Exploring the relationships between food insecurity, maternal stress and maternal / infant health outcomes during the COVID-19 pandemic: a DOHaD framework

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A thesis submitted in partial fulfillment of the requirements for the

Master of Science degree in Interdisciplinary Health Sciences

Presented to the Interdisciplinary School of Health Sciences

Faculty of Health Sciences

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Submitted October 2024

Abstract

Adverse psychosocial, lifestyle and environmental exposures during the first 1,000 days of life can result in undesirable offspring health outcomes, including increased risk of chronic diseases in adulthood. Food insecurity (FI) and heightened stress are factors that may contribute to adverse developmental programming events, which were exacerbated for many Canadians during the COVID-19 pandemic. This study aimed to examine the relationships between maternal FI and stress during the COVID-19 pandemic and how they were associated with maternal gestational weight gain (GWG) and newborn birth weight in a Canadian pregnant cohort. Data were collected retrospectively from 273 pregnant participants of varying socioeconomic status who were pregnant and delivered infants during the pandemic (March 2020–March 2023). The participants responded to an online survey developed from previously validated questionnaires addressing FI, pandemic-related stress, self-reported GWG, and infant birth weight. Over half (55%) of the participants experienced household FI, while one fifth (20%) reported heightened stress related to pregnancy preparedness and over one third (34%) reported heightened stress related to COVID-19 infection. Participants from food secure and insecure households differed significantly in age, sexual orientation, household type, total household income, housing status, number of kids in the household and whether the pregnancy was planned or unplanned ($p < 0.01$). Heightened stress was also significantly associated these same factors except from age group and housing status ($p < 0.05$). GWG outside the recommended guidelines was reported by 77% of participants; however, no associations were observed with FI or pandemic-related stress. Infant birth weight extremes (small or large for gestational age) were reported by 32% of participants. While no associations were observed with FI status, positive associations between birth weight extremes and heightened stress related to both pregnancy preparedness and COVID-19 infection

were found ($p < 0.02$). The results of this study provide a better understanding of the extent of FI, gestational stress, and factors potentially influencing them during the COVID-19 pandemic in a Canadian pregnant population. Recognizing the specific challenges faced by vulnerable pregnant populations can guide tailored interventions and programs aimed at improving maternal and infant health and well-being during emergency/pandemics.

Résumé

Le développement durant les 1000 premiers jours de la vie, de la conception jusqu'à la petite enfance, peut être affecté négativement par divers facteurs psychosociaux, environnementaux et liés au mode de vie, augmentant le risque de maladies chroniques à l'âge adulte. L'insécurité alimentaire (IA) et le stress maternel pendant la pandémie de COVID-19 ont été exacerbés et pourraient avoir influencé le développement fœtal. Cette étude visait à examiner les relations entre l'IA, le stress maternel et leurs effets sur le gain de poids gestationnel (GPG) des mères et le poids des nouveau-nés canadiens pendant la pandémie de COVID-19. Les données ont été collectées rétrospectivement auprès de 273 femmes enceintes canadiennes de différents milieux socio-économiques, ayant accouché entre mars 2020 et mars 2023. Une enquête en ligne utilisant des questionnaires validés a permis d'évaluer l'IA, le stress, le GPG et le poids du nouveau-né à la naissance. Plus de la moitié (55%) des participantes ont souffert d'IA, et une proportion importante a vécu un stress accru lié soit à la préparation à la grossesse (20%) ou à l'infection par la COVID-19 (34%). L'IA était significativement associée à l'âge, l'orientation sexuelle, type de ménage, revenu total du ménage, type de logement, nombre d'enfants dans le ménage et si la grossesse était planifiée ou non ($p<0,01$). Le stress accru était également significativement associé à ces mêmes facteurs, à l'exception de l'âge et du statut de logement ($p<0,05$). La majorité des femmes (77%) ont rapporté un gain de poids gestationnel

non conforme aux recommandations. Les poids extrêmes à la naissance (faibles ou élevés; 32%) étaient associés à un stress accru lié à la fois à la préparation de la grossesse et à l'infection par la COVID-19 ($p<0,02$). Ces résultats soulignent l'importance de mieux comprendre les conséquences de l'IA et du stress maternel pendant la grossesse, particulièrement en situation de crise telle que la pandémie de COVID-19. Identifier les défis spécifiques rencontrés par les populations vulnérables enceintes peut guider le développement d'interventions visant à améliorer la santé maternelle et infantile dans des contextes d'urgence ou de pandémie.

Acknowledgments

This thesis is dedicated to my late father who inspired me to be the greatest I could be. His love, courage, passion, and dedication to his family and to learning pushed me to strive beyond imagination and aim for opportunities that I did not even believe I could attain. I cannot begin to express my gratitude to the entire village that has been with me since the beginning of this incredible journey in 2021. Firstly, I want to thank God for his blessings, and knowledge throughout this journey. Secondly, I want to thank my supervisors, Dr. Shannon Bainbridge and Dr. Benedicte Fontaine Bisson, who have not only been excellent advisors but also great role models. I want to thank you both for supporting me throughout the ups and downs, from setbacks with ethics, data collection, to memorable conferences, and team gatherings. Thank you for challenging me to produce high-quality work, and for pushing me to think outside of the box. I sincerely appreciate your patience, your compassion, and your leadership. I could not have asked for a better team to get me through the last three years. To my thesis advisory committee, Dr. Alex Dumas and Dr. Kristi Adamo, thank you for offering your knowledge, and time for my project. Your respective expertise and points of view were instrumental in shaping me as a researcher, and I am sincerely thankful for your commitment. To my family, what can I say rather than thank you from the bottom of my heart. You've been supportive of my entire academic journey for as long as I can remember, and I hope to continue making you proud. To my academic colleagues and mentors, Dr. Gloire Rubambiza, Alixe, Julia, Raphaelle, Dina, Malik, Coralie, Joie, Rewa, Nurasha, Carole and everyone else, thank you for your endless support, and for always providing an intellectually stimulating environment. To my brothers and friends, David, Niyo, Naya, Sam, Jack, Shore, Racheal, Glow, Danny, Claire, Jacob, Jonathan, Joachim, Jedija, Julie, Brett, and Aaliyah, thank you!

Table of Contents

List of figures and tables

Tables

Appendices

ABBREVIATIONS & DEFINITIONS

AAP	American Academy of Pediatrics
ACOG	American College of Obstetricians and Gynecologists
AGA	Appropriate for gestational age
BIPOC	Black, Indigenous, and People of Colour
BMI	Body Mass Index
CDC	Centers for Disease Control and Prevention
CCHS	Canadian Community Health Survey
CMES	Canadian Maternity Experience Survey
CPNP	Canadian Prenatal Nutrition Program
CPSS	Canadian Perinatal Surveillance System
COVID-19	Coronavirus Disease 2019
DOHAD	Developmental Origins of Health and Disease
Emat Health Survey	Electronic Maternal Health Survey
FAO	Food and Agriculture Organization
FI	Food Insecurity
GPG	Gain de Poids Gestationnel
GWG	Gestational Weight Gain
HFSSM	Household Food Security Survey Module
HPA	Hypothalamic-Pituitary-Adrenal (axis)
IGA	Inappropriate Gestational Age
IOM	Institute of Medicine

LBW	Low Birth Weight
LGA	Large for Gestational Age
LGBTQ+	Lesbian, Gay, Bisexual, Transgender, Queer/Questioning & others
MES	Maternity Experiences Survey
PARs	Predictive Adaptive Responses
PREPS	Pandemic-Related Pregnancy Stress
SARS-CoV-2	Severe Acute Respiratory Syndrome Coronavirus 2
SDH	Social Determinants of Health
SGA	Small for Gestational Age
VLBW	Very Low Birth Weigh

CHAPTER 1: INTRODUCTION

1.1 Introduction

Adverse conditions related to psychosocial, lifestyle, and environmental factors during critical windows of human development can have lasting health impacts, associated with the future development of chronic diseases. One major window of interest is pregnancy, a complex yet critical time of behavioural, psychological and physiological changes (Atkinson & Teychenne, 2022). According to the Food and Agriculture Organization (FAO), which defines Food Insecurity (FI) as the lack of consistent access to sufficient, safe, and nutritious food necessary for normal growth, development, and maintaining an active, healthy life, an estimated 30% of the global population was moderately or severely food insecure in 2022 (FAO, 2023). Furthermore, approximately 25% of the general population experienced heightened stress during the COVID-19 pandemic (Mahmud et al., 2023). Both FI and heightened stress levels serve as strong mediators of adverse in utero exposure, potentially amplifying the risks to maternal and fetal health. However, individuals exposed to either natural disasters, emergency and conflict situations during pregnancy are generally at increased risks for both FI and elevated gestational stress, placing their fetus at higher risk for adverse health outcomes (World Health Organization [WHO], 2016). Due to the increased vulnerability period during pregnancy, the American Academy of Pediatrics (AAP) and American College of Obstetricians and Gynecologists (ACOG) have recommended that pregnant individuals be screened for a number of psychosocial and lifestyle factors such as stress, nutrition and barriers to care, with the aim of improving their health outcomes as well as that of their infants (AAP & ACOG, 2017). Although some of the above risk factors can be modified, research consistently shows that all pregnant individuals are vulnerable to at least one adverse pregnancy exposure that could impact their health outcomes

(Poels et al., 2017; Rezaee et al., 2022). However, despite recommendations, psychosocial and lifestyle exposures are still not regularly assessed in routine obstetric practice as emphasis is often placed on biological factors (Blount et al., 2021; Woods et al., 2010). In the current thesis, two adverse psychosocial pregnancy exposures that were considerably exacerbated during the COVID-19 pandemic for many Canadians, food insecurity (FI) and elevated stress levels during the perinatal period, are specifically examined. Sociodemographic factors that placed pregnant Canadians at risk for experiencing these exposures, and their associations with adverse pregnancy outcomes were also studied.

Obtaining an adequate and healthy diet during the perinatal period is crucial due to the elevated maternal nutritional needs to support the developing fetus, and the fact that pregnancy and childbirth, especially during a public health disaster like the COVID-19 pandemic, exert extra pressure on pregnant individuals' mental state and resources, increasing their risk for adverse maternal-infant health outcomes (Blumenshine et al., 2010; Marshall et al., 2022; Ramakrishnan et al., 2012). A 2019 household FI report in the United States showed that approximately 1 in 3 individuals seen for prenatal care could not afford to purchase the food needed to support a healthy pregnancy (Coleman-Jensen et al., 2020). FI during pregnancy is associated with increased risk of low birth weight (LBW), premature birth, neonatal mortality and abnormalities, poor maternal dietary quality, inadequate nutrient intake, inappropriate gestational weight gain (GWG) and higher chances of pregnancy anxiety and stress (Augusto et al., 2020; Azevedo et al., 2023; Carmichael et al., 2007; B. Laraia et al., 2015; B. A. Laraia et al., 2010). Despite being documented in the general Canadian population and recognized as a significant social determinant of health driving inequities (Research to identify policy options to reduce food insecurity et al., 2024), FI remains a neglected aspect of routine obstetric care, with

limited evidence documenting its prevalence during pregnancy or effects on maternal-infant health outcomes in the Canadian context (Hutchinson & Tarasuk, 2022; Kirkpatrick & Tarasuk, 2008; Ménard et al., 2020; Oresnik, 2020; Quintanilha et al., 2019; Savard et al., 2012; Tarasuk et al., 2020; Wong et al., 2019). One pre-pandemic Canadian study documented a FI prevalence of approximately 13% among urban pregnant individuals receiving prenatal care in Toronto, Ontario (Shirreff et al., 2021). More research is needed to estimate the prevalence of FI among pregnant populations across Canada to advocate for equitable and reliable public policies, services and resources needed to target and serve vulnerable pregnant populations.

Like FI, prenatal stress is a multifaceted gestational exposure that extends beyond psychological factors, involving various contributing elements that can interact and present in different ways (Jagtap et al., 2023; Kinsella & Monk, 2009). Prenatal stress can be severe (i.e., resulting from trauma), moderate (i.e., resulting from significant life changes), or mild (i.e., resulting from everyday challenges) (Lobel, 1994). Relevant to this thesis are psychosocial stress and pregnancy-specific distress related to changes in personal life, job status, housing, domestic violence, family makeup, concerns about fetal health, pregnancy uncertainty and unpreparedness, etc. (Lobel et al., 2008; Orr et al., 1992), which happened as a result of the COVID-19 pandemic and associated lockdowns (Ataman & Tuncer, 2023; Kolker et al., 2021; Muñoz-Vela et al., 2023). A large body of evidence has shown that psychosocial stress is associated with multiple adverse maternal-infant health outcomes such as inappropriate GWG and poor fetal growth trajectories (Brunton, 2013; Hobel & Culhane, 2003; Mulder et al., 2002; Paarlberg et al., 1995; Wadhwa et al., 1993). Additionally, experiencing FI during pregnancy is also linked to higher stress levels and compromised nutritional habits, making them interrelated gestational exposures (Augusto et al., 2020; B. Laraia et al., 2015; Wolfson et al., 2021). Evidence shows that more

than half (59%) of pregnant individuals surveyed in the United States reported increased stress due to the worry of running out of food or not having any food available during the pandemic (Moyer et al., 2020). On top of intensifying both FI and stress levels, the COVID pandemic affected multiple psychosocial and lifestyle aspects of pregnant individuals, including the type of prenatal care received and worrying about their source of income (Javaid et al., 2021; Kolker et al., 2021; Kotlar et al., 2021; Mari et al., 2023), rendering them more vulnerable. Like pouring gasoline on a fire, the COVID-19 pandemic served to exacerbate conditions of FI in vulnerable pregnant populations, while simultaneously intensifying maternal stress levels – likely contributing to adverse developmental programming events and pregnancy outcomes.

1.2 Purpose statement & thesis structure

The purpose of this thesis was to explore the social determinants of health associated with pandemic-related FI and elevated maternal stress; and the associations between these adverse early life exposures and maternal and newborn health outcomes in Canada. Specific research aims included:

Aim 1.1: Characterizing associations between the social determinants of health and pandemic-related pregnancy FI.

Aim 1.2: Characterizing associations between the social determinants of health and pandemic-related pregnancy stress.

Aim 2.1: Examining associations between pandemic-related FI, and maternal GWG and infant birthweight.

Aim 2.2: Examining associations between pandemic-related pregnancy stress and maternal GWG and infant birthweight.

This thesis consists of four chapters: Chapter one, the current chapter, provides a high-level overview of this thesis's primary objectives and overarching structure. Chapter two gives a more in-depth literature review highlighting the main themes and topics covered in the thesis. Chapter three presents a scientific article aimed for publication in the *Journal of Developmental Origins of Health and Disease*; and finally, chapter four provides an integrated discussion and summary of the main findings, including the interdisciplinary aspects of this project, contributions to the broader scientific knowledge base, implications for public policy, an expanded discussion on study limitations and future avenues of exploration to consider.

CHAPTER 2: LITERATURE REVIEW

2.1 The developmental origins of health and diseases (DOHaD)

Environmental exposures experienced during early life development can significantly impact the long-term health outcomes of a population (Mandy & Nyirenda, 2018). The first 1,000 days of life, from conception to two years of age, is a particularly critical window of development during which all major organ systems demonstrate considerable plasticity and their developmental trajectories can be forever changed by positive or negative environmental exposures, contributing significantly to one's health profile and disease risk in adulthood (Jacob & Hanson, 2020; Moyer et al., 2016; Qiu et al., 2023). The strong evidence that supports the DOHaD paradigm highlights the plasticity and potential vulnerability of the developing fetus, which if subjected to any adverse intrauterine exposures can alter its developmental trajectory to protect its immediate health viability, often at the expense of its long-term health and viability (Gluckman et al., 2005; Hales & Barker, 2001). There is now overwhelming evidence to indicate that the most common and debilitating chronic diseases faced by Canadians today (e.g., cardiovascular disease, diabetes, etc.) can be traced back to adverse developmental programming events of the offspring in early life (Wadhwa et al., 2009). The term 'developmental programming' refers to the permanent alterations in the structure and/or function of developing fetal organ systems following early life exposures (Sutton et al., 2016). The most commonly described mechanism through which fetal programming takes place is lasting epigenetic changes which alter gene expression profiles. However, programming events can also result from irreversible changes to developing organ structures and shifts in the body's natural balance points (homeostatic setpoints) (Mandy & Nyirenda, 2018).

The DOHaD paradigm is founded on landmark epidemiological evidence highlighting the programming effects of altered maternal nutritional status on offspring health outcomes (Uauy et al., 2011). This altered nutrition (i.e., poor diet, decreased intake of fruit and vegetables, milk products, nutrient inadequacies, etc.) often comes as a direct consequence of experiencing FI (Kirkpatrick & Tarasuk, 2008). As a DOHaD exposure, altered nutrition has been associated with functional changes in fetal tissues and organ systems, including the pancreas, the liver and cardiovascular system, thereby predisposing the offspring to chronic diseases in later life (Barker & Clark, 1997; Heindel & Vandenberg, 2015). Evidence from the Dutch famine birth cohort found that undernutrition during pregnancy was strongly associated with poor health and chronic disease in later life of the offspring, including: decreased glucose tolerance and raised insulin levels, increased risk of developing microalbuminuria, poor creatinine clearance (Painter et al., 2005), obstructive airway disease, a more atherogenic plasma lipid profile, coronary heart disease, and psychological problems (Dana et al., 2019; Lopuhaa et al., 2000; Painter et al., 2005; Ravelli et al., 1998; Roseboom et al., 2000). It is hypothesized that pregnancies impacted by FI and elevated maternal stress, serving as adverse early life exposures, are likely to experience compounded developmental programming of the fetus, resulting in adverse infant health outcomes.

2.2 Maternal & infant health outcomes in the DOHaD context

The negative health outcomes of programming can be immediately apparent, with babies being born too early or being born too small (fetal growth restriction), clinical observations that are highly predictive of a newborn adverse intrauterine environment and their predisposition to disease and dysfunction in later life. The Canadian Perinatal Surveillance System (CPSS) has highlighted thirteen crucial indicators for poor future health outcomes, which include preterm

birth (<37 gestational weeks at birth), small for gestational age (SGA; <10th percentile for birthweight), and large for gestational age (LGA; >90th birthweight percentile) (Irvine et al., 2015). Infant birth weight has been shown to be a surrogate metric of adverse intrauterine exposure and an important determinant of long-term health, given that low birth weight (LBW) is associated with metabolic diseases in adulthood, such as diabetes mellitus (Mi et al., 2017).

For pregnant individuals, GWG is a relevant metric used to not only predict maternal health post-partum but also the fetal health outcome. It is important for pregnant individuals to gain appropriate weight during pregnancy given that excessive weight gain during this critical period is associated with preeclampsia, gestational diabetes, and postpartum weight retention; while insufficient gestational weight is associated with preterm delivery, LBW, and delivering an SGA infant (Gong et al., 2022; Haugen et al., 2014; Hedderson et al., 2010; Montvignier Monnet et al., 2022). The Institute of Medicine (IOM) guidelines recommend that pregnant individuals gain weight depending on their pre-pregnancy Body Mass Index (BMI) as follows; underweight (BMI ≤ 18.5), normal weight (BMI 18.5-24.9), overweight (BMI 25-29.9), and obese individuals (BMI ≥ 30) are recommended to gain between 28-40, 25-35, 15-25, and 11-20 lbs, respectively (IOM, 2010). However, over 60% of pregnant individuals gain weight outside of their recommended ranges (Deputy et al., 2015), with this influenced by psychosocial factors such as FI, pregnancy stress, financial distress, intimate partner violence, lack of social support, and eating disorders (Athar et al., 2021; Cheu et al., 2020; Siega-Riz et al., 2009). Hence, maternal GWG and infant birthweight remain reliable and easily acquired metrics collected perinatally, that can predict long-term health outcomes as suggested by the DOHaD paradigm. This understanding shows tremendous promise, as it identifies pregnancy and early life as critical windows for screening and intervention to improve lifelong health outcomes.

2.3 Health Equity and the Social Determinants of Health (SDH)

The social determinants of health (SDH) encompass the complex conditions into which individuals are born, grow, work, and age, that are influenced by interrelated political, social, and economic factors (Dongarwar et al., 2020). It is estimated that nearly 60% of an individual's health status is determined by social determinants (Marmot & Allen, 2014). The World Health Organization (WHO) Global Commission on the SDH asserts that preventable health disparities not only result from individuals' circumstances but also from the systems established to manage illness, that in turn hinder them from achieving the best health that is biologically possible (WHO, 2008). Essentially, the uneven living conditions result from deeper structural factors (i.e., poor social policies and programs, economic disparities, political will, etc.) that influence how societies function (WHO, 2008). Research applying the SDH framework has identified adverse early life experiences, nutrition, and stress as significant factors driving health disparities (Marmot, 2005). Understanding the above psychosocial factors and their relationships to maternal-infant health outcomes is fundamental to identifying and potentially eliminating disparities in both communicable and non-communicable disease burden, especially during vulnerable windows such as pregnancy (Marmot, 2005).

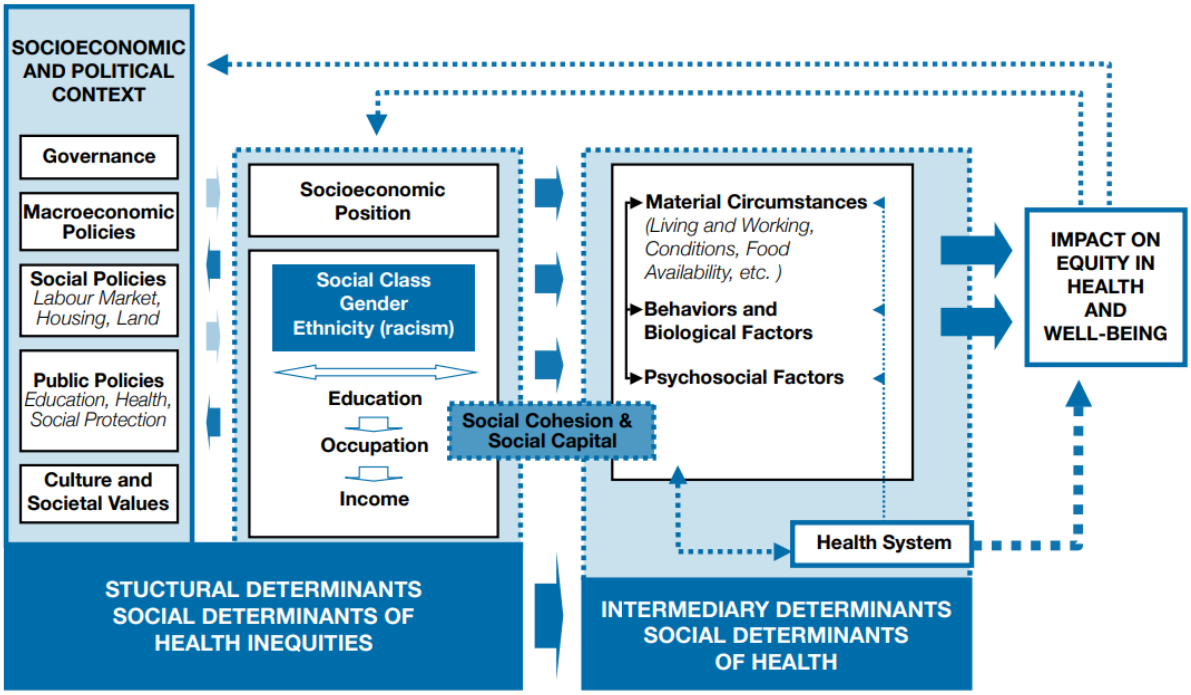

Figure 1: Conceptual framework for action on the social determinants of health. This figure from the WHO website (WHO, 2010)**,** illustrates how various dimensions—such as social, economic, and political factors—interact and influence health outcomes. These dimensions are interconnected and impact both structural factors (like access to healthcare) and intermediary risk factors (such as stress and lifestyle choices). This interplay affects how individuals experience and respond to health risks, shaping their exposure to and vulnerability to adverse health conditions. For instance, economic instability can exacerbate social inequalities, which may, in turn, increase stress levels and reduce access to essential services. By understanding these dimensions and their interactions, we gain insight into how multiple factors collectively impact overall health and well-being.

According to the Centers for Disease Control and Prevention (CDC), health inequity aims to provide everyone with a fair opportunity to achieve optimal health, necessitating ongoing societal efforts to address historical and current injustices, reform systems and policies, overcome economic and social barriers, and eliminate preventable disparities (CDC, 2024). The COVID-19 pandemic highlighted the relevance of SDH in understanding the health, well-being, and overall quality of life of the population, and emphasized the profound health inequities present here in Canada (Blankenship & Blancato, 2022). Critical health inequities that became highly apparent during this pandemic, and which can have multi-generational health impacts, included access to adequate health care, social support and nutrition during pregnancy – all of which demonstrated vast disparities for pregnant individuals according to socioeconomic status, race, education and geographical location (Burroughs et al., 2021; Emeruwa et al., 2022; Janevic et al., 2022; Meaney et al., 2022; Montgomery et al., 2023; Robson et al., 2022). Recognizing and tacking these inequities is an essential step in the development of relevant social policy necessary for the improvement of long-term maternal-infant health outcomes.

2.4 Food insecurity (FI) during pregnancy

FI is a multidimensional concept, defined as the physical, social, and economic incapacity to acquire or consume enough quality food to meet an individual's dietary needs and food preference (B. Laraia et al., 2015; Shirreff et al., 2021). Global reports have shown that over 3.1 billion people could not afford a healthy diet in 2022, with close to 783 million facing hunger, and approximately 2.24 billion going through some sort of FI (FAO, 2023). FI is more than just the lack of access to food, as it relates to other markers of social and economic disadvantages such as low socioeconomic status, single-parent households, renting rather than owning a home, and belonging to a minority Black, Indigenous, and people of colour (BIPOC)

community (Tarasuk et al., 2019). In Canada FI is measured at the household level, using the Canadian Community Health Survey (CCHS). The definition of FI relates to uncertain, insufficient or inadequate food access, availability and utilization due to limited financial resources (Tarasuk & Mitchell, 2020). The CCHS is a nationwide multiorganization government initiative that was started in the year 2000 to collect data on the determinants of health, health status, and health system utilization of the Canadian population (Government of Canada, 2024). The Household Food Security Survey Model (HFSSM), adapted and added in 2004 from the American food security measurement (United States Department of Agriculture, 2023), is the self-reported section of the CCHS that systematically assesses household food security in Canada (Government of Canada, 2024). The HFSSM also measures compromised eating patterns and food consumption that might result from experiencing any level of FI (Government of Canada, 2024). Four possible degrees of food security can be identified based on the number of positive responses to the 18 questions of the HFSSM and include (10 for adults and 8 for children in the household): 1) food secure, 2) marginally, 3) moderately, and 4) severely FI (Tarasuk & Mitchell, 2020). FI is recognized as a crucial determinant of health due to its complex psychosocial effects and its link to adverse health outcomes that vary between food secure and insecure groups. Within the general population, experiencing FI is associated with poor nutrition, negative mental and physical health impacts across the life cycle, and higher healthcare use and costs(Gundersen et al., 2018; Kirkpatrick & Tarasuk, 2008). For example, an Ontario-based study conducted by Tarasuk et al. showed that household FI was a significant predictor of health care utilization and cost, even after adjusting for relevant sociodemographic characteristics, with the mean individual-level health care cost rising systematically with the level of household FI severity (Tarasuk et al., 2015). Further, a nationwide study by Men et al. found that acute care

hospitalization, re-admission, lengths of stay, and higher patient costs once hospitalized all increased with the severity of FI (Men et al., 2020). Beyond the general population, research shows that pregnant individuals are more vulnerable to FI and its adverse health outcomes, given their elevated nutritional demands (McKay et al., 2022), their societal role as child-bearers, caregivers, and their disproportionately higher rates of poor economic status (Ivers & Cullen, 2011).

The pregnancy period is an essential window where adequate nutrition is pivotal as individuals undergo behavioural, physiological, and psychological changes (Cheu et al., 2020; B. Laraia et al., 2015). For instance, energy requirements during the first trimester of pregnancy are estimated to be the same as pre-gravid given that the energy costs for weight gain are assumed minimal (Most et al., 2019). However, during the second and third trimesters the pregnancy recommendations to meet energy requirements increase to around 340 kcal/d and 452 kcal/d, respectively (Council et al., 2010; Gilmore & Redman, 2015; Most et al., 2019). Experiencing FI during pregnancy significantly impacts fetal health and development, with documented associations to an increased risk of LBW, premature delivery, and birth defects (Carmichael et al., 2007; de Freitas Rocha et al., 2024; Patriota et al., 2024; Sandoval et al., 2021). FI during pregnancy is also linked to various negative health outcomes for the mother. These include disordered eating, , inappropriate weight gain during pregnancy (both inadequate and excessive), and heightened levels of maternal stress (Ivers & Cullen, 2011; B. Laraia et al., 2015; Seligman et al., 2010, 2010). These findings underscore that FI is indeed a public health concern that extends beyond individual health outcomes, necessitating further research and public policy consideration to address its broader impacts, especially when it comes to vulnerable populations.

2.5 Maternal stress during pregnancy

Stress is a physiological process through which environmental demands placed on an individual exceed their adaptive capacity, causing psychological and biological changes which ultimately increase disease susceptibility (Cohen et al., 1998, 2016). More specific to pregnancy, prenatal maternal stress, including anxiety, depression, and stressful life events like pandemics and natural disasters, is linked to suboptimal fetal and infant development (Lafortune et al., 2021; Madigan et al., 2018; Van den Bergh et al., 2020). The severity of adverse fetal and infant health outcomes vary by the type and intensity of prenatal stress exposure. In fact, Wadhwa et al. demonstrated that for each unit increase of prenatal life stress event experienced by pregnant individuals was associated with an approximate 55 grams decrease in infant birth weight and a 32% increase in the chances of having a LBW infant, independent of biomedical risk (Wadhwa et al., 1993). A longitudinal study exploring the trajectories and risk factors of prenatal maternal stress, in Southwestern China, found its prevalence to be quite high (77-78%). However, the symptoms reported were mild in most cases (Gao et al., 2023). Importantly, in this study <8% of all study participants (n=916) reported being free of any stress throughout all three trimesters of pregnancy – emphasizing the magnitude of this exposure at a population level. Factors associated with high risk of maternal stress included residing in a less developed region, inadequate family care and social support (Gao et al., 2023). In the Canadian context, evidence has shown that approximately 12.5% of women reported that most days were very stressful in the 12 months before childbirth, while 13% reported having little or no support available to them during their pregnancy (Public Health Agency of Canada, 2014). Further evidence from the Canadian Maternity Experience Survey (CMES) revealed that close to 12% of women experienced high levels of perceived stress and 17% reported having three or more stressful life events in the year prior to the birth of their baby (Kingston et al., 2012). This Canadian evaluation found that a pre-

pregnancy depression diagnosis, low social support, and numerous stressful life events were linked to heightened prenatal stress levels, with the number of stressful life events having the strongest association with perceived stress (Kingston et al., 2012). Despite single, Aboriginal, and low-income women being more likely to experience multiple stressful life events, their perceived stress levels were not higher after adjusting for other factors, indicating a need for further research in vulnerable population groups (Kingston et al., 2012).

Overall, the experience of prenatal maternal stress during pregnancy is recognized as an adverse fetal programming exposure associated with poor pregnancy and long-term health outcomes for the offspring (Glover, 2014; Mulder et al., 2002). Individuals who experience major stressful life experiences or report heightened perceived stress during pregnancy demonstrate a higher risk for the development of hypertensive disorders of pregnancy and preterm labour, as well as increased risk of giving birth to LBW and very low birth weight (VLBW) (Tandu-Umba et al., 2014; Witt et al., 2014). These offspring continue to demonstrate elevated risk for poor health profiles across their lifespan, with a recent meta-analysis demonstrating an association between elevated prenatal maternal stress with increased BMI and adiposity levels, and worse cognitive, motor, socio-emotional and behavioural consequences in children (Lafortune et al., 2021). Another systematic review found that increased prenatal maternal stress was linked to gravidity, gestational age at delivery, monthly family income, and both prematurity and preterm delivery (Pais & Pai, 2018). Project Ice Storm, a longitudinal cohort of mother-offspring pairs whose pregnancies took place during the historic "Ontario-Quebec Ice Storm" of 1998, has provided considerable insight into the long-term health programming of offspring exposed to natural disaster-specific maternal stress. Longitudinal follow up studies on these offspring have demonstrated important associations between elevated

maternal stress and elevated offspring cortisol and HPA Axis reactivity (Yong Ping et al., 2020), elevated childhood BMI and adiposity (Liu et al., 2016), externalizing behaviours and aggression (Jones et al., 2019; Nguyen et al., 2018), lower cognitive and language abilities (Jagtap et al., 2023), and autism phenotype in these young adults (X. Li et al., 2023). It is thought that gene-environment interactions, and heightened cortisol mediated epigenetic changes are responsible for programming effects seen in these offspring (Bowers & Yehuda, 2016; Cao-Lei et al., 2020; Fransquet et al., 2022).

Recent evidence shows that elevated maternal stress during pregnancy is intimately intertwined with FI (B. Laraia et al., 2015; B. A. Laraia et al., 2006; Shreffler et al., 2024; Wolfson et al., 2021). Previously, Laraia et al. have found that perceived stress was higher among individuals experiencing FI during pregnancy, with a dose-response relation with increasing levels of FI (B. A. Laraia et al., 2006). In another study conducted in Ethiopia, Jebena et al. found that pregnant individual living in FI households were 4 times more likely to experience mental distress than those in food secure households (Jebena et al., 2015). Considering this relationship, it is hypothesized that pregnancies impacted by FI and maternal stress, serving as adverse early life exposures, are likely to experience compounded developmental programming of the fetus.

2.6 Pregnancy in the context of the COVID-19 pandemic

The highly transmissible and pathogenic coronavirus disease 2019 (COVID-19) is caused by the severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) (Ravi et al., 2022). Emerging in late 2019, it posed a significant threat to global public health and was declared a global pandemic by the WHO in March 2020 (Cucinotta & Vanelli, 2020). Canada experienced multiple waves of COVID-19, marked by spikes in cases, hospitalizations, deaths and general

increase in FI and stress levels (Public Health Agency of Canada, 2023). In response, with regional variations, stringent measures were implemented, including lockdowns, mandatory masking, social distancing, and reduced social activities to address the health, social, and economic impacts of the pandemic (Allin et al., 2021; Public Health Agency of Canada, 2020). Overall, the COVID-19 pandemic was a major traumatic event that disrupted numerous aspects of daily life and disproportionately affected vulnerable populations, such as pregnant individuals, across the globe (Provenzi et al., 2023; WHO, 2020). There was a general increase in household FI across the globe as a result of the COVID-19 pandemic and its associated lockdowns, with individuals who identify as BIPOC, those with less than a high school education, families with children under 18 years, renters, lone-parent households and those on social assistance being more affected (Azevedo et al., 2023; Kakaei et al., 2022; Polsky & Garriguet, 2022). Among Canadian families, the COVID-19 pandemic resulted in reduced food resources, increased economic instability, and an increase in stress levels (Carroll et al., 2020; Polsky & Garriguet, 2022; Wakefield, n.d.). Government of Canada data indicates that during the early phases of the pandemic (April 2020 - April 2021), FI prevalence was between 14% to 17% in the general population (Idzerda et al., 2022). However, it rose to 18%-23% among those aged 18 to 44, 19%-22% in households with children, 26% in individuals with job insecurity, and 24%-39% in those who lost their jobs or stopped working due to the pandemic (Idzerda et al., 2022). Daly et al. reported that 37% of Canadians experiences worsened mental health, including psychosocial distress because of the COVID-19 pandemic (Daly et al., 2021). Pongou et al. demonstrated that despite advancements in vaccines to control the COVID-19 pandemic, Canadians, particularly women, continued to face numerous psychosocial, economic, and health challenges (Pongou et al., 2022). This literature is similar to what has been shown in the case of the 2003 SARS

outbreak with documented psychosocial impact on different population groups (Hawryluck et al., 2004; Maunder, 2009; May et al., 2004; Tsang et al., 2004; Tzeng et al., 2020).

A large body of evidence from the pandemic has shown that pregnant individuals were disproportionally affected by increased stress levels, reduced social support, economic insecurity and material deprivation, compromised access to healthcare services, and increased worry of being unprepared for childbirth (Gholami et al., 2023; Johnson, 2021; Lin et al., 2021; Mayopoulos et al., 2021; Morden et al., 2023; Preis, Mahaffey, Heiselman, et al., 2020). For instance, in a study conducted among pregnant individuals during the COVID-19 pandemic (87% residing in Canada), Bogler et al. found that common sources of pregnancy worry came from hospital policies, availability of support persons during labour, getting infected by COVID-19, not being able to introduce their infant to family, and not having postpartum support because of physical distancing (Bogler et al., 2021). Moyer et al. showed that the 26% of pregnant individuals surveyed stopped in-person prenatal care visits, while 15% shifted to video and 32% to phone calls as a result of the COVID-19 pandemic (Moyer et al., 2020). Further, 64% of pregnant individuals reported increased worry about losing their employment or household income (Moyer et al., 2020). The COVID-19 pandemic intensified both FI and stress in vulnerable Canadian pregnant populations (Idzerda et al., 2022; Pagès et al., 2022; Pearson et al., 2023; Rudrum, 2021), which likely contributed significantly to adverse developmental programming events and negative pregnancy outcomes. Giesbrecht et al. found that among pregnant Canadians, fear related to COVID-19 was significantly associated with FI, low household income, low educational attainment, immigration status, geographical location, and non-white ethnicity ($p<0.0001$)(Giesbrecht et al., 2022). For obstetric outcomes, COVID-19 worry was linked to reduced birthweight ($p<0.001$), birth length ($p=0.003$), and gestational age at

birth (p=0.001), resulting in reductions of 192 grams, 1.3 cm, and 6.1 days, respectively, for those with the highest fear levels compared to those with the lowest (Giesbrecht et al., 2022). Within the contextual framework of the DOHaD paradigm, it is of tremendous concern to consider the complex interactions between these different adverse in utero exposures, namely FI and maternal stress, maternal and infant health outcomes and what this might mean for the future health of these offspring.

CHAPTER 3: THESIS ARTICLE

Exploring the relationships between food insecurity, maternal stress, and maternal / infant health outcomes during the COVID-19 pandemic

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3.1 Abstract

Background: Adverse psychosocial, lifestyle and environmental exposures during the first 1,000 days of life can result in undesirable offspring health outcomes, including increased risk of chronic diseases in adulthood. Food insecurity (FI) and heightened stress are factors that may contribute to adverse developmental programming events, which were exacerbated in many Canadians during the COVID-19 pandemic.

Objective: This study aimed to identify key social determinants of health associated with COVID-19 pandemic-related FI and elevated maternal stress, and how these adverse exposures in pregnancy were associated with maternal gestational weight gain (GWG) and newborn birth weight in a Canadian pregnant cohort.

Methods: Data were collected retrospectively from 273 pregnant individuals of varying socioeconomic status who were pregnant and delivered infants during the pandemic (March 2020–March 2023). The participants responded to an online survey developed from previously validated questionnaires addressing FI, pandemic-related stress, self-reported GWG, and infant birth weight.

Results: Over half (55%) of the participants experienced household FI, while one fifth (20%) and over one third (34%) reported heightened stress related to pregnancy preparedness and COVID-19 infection, respectively. Participants from food secure and insecure households differed significantly in age, sexual orientation, household type, total household income, housing status, number of kids in the household and whether the pregnancy was planned or unplanned ($p < 0.01$). Heightened stress for both preparedness and COVID-19 infection was also significantly associated these same factors except from age group and housing status ($p < 0.05$). GWG outside

the recommended guidelines was reported by 77% of participants; however, no associations were observed with FI or pandemic-related stress. Infant birth weight extremes (small or large for gestational age) were reported by 32% of participants. While no associations were observed with FI status, associations between birth weight extremes and heightened stress related to both pregnancy preparedness and COVID-19 infection were observed ($p < 0.02$).

Conclusion: The results of this study provide a better understanding of the extent of FI, gestational stress, and factors potentially influencing them during the COVID-19 pandemic in a Canadian pregnant population. Recognizing the specific challenges faced by vulnerable pregnant populations can guide tailored interventions and programs aimed at improving maternal and infant health and well-being during emergency/pandemics.

3.2 Introduction

The well-established DOHaD paradigm emphasizes the association between negative psychosocial, lifestyle, and/or environmental exposures during gestation and adverse short- and long-term infant health outcomes. Several health metrics measured during pregnancy and/or at the time of delivery, including inappropriate gestational weight gain (GWG) and infant birth weight extremes, can be indicative of adverse in utero exposures and fetal programming events as well as higher risk for future disease in adulthood (D'Agostin et al., 2023; Hack et al., 1995; Rasmussen et al., 2009; Scifres, 2021). Suboptimal nutrition and heightened stress during pregnancy, which were exacerbated for many pregnant individuals during the COVID-19 pandemic (Azevedo et al., 2023; Moyer et al., 2020; Pagès et al., 2022; Vaghef-Mehrabani et al., 2022), are recognized as contributing factors to adverse developmental programming events (Coussons-Read, 2013; de Oliveira et al., 2020; Franco et al., 2021; Gallegos et al., 2021; Meng et al., 2019). Suboptimal nutrition and poor diet quality often go hand in hand with food

insecurity (FI) (Choi et al., 2022; Davison et al., 2017; Morales & Berkowitz, 2016). Although FI is defined as inadequate or insecure access to food due to financial constraints, its concept expands beyond the direct access to nutritious food (Fafard St-Germain & Tarasuk, 2020). FI is related to other markers of social and economic disadvantages such as low socioeconomic status, single-parent households, renting rather than owning a home, identifying with a minority group (such as Black or Indigenous), and all other kinds of social and material deprivation (T. Li et al., 2023).

The latest United Nations State of Food Security and Nutrition in the World report revealed that roughly 2.4 billion people were in a state of moderate to severe FI worldwide in 2022 (FAO, 2023). In Canada alone, approximately 23% of the entire population, including 1.8 million children experienced household FI in 2022 (T. Li et al., 2023). This prevalence has been on the rise and represents an increase of approximately one-in-five Canadian households struggling with FI, as opposed to only one-in-eight households reported in 2017-2018, before the pandemic (Tarasuk & Mitchell, 2020). The experience of FI is particularly consequential when it occurs during pregnancy, given the crucial need for optimal nutrition during this critical window of development, to accommodate the changing metabolic requirements of both mother and offspring (Marshall et al., 2022). FI during pregnancy is associated with an increased risk of inappropriate fetal growth profiles, birth defects, and stunted offspring growth (Carmichael et al., 2007; Chowdhury et al., 2018; Karbin et al., 2022). For mothers, the experience of FI during pregnancy has been linked to hypertensive disorders of pregnancy, disordered eating patterns, inappropriate GWG and gestational diabetes (Call et al., 2023; Hoseini et al., 2018; KC et al., 2015; Kidane et al., 2022; Laraia et al., 2010). Studies have also shown associations between FI

and maternal generalized anxiety disorders and major depressive episodes, even after adjusting for sociodemographic and maternal physical health factors (Whitaker et al., 2006).

Maternal stress is a well-documented gestational exposure independently associated with adverse maternal and infant health outcomes (Coussons-Read, 2013). Studies have shown that heightened maternal stress during pregnancy may lead to inappropriate GWG (Kominiarek et al., 2018), preeclampsia (Y. Yu et al., 2013), gestational diabetes (Horsch et al., 2016; OuYang et al., 2021), postpartum weight retention (Whitaker et al., 2014), and birthweight extremes (Mélançon et al., 2020). Maternal psychological and social stress have also been associated with preterm delivery and low birth weight in the offspring, even when adjusted for sociodemographic and behavioural risk factors (Behrman et al., 2007, 2007; Federenko & Wadhwa, 2004; Lilliecreutz et al., 2016).

The COVID-19 pandemic was a major traumatic event that disrupted numerous aspects of daily life while disproportionately affecting vulnerable populations, including pregnant and food insecure individuals (Dolin et al., 2021; Schoenmakers et al., 2022). Among Canadian families, the COVID-19 pandemic has led to reduced food resources, increased economic instability, and increased stress levels (Carroll et al., 2020). A body of research has indicated that pregnant individuals were disproportionally affected by both the direct impact of COVID-19 infection and the indirect social impact of living through the global pandemic (Khan et al., 2020; Wei et al., 2021) (ref). Pregnant individuals experienced compromised access and utilization of healthcare services and heightened prevalence of maternal anxiety and depression related to ongoing concerns over economic insecurity and lack of appropriate social support over the pandemic (Arzamani et al., 2022; Bermúdez-González et al., 2022; Joo & Liu, 2023; Thayer & Gildner, 2021).

The COVID-19 pandemic exacerbated FI among vulnerable pregnant populations and amplified maternal stress levels, likely contributing to adverse developmental programming events and pregnancy outcomes. Given that an infant's short- and long-term health and well-being appear to be influenced by both maternal FI and stress during pregnancy, further research is needed to better understand their causes and consequences, and how they are associated, particularly in the context of health inequalities. Investigating these associations could provide crucial information on the importance of perinatal screening and implementation of targeted interventions to enhance lifelong offspring health outcomes, especially during natural disasters or pandemics. The purpose of this study was to identify relevant social determinants of health associated with pandemic-related FI and heightened maternal stress and to explore the relationship between these adverse pregnancy exposures and maternal GWG and newborn birth weight in a Canadian pregnant cohort.

3.3 Research Methods

Study population and design

This was a retrospective cohort survey of Canadian participants (n = 273) who gave birth to a live singleton infant during the COVID-19 pandemic (March 2020 to March 2023). Participants were recruited using a purposive sampling method from November 2022 to April 2023 using study advertisements on social media platforms (Facebook, Twitter, and Instagram), and from our research network in Ontario, including community health centres, and food banks. Targeted recruitment strategies were also employed to ensure the inclusion of food insecure participants, including email campaigns to institutions that serve vulnerable populations across Canada, mainly partners from the Canada Prenatal Nutrition Program (CPNP) (Government of Canada, 2010). Eligible participants were of varying socioeconomic status and residing in

Canada during pregnancy. Individuals below 18 years of age and those who did not understand either French or English were ineligible for study inclusion. Eligible participants received a $25 gift card following the completion of the questionnaire. After survey completion, all data were screened using a systematic approach to ensure the validity of the collected data and to screen out fraudulent (bot) responses (Supplementary Material). Ethics approval for this study was obtained from the University of Ottawa's Health Sciences and Science Research Ethics Board (#H-07-22-8071).

Development of the online survey

The online survey (Thesis Appendix B) was developed through the integration and adaptation from previously validated questionnaires. Participants had to answer anywhere between 100 and 159 questions, depending on their answers to questions with filters and needing additional details. The survey was developed to collect information on social determinants of health, household food insecurity, pandemic-related maternal stress, and self-reported adverse health outcomes, as detailed below. Data was collected and managed using REDCap electronic data capture tools hosted on the server of Montfort Hospital (*REDCap*, 2024).

1) Social Determinants of Health: Maternal social, economic, and demographic characteristics were collected using questions from the validated Canadian Community Health Survey (CCHS) (Government of Canada, 2024), Maternity Experience Survey (MES) (Government of Canada, 2006), Electronic Maternal Health Survey (EMat Health Survey) (Ockenden et al., 2016), and the Survey on Maternal Health (Government of Canada, 2018). The range of questions covered themes such as sexual orientation, gender identity, ethnicity, household income, marital status, household status, place of birth and residence, education level, number of children in the household, and whether pregnancy was planned.

2) Household Food Insecurity: Food insecurity during pregnancy was measured using the Canadian Household Food Security Survey Module (HFSSM), an 18-item validated questionnaire designed to assess household food security in the last 12 months (Canada, 2010). The HFSSM is divided into a 10-item adult food security scale and an 8-item child food security scale, if children under 18 years old are living in the household. The HFSSM focuses on self-reports of inadequate or uncertain access to food and compromised eating habits owing to financial constraints. Health Canada's method was used to classify participants as food secure or insecure, and to categorize them into a gradient of FI status ranging from food secure, marginally insecure, moderately insecure, to severely insecure, as described by Tarasuk et al. 2015 (Tarasuk et al., 2015). For this study, the HFSSM was adapted by asking study participants to consider their pregnancy period rather than the standard past 12 months while answering questions about their household food security experiences. In addition to the HFSSM questions, participants were further asked three questions about pandemic-related changes in food quantity, quality, and accessibility to capture the specific pandemic-related effects on dietary behaviours (Appendix B).

3) Pandemic-Related Maternal Stress: Maternal stress during the COVID-19 pandemic was assessed using the Pandemic-Related Pregnancy Stress Scale (PREPS), a validated questionnaire developed to assess prenatal maternal stress and coping (Preis, Mahaffey, & Lobel, 2020). The PREPS asked participants to report their general worries related to pandemic preparation for birth and postpartum (PREPS-Preparedness), fear of maternal or infant COVID-19 infection (PREPS-Infection), and aspects of the pandemic that were perceived as positive (PREPS-Positive appraisal). The score for each PREPS subscale was calculated as the mean

response of the items using a 5-point Likert scale, with higher scores indicating higher levels of prenatal stress.

4) *Maternal and infant Health Outcomes*: The collected maternal and infant health outcomes included self-reported pre-pregnancy height and weight, pre-delivery weight, infant birth weight, sex, and gestational age at delivery. Maternal Gestational Weight Gain (GWG) was calculated and categorized into three groups (inadequate, adequate, or excessive) according to the 2009 IOM guidelines (IOM, 2010), and was analyzed as a binary outcome (within recommended and outside recommended GWG). Infant birth weights were normalized by fetal sex and gestational age at delivery and analyzed as birth weight percentiles derived for the Canadian population (Government of Canada, 2004). Birthweight centiles were categorized as Appropriate for Gestational Age (AGA – between 10^{th}-90^{th} percentile) and Inappropriate for Gestational Age (IGA), which included both small for gestational age ($<10^{th}$ percentile) and large for gestational age ($>90^{th}$ percentile) infants.

Data Analysis

Statistical analyses were performed using SAS software (version 9.4; SAS Institute Inc., Cary, NC, USA). Descriptive statistics (e.g., means, frequencies, and percentages) were used to characterize the study population. The chi-square test for categorical variables and Fisher's exact test were used to compare the various categorical social, economic, and demographic characteristics between food secure and insecure participants, while the independent samples t-test (two groups) and ANOVA (more than two groups) were used to compare the mean differences in stress levels between groups. Tukey's post hoc test was used to assess significant differences between the pair of group means when using ANOVA. Independent sample t-tests were also conducted to compare the mean stress levels between participants within the

recommended and outside recommended maternal GWG, and infants with AGA and IGA. Univariate logistic regression was used to examine the relationships between FI or heightened stress and maternal-infant health outcomes (within vs. outside recommended GWG and AGA vs. IGA). FI and stress were tested for potential interactions, but no significant associations were found between potential confounding variables, predictors, and outcomes of interest; therefore, the regression models were not further adjusted for these variables. Statistical significance was defined as a two-sided p-value < 0.05.

3.4 Study Results

Food insecurity and social determinants of health

The sociodemographic characteristics of the entire study cohort, stratified according to FI status, are shown in **Table 1**. More than one half of the households surveyed (55.7%) reported FI during the COVID-19 pandemic. When FI was stratified by severity, approximately 15% of households were marginally food insecure, 30% were moderately food insecure, and 11% were severely food insecure. Participants from food secure and insecure households differed significantly in household type, age group, sexual orientation, housing status, total household income, and the mean number of children in households (**Table 1**; $p < 0.001$).

Table 1. Sociodemographic characteristics by household food security status

Characteristic	**All participants n (%)**	**Food secure n (%)**	**Food insecure n (%)**	**P value**
Household type				**0.0001**
- Two-parent	235 (86.1)	115 (48.9)	120 (51.1)	
- Single-parent	38 (13.9)	6 (15.8)	32 (84.2)	

Age group				**0.0004**
- 18-23	15 (5.5)	7 (46.7)	8 (53.3)	
- 24-29	110 (40.3)	33 (30.0)	77 (70.0)	
- 30-34	103 (37.7)	52 (50.5)	51 (49.5)	
- 35+	45 (16.5)	29 (64.4)	16 (35.6)	
Sexual Orientation				**0.0005**
- Heterosexual	229 (83.9)	112 (48.9)	117 (51.1)	
- LGBTQ2S+	44 (16.1)	9 (20.5)	35 (79.6)	
Housing status[a]				**0.0002**
- Owner	165 (63.9)	87 (52.7)	78 (47.3)	
- Renter	93 (36.1)	27 (29.0)	66 (71.0)	
Total household Income[b]				**<0.0001**
- < $25,000	20 (7.9)	3 (15.0)	17 (85.0)	
- $25,000-$49,999	53 (20.9)	12 (22.6)	41 (77.4)	
- $50,000-$74,999	50 (19.8)	21 (42.0)	29 (58.0)	
- $75,000-$99,999	38 (15.0)	24 (63.2)	14 (36.8)	
- $100,000-124,999	29 (11.5)	9 (31.0)	20 (69.0)	
- $125,000-149,999	28 (11.1)	9 (32.1)	19 (67.9)	
- >$150,000	35 (13.8)	31 (88.6)	4 (11.4)	
Number of kids in house[c]				**<0.0001**
- 0	118 (44.2)	65 (55.8)	53 (44.9)	
- 1	110 (41.2)	48 (43.6)	62 (56.4)	
- 2+	39 (14.6)	6 (15.4)	33 (84.6)	
Planned pregnancy[d]				**0.009**

- YES	177 (65.1)	89 (50.3)	88 (49.7)	
- NO	95 (34.9)	32 (33.7)	63 (66.3)	
Gender Identity				0.50
- Woman	264 (96.7)	118 (44.7)	146 (55.3)	
- Other	9 (3.3)	3 (33.3)	6 (66.7)	
Indigenous Identity[e]				0.17
- YES	50 (18.5)	18 (36.0)	32 (64.0)	
- NO	221 (81.6)	103 (46.6)	118 (53.4)	
Visible minority Identity				0.68
- YES	55 (20.2)	23 (41.8)	32 (58.2)	
- NO	218 (79.9)	98 (45.0)	120 (55.1)	
Education[d]				0.05
- Highschool diploma	254 (93.4)	116 (45.7)	138 (54.3)	
- No high school diploma	18 (6.6)	4 (22.2)	14 (77.8)	
Region of residence				0.24
- Atlantic region	19 (7.0)	9 (47.4)	10 (52.6)	
- Central region	178 (65.2)	78 (43.8)	100 (56.2)	
- Prairies region	37 (13.6)	12 (32.4)	25 (67.6)	
- West Coast region	24 (8.8)	15 (62.5)	9 (37.5)	
- Northern region	15 (5.5)	7 (46.7)	8 (53.3)	
Immigration status[d]				0.90
- Born in Canada	241 (88.6)	106 (44.0)	135 (56.0)	
- Born outside Canada	31 (11.4)	14 (45.2)	17 (54.8)	

Values are presented as frequencies (n) and percentages (%). P-values are from chi-square tests, comparing food insecure and food secure populations. Statistically significant values are bolded.

[a] sample size n =258 due to missing data

[b] sample size n =253 due to missing data

[c] sample size n =267 due to missing data

[d] sample size n =272 due to missing data

[e] sample size n =271 due to missing data

In response to the COVID-19 pandemic, nearly half of all participants, regardless of food security status, reported a reduction in daily portion size or meal frequency (42%) and a change in food quality (49%), while slightly more than half (61%) reported decreased food accessibility **(Table 2).** However, food-insecure participants were significantly more affected: they were seven times more likely (OR 7.29, 95% CI: 4.14–12.8) to reduce portion sizes or meal frequency, more than four times as likely (OR 4.5, 95% CI: 2.70–7.62) to report changes in food quality, and over three times as likely (OR 3.56, 95% CI: 2.13–5.94) to experience reduced food accessibility during the pandemic.

Table 2. Household food security status and compromised dietary behaviours during the COVID-19 pandemic.

	Household food security status			
	All participants	**Food secure**	**Food insecure**	**P value**
Reducing daily portion size or meal frequency				**<.0001**
- YES	116 (42.4%)	22 (19.0%)	94 (81.0%)	
- NO	157 (57.6%)	99 (63.1%)	58 (36.9%)	
Changing the quality of their food				**<.0001**
- YES	131 (49.0%)	35 (26.7%)	96 (73.3%)	

- NO	138 (51.0%)	86 (62.3%)	52 (37.7%)	
Decreased food accessibility				**<.0001**
- YES	166 (61.0%)	54 (32.5%)	112 (67.5%)	
- NO	106 (39.0%)	67 (63.2%)	39 (36.8%)	

Values are presented as frequencies (n) and percentages (%). P-values are from chi-square tests, comparing food insecure and food secure populations. Statistically significant values are bolded

Maternal Stress and social determinants of health

Maternal stress and coping during the pandemic were assessed using the PREPS subscales (preparedness, infection, and positive appraisal) (**Table 3**). Approximately one third (33.7%), and one fifth (19.7%) of the study participants reported a score of at least 4 (out of 5) on the PREPS-Infection and PREPS-Preparedness subscales, respectively, indicating heightened levels of pandemic-related pregnancy stress. Conversely, only 13% of study participants received a score of at least 4 (out of 5) on the PREPS- Positive Appraisal subscale, indicating that most participants did not perceive the COVID-19 pandemic as a positive event during their pregnancy **(Table 3)**. Increased maternal stress scores (for both preparedness and COVID-19 infection) were associated with single-parent households, LGBTQ2S+ identity, low-income households, households with two or more children, and households with unplanned pregnancies (**Table 3;** all $p < 0.05$). The perception of positive appraisal of the COVID-19 pandemic differed significantly by age group, total household income, and number of children in the household (**Table 3;** all $p < 0.05$).

Table 3. Maternal stress scores (PREPS) and associated sociodemographic characteristics.

Characteristic	**N**	**PREPS-Preparedness**	**PREPS-Infection**	**PREPS-Positive Appraisal**
All participants		3.10 ± 0.95	3.40 ± 0.99	2.66 ± 0.94

Household type		**p = 0.02**	**p = 0.02**	p = 0.78
- Two-parent	229	3.05 ± 0.06	3.32 ± 0.07	2.66 ± 0.06
- Single-parent	35	3.46 ± 0.15	3.74 ± 0.15	2.70 ± 0.15
Age group		p = 0.77	p = 0.63	**p = 0.042**
- 18-23	15	3.01 ± 1.06	3.41 ± 1.02	2.40 ± 0.61
- 24-29	106	3.18 ± 0.98	3.37 ± 1.02	2.82 ± 0.90
- 30-34	99	3.05 ± 0.91	3.42 ± 0.94	2.65 ± 0.95
- 35+	44	3.07 ± 0.96	3.25 ± 1.06	2.38 ± 1.08
Sexual Orientation		**p < 0.0001**	**p = 0.005**	p = 0.07
- Heterosexual	221	3.00 ± 0.06	3.30 ± 0.07	2.62 ± 0.06
- LGBTQ2S+	43	3.63 ± 0.12	3.76 ± 0.11	2.90 ± 0.15
Housing Status[f]		p = 0.73	p = 0.05	p = 0.75
- Owner	162	3.09 ± 0.08	3.30 ± 0.08	2.66 ± 0.07
- Renter	90	3.13 ± 0.09	3.54 ± 0.09	2.70 ± 0.09
Total household income[g]		**p = 0.0002**	**p = 0.04**	**p = 0.02**
- <$25,000	18	3.43 ± 0.98	3.59 ± 1.11	2.80 ± 0.77
- $25,000 - $49,999	53	3.04 ± 0.91	3.38 ± 0.93	2.64 ± 0.87
- $50, 000 - $74,999	48	2.83 ± 0.92	3.10 ± 0.96	2.70 ± 0.83
- $75, 000 - $99,999	36	2.94 ± 0.90	3.18 ± 1.06	2.68 ± 1.00
- $100, 000 - $124,999	27	3.59 ± 0.68	3.69 ± 0.79	2.72 ± 0.90
- $125, 000 - $149,999	28	3.51 ± 0.85	3.68 ± 0.90	2.81 ± 1.14
- >$150,000	34	2.85 ± 0.91	3.20 ± 1.04	2.06 ± 0.88
Number of kids in house[h]		**p = 0.003**	**p = 0.008**	**p = 0.006**
- 0	112	3.21 ± 1.00	3.50 ± 1.06	2.45 ± 0.98
- 1	107	2.93 ± 0.93	3.21 ± 0.95	2.85 ± 0.93

- 2+	39	3.44 ± 0.75	3.67 ± 0.74	2.82 ± 0.80
Planned pregnancy		**p = 0.002**	**p = 0.046**	p = 0.85
- YES	173	2.97 ± 0.07	3.28 ± 0.06	2.66 ± 0.07
- NO	91	3.35 ± 0.10	3.54 ± 0.10	2.68 ± 0.09
Gender Identity		p = 0.06	p = 0.13	p = 0.64
- Woman	255	3.08 ± 0.06	3.35 ± 0.06	2.67 ± 0.06
- Other	9	3.70 ± 0.32	3.90 ± 0.37	2.52 ± 0.22
Indigenous Identity[i]		p = 0.51	p = 0.54	p = 0.12
- YES	50	3.18 ± 0.13	3.44 ± 0.14	2.85 ± 0.11
- NO	213	3.08 ± 0.95	3.35 ± 0.07	2.62 ± 0.08
Visible minority Identity		p = 0.54	p = 0.64	p = 0.09
- YES	51	3.18 ± 0.14	3.31 ± 0.15	2.86 ± 0.12
- NO	213	3.08 ± 0.95	3.39 ± 0.08	2.62 ± 0.07
Education[i]		p = 0.95	p = 0.61	p = 0.72
- Highschool diploma	245	3.10 ± 0.06	3.38 ± 0.06	2.66 ± 0.06
- No high school diploma	18	3.12 ± 0.20	3.26 ± 0.20	2.74 ± 0.21
Region of residence		p = 0.52	p = 0.84	p = 0.82
- Atlantic region	19	2.95 ± 0.87	3.31 ± 0.77	2.82 ± 0.86
- Central region	172	3.11 ± 0.96	3.38 ± 1.03	2.64 ± 1.00
- Northern region	13	3.08 ± 1.15	3.45 ± 1.04	2.49 ± 1.12
- Prairies region	36	3.30 ± 0.88	3.48 ± 0.87	2.75 ± 0.74
- West Coast region	24	2.90 ± 0.97	3.18 ± 1.13	2.70 ± 0.77
Immigration status[i]		p = 0.64	p = 0.87	p = 0.77
- Born in Canada	235	3.09 ± 0.06	3.37 ± 0.06	2.67 ± 0.06
- Born outside Canada	28	3.18 ± 0.17	3.34 ± 0.23	2.61 ± 0.20

Values are means ± SEM. P-values were obtained using two-sample t-tests and ANOVA. Statistically significant values are bolded

[f] sample size n =252 due to missing data

[g] sample size n =244 due to missing data

[h] sample size n =258 due to missing data

[i] sample size n =263 due to missing data

Food insecurity and maternal-infant health outcomes

The majority (77%) of respondents reported GWG values outside the recommended guidelines, with 31% reporting inadequate GWG and 46% reporting excessive GWG (**Table 4**). Food insecurity was not associated with the odds of inappropriate GWG (OR = 1.050 (95% CI 0.55, 2.02), p = 0.88). One third of the study participants (32%) reported having an IGA infant, 17% reported small for gestational age (SGA) birth weights (< 10th percentile), and 15% reported large for gestational age (LGA) birth weights (>90th percentile) (**Table 4**). Similarly, being food insecure was not associated with increased odds of having an infant with birth weight extremes (OR = 1.4 (95% CI [0.686, 2.820], p = 0.36)) (**Table 4**).

Table 4. GWG and infant birthweight categories according to household food security status

		Household food security status		
	All Participants	**Food secure**	**Food insecure**	**P value**
IOM gestational weight gain category[j]				0.88
- Within Recommended, n (%)	47 (22.6)	21 (44.7)	26 (55.3)	
- Outside Recommended, n (%)	161 (77.4)	70 (43.0)	91 (57.0)	
Infant birthweight category[k]				0.36
- Appropriate birthweights (AGA)	98 (67.6)	62 (63.3)	36 (36.7)	

(10-90th centile), n (%)				
- Inappropriate birthweights (IGA) (<10th centile or >90th centile), n (%)	47 (32.4)	26 (55.3)	21 (44.7)	

Values shown are frequencies (n) and percentages (%). P-values were obtained using chi-square tests.

[j] sample size n =208 due to missing data

[k] sample size n =145 due to missing data

Maternal stress and maternal-infant health outcomes

Heightened maternal stress scores relating to pandemic preparedness and COVID-19 infection were not associated with GWG outside the recommended ranges (**Table 5**; OR = 0.86 (95% CI [0.59, 1.24], p = 0.42) and 0.80 (95% CI [0.56, 1.14], p = 0.22), respectively). Increased perception of positive appraisal of the COVID-19 pandemic had no effect on GWG outside the recommended ranges (**Table 5**; OR = 0.88 (95% CI [0.62, 1.26], p = 0.50)). Heