 292-301.

King, M., Burrows, G., & Stanley, G. (1983). Measurement of stress and arousal: Validation of the stress/arousal adjective checklist. *British journal of psychology, 74*(4), 473-479.

Kipnis, V., Subar, A. F., Midthune, D., Freedman, L. S., Ballard-Barbash, R., Troiano, R. P., . . . Carroll, R. J. (2003). Structure of dietary measurement error: results of the OPEN biomarker study. *American Journal of Epidemiology, 158*(1), 14-21.

Kirschbaum, C., Pirke, K.-M., & Hellhammer, D. H. (1993). The "Trier Social Stress Test": A tool for investigating psychobiological stress responses in a laboratory setting. *Neuropsychobiology, 28*(1-2), 76-81.

Kirschbaum, C., Prussner, J. C., Stone, A. A., Federenko, I., Gaab, J., Lintz, D., . . . Hellhammer, D. H. (1995). Persistent high cortisol responses to repeated psychological stress in a subpopulation of healthy men. *Psychosom Med, 57*(5), 468-474.

Klonoff-Cohen, H. S., Cross, J. L., & Pieper, C. F. (1996). Job stress and preeclampsia. *Epidemiology, 7*(3), 245-249.

Kozhimannil, K. B., Pereira, M. A., & Harlow, B. L. (2009). Association between diabetes and perinatal depression among low-income mothers. *JAMA, 301*(8), 842-847.

Krebs-Smith, S. M., Pannucci, T. E., Subar, A. F., Kirkpatrick, S. I., Lerman, J. L., Tooze, J. A., . . . Reedy, J. (2018). Update of the healthy eating index: HEI-2015. *Journal of the Academy of Nutrition and Dietetics, 118*(9), 1591-1602.

Kristenson, M., Olsson, A. G., & Kucinskiene, Z. (2005). Good self-rated health is related to psychosocial resources and a strong cortisol response to acute stress: the LiVicordia study of middle-aged men. *International Journal of Behavioral Medicine, 12*(3), 153.

Lauenborg, J., Mathiesen, E., Hansen, T., Glumer, C., Jørgensen, T., Borch-Johnsen, K., . . . Damm, P. (2005). The prevalence of the metabolic syndrome in a Danish population of

women with previous gestational diabetes mellitus is three-fold higher than in the general population. *The Journal of Clinical Endocrinology & Metabolism, 90*(7), 4004-4010.

Lovallo, W. R. (2013). Early life adversity reduces stress reactivity and enhances impulsive behavior: Implications for health behaviors. *International Journal of Psychophysiology, 90*(1), 8-16.

Lovallo, W. R., Farag, N. H., Sorocco, K. H., Cohoon, A. J., & Vincent, A. S. (2012). Lifetime adversity leads to blunted stress axis reactivity: studies from the Oklahoma Family Health Patterns Project. *Biological Psychiatry, 71*(4), 344-349.

Low, C. A., Salomon, K., & Matthews, K. A. (2009). Chronic life stress, cardiovascular reactivity, and subclinical cardiovascular disease in adolescents. *Psychosomatic Medicine, 71*(9), 927.

Lyssenko, V., Jonsson, A., Almgren, P., Pulizzi, N., Isomaa, B., Tuomi, T., . . . Groop, L. (2008). Clinical risk factors, DNA variants, and the development of type 2 diabetes. *New England Journal of Medicine, 359*(21), 2220-2232.

Madhu, S., Siddiqui, A., Desai, N., Sharma, S., & Bansal, A. (2019). Chronic stress, sense of coherence and risk of type 2 diabetes mellitus. *Diabetes & Metabolic Syndrome: Clinical Research & Reviews, 13*(1), 18-23.

McEwen, B. S. (2015). Biomarkers for assessing population and individual health and disease related to stress and adaptation. *Metabolism, 64*(3), S2-S10.

McSherry, W. C., & Holm, J. E. (1994). Sense of coherence: Its effects on psychological and physiological processes prior to, during, and after a stressful situation. *Journal of clinical psychology, 50*(4), 476-487.

Meaney, M. J. (2001). Maternal Care, Gene Expression, and the Transmission of Individual Differences in Stress Reactivity Across Generations. *Annual Review of Neuroscience, 24*(1), 1161-1192. doi:10.1146/annurev.neuro.24.1.1161

Miller, G. E., Chen, E., & Zhou, E. S. (2007). If it goes up, must it come down? Chronic stress and the hypothalamic-pituitary-adrenocortical axis in humans. *Psychological Bulletin, 133*(1), 25.

Minkel, J., Moreta, M., Muto, J., Htaik, O., Jones, C., Basner, M., & Dinges, D. (2014). Sleep deprivation potentiates HPA axis stress reactivity in healthy adults. *Health Psychology, 33*(11), 1430.

Monnier, L., Mas, E., Ginet, C., Michel, F., Villon, L., Cristol, J.-P., & Colette, C. (2006). Activation of oxidative stress by acute glucose fluctuations compared with sustained chronic hyperglycemia in patients with type 2 diabetes. *JAMA, 295*(14), 1681-1687.

Morris, N., Toms, M., Easthope, Y., & Biddulph, J. (1998). Mood and cognition in pregnant workers. *Applied Ergonomics, 29*(5), 377-381.

Moses, R. G. (1996). The recurrence rate of gestational diabetes in subsequent pregnancies. *Diabetes Care, 19*(12), 1348-1350.

Moshfegh, A. J., Rhodes, D. G., Baer, D. J., Murayi, T., Clemens, J. C., Rumpler, W. V., . . . Ingwersen, L. A. (2008). The US Department of Agriculture Automated Multiple-Pass Method reduces bias in the collection of energy intakes–. *The American journal of clinical nutrition, 88*(2), 324-332.

O'Sullivan, J. B., Charles, D., Mahan, C. M., & Dandrow, R. V. (1973). Gestational diabetes and perinatal mortality rate. *Am J Obstet Gynecol, 116*.

Obel, C., Hedegaard, M., Henriksen, T. B., Secher, N. J., Olsen, J., & Levine, S. (2005). Stress and salivary cortisol during pregnancy. *Psychoneuroendocrinology, 30*(7), 647-656.

Ode, S., Hilmert, C. J., Zielke, D. J., & Robinson, M. D. (2010). Neuroticism's importance in understanding the daily life correlates of heart rate variability. *Emotion, 10*(4), 536-543. doi:2010-15709-008 [pii]10.1037/a0018698

Organization for Economic Co-operation and Development. (2017). *OECD Health Statistics 2017 - Frequently Requested Data*. Retrieved from: http://stats.oecd.org/index.aspx?DataSetCode=HEALTH_STAT

Phillips, A. C., Carroll, D., Ring, C., Sweeting, H., & West, P. (2005). Life events and acute cardiovascular reactions to mental stress: a cohort study. *Psychosomatic Medicine, 67*(3), 384-392.

Plat, L., Byrne, M. M., Sturis, J., Polonsky, K. S., Mockel, J., Fery, F., & Cauter, E. V. (1996). Effects of morning cortisol elevation on insulin secretion and glucose regulation in humans. *American Journal of Physiology-Endocrinology and Metabolism, 270*(1), E36-E42. doi:10.1152/ajpendo.1996.270.1.E36

Pluess, M., Bolten, M., Pirke, K.-M., & Hellhammer, D. (2010). Maternal trait anxiety, emotional distress, and salivary cortisol in pregnancy. *Biological Psychology, 83*(3), 169-175.

Pluess, M., Wurmser, H., Buske-Kirschbaum, A., Papousek, M., Pirke, K.-M., Hellhammer, D., & Bolten, M. (2012). Positive life events predict salivary cortisol in pregnant women. *Psychoneuroendocrinology, 37*(8), 1336-1340.

Reedy, J., Lerman, J. L., Krebs-Smith, S. M., Kirkpatrick, S. I., Pannucci, T. E., Wilson, M. M., . . . Tooze, J. A. (2018). Evaluation of the Healthy Eating Index-2015. *Journal of the Academy of Nutrition and Dietetics, 118*(9), 1622-1633.

Rini, C., Dunkel-Schetter, C., Wadhwa, P. D., & Sandman, C. A. (1999). Psychological adaptation and birth outcomes: The role of personal resources, stress, and sociocultural context in pregnancy. *Health Psychology, 18*(4), 333-345.

Robinson, M. D., Ode, S., & Hilmert, C. J. (2011). Regulated and unregulated forms of cortisol reactivity: a dual vulnerability model. *Psychosom Med, 73*(3), 250-256. doi:PSY.0b013e3182099deb [pii]10.1097/PSY.0b013e3182099deb

Robinson, M. D., Ode, S., & Hilmert, C. J. (2014). Cortisol reactivity in the laboratory predicts ineffectual attentional control in daily life. *Psychol Health*. doi:10.1080/08870446.2014.884224

Ross, G. (2006). Gestational diabetes. *Aust Fam Physician, 35*(6), 392-396.

Ryser Rüetschi, J., Jornayvaz, F., Rivest, R., Huhn, E., Irion, O., & Boulvain, M. (2016). Fasting glycaemia to simplify screening for gestational diabetes. *BJOG: An International Journal of Obstetrics & Gynaecology, 123*(13), 2219-2222.

Sandman, C. A., Glynn, L., Schetter, C. D., Wadhwa, P., Garite, T., Chicz-DeMet, A., & Hobel, C. (2006). Elevated maternal cortisol early in pregnancy predicts third trimester levels of placental corticotropin releasing hormone (CRH): priming the placental clock. *Peptides, 27*(6), 1457-1463. doi:10.1016/j.peptides.2005.10.002

Sapolsky, R. M. (2004). *Why zebras don't get ulcers* (3rd ed.). New York: Times Books.

Saunders, T. A., Lobel, M., Veloso, C., & Meyer, B. A. (2006). Prenatal maternal stress is associated with delivery analgesia and unplanned cesareans. *Journal of Psychosomatic Obstetrics & Gynecology, 27*(3), 141-146.

Schlotz, W., Yim, I. S., Zoccola, P. M., Jansen, L., & Schulz, P. (2011). The perceived stress reactivity scale: Measurement invariance, stability, and validity in three countries. *Psychological Assessment, 23*(1), 80.

Schommer, N. C., Hellhammer, D. H., & Kirschbaum, C. (2003). Dissociation between reactivity of the hypothalamus-pituitary-adrenal axis and the sympathetic-adrenal-medullary system to repeated psychosocial stress. *Psychosomatic Medicine, 65*(3), 450-460.

Schutte, A. E., Huisman, H. W., van Rooyen, J. M., Oosthuizen, W., & Jerling, J. C. (2003). Sensitivity of the Finometer device in detecting acute and medium-term changes in cardiovascular function. *Blood pressure monitoring, 8*(5), 195-201.

Siddiqui, A., Madhu, S., Sharma, S., & Desai, N. (2015). Endocrine stress responses and risk of type 2 diabetes mellitus. *Stress, 18*(5), 498-506.

Smyth, J., Ockenfels, M. C., Porter, L., Kirschbaum, C., Hellhammer, D. H., & Stone, A. A. (1998). Stressors and mood measured on a momentary basis are associated with salivary cortisol secretion. *Psychoneuroendocrinology, 23*(4), 353-370.

Spielberger, C. D. (1985). Assessment of state and trait anxiety: Conceptual and methodological issues. *Southern Psychologist, 2*(4), 6-16.

Spirito, A., Ruggiero, L., Bowen, A., McGarvey, S., Bond, A., & Coustan, D. (1991). Stress, coping, and social support as mediators of the emotional status of women with gestational diabetes. *Psychology and Health, 5*(2), 111-120.

Steptoe, A., Hackett, R. A., Lazzarino, A. I., Bostock, S., La Marca, R., Carvalho, L. A., & Hamer, M. (2014). Disruption of multisystem responses to stress in type 2 diabetes: investigating the dynamics of allostatic load. *Proceedings of the National Academy of Sciences, 111*(44), 15693-15698.

Strahm, A. M., Hilmert, C. J., Teoh, A. N., Sandman, C., Glynn, L., Hobel, C. J., & Dunkel Schetter, C. (in preparation). Blood pressure sensitivity to stress during pregnancy in African Americans and Non-Hispanic Whites.

Strahm, A. M., Rued, H. A., Bagne, A., & Hilmert, C. J. (in preparation). Using virtual environments to reliably elicit stress reactivity in the laboratory.

Surwit, R. S., Schneider, M. S., & Feinglos, M. N. (1992). Stress and diabetes mellitus. *Diabetes Care, 15*(10), 1413-1422.

Susman, E. J., Dorn, L. D., Inoff-Germain, G., Nottelmann, E. D., & Chrousos, G. P. (1997). Cortisol reactivity, distress behavior, and behavioral and psychological problems in young adolescents: A longitudinal perspective. *Journal of Research on Adolescence, 7*(1), 81-105.

Taylor, S. E., Burklund, L. J., Eisenberger, N. I., Lehman, B. J., Hilmert, C. J., & Lieberman, M. D. (2008). Neural bases of moderation of cortisol stress responses by psychosocial resources. *Journal of Personality and Social Psychology, 95*(1), 197-211. doi:10.1037/0022-3514.95.1.197

Taylor, S. E., Way, B. M., Welch, W. T., Hilmert, C. J., Lehman, B. J., & Eisenberger, N. I. (2006). Early Family Environment, Current Adversity, the Serotonin Transporter Promoter Polymorphism, and Depressive Symptomatology. *Biological Psychiatry, 60*(7), 671-676. doi:10.1016/j.biopsych.2006.04.019

Teoh, A. N., & Hilmert, C. J. (2018). Social support as a comfort or an encouragement: A systematic review on the contrasting effects of social support on cardiovascular reactivity. *British Journal of Health Psychology, 23*(4), 1040-1065. doi:10.1111/bjhp.12337

Tomaka, J., Blascovich, J., Kibler, J., & Ernst, J. M. (1997). Cognitive and physiological antecedents of threat and challenge appraisal. *Journal of Personality & Social Psychology, 73*(1), 63-72.

Treiber, F. A., Kamarck, T., Schneiderman, N., Sheffield, D., Kapuku, G., & Taylor, T. (2003). Cardiovascular reactivity and development of preclinical and clinical disease states. *Psychosomatic Medicine, 65*(1), 46-62.

Van der Colff, J. J., & Rothmann, S. (2009). Occupational stress, sense of coherence, coping, burnout and work engagement of registered nurses in South Africa. *SA Journal of Industrial Psychology, 35*(1), 1-10.

Vogt, K., Hakanen, J. J., Jenny, G. J., & Bauer, G. F. (2016). Sense of coherence and the motivational process of the job-demands–resources model. *Journal of Occupational Health Psychology, 21*(2), 194.

Wadhwa, P. D., Sandman, C. A., Porto, M., Dunkel-Schetter, C., & Garite, T. J. (1993). The association between prenatal stress and infant birth weight and gestational age at birth: a prospective investigation. *Am J Obstet Gynecol, 169*(4), 858-865.

WHO. (1999). *Definition, diagnosis and classification of diabetes mellitus and its complications: report of a WHO consultation. Part 1, Diagnosis and classification of diabetes mellitus*: Geneva: World Health Organization.

WHO. (2011). *WHO recommendations for induction of labour*: Geneva: World Health Organization.

Wilson, P. W., Meigs, J. B., Sullivan, L., Fox, C. S., Nathan, D. M., & D'Agostino, R. B. (2007). Prediction of incident diabetes mellitus in middle-aged adults: the Framingham Offspring Study. *Archives of Internal Medicine, 167*(10), 1068-1074.

Wu, T., Snieder, H., & de Geus, E. (2010). Genetic influences on cardiovascular stress reactivity. *Neuroscience & Biobehavioral Reviews, 35*(1), 58-68.

Zhang, S. C., Ding, Z. Y., Liu, H., Chen, Z. X., Wu, J. H., Zhang, Y. D., & Yu, Y. X. (2013). Association Between Mental Stress and Gestational Hypertension/Preeclampsia: A Meta-Analysis. *Obstetrical & Gynecological Survey, 68*(12), 825-834.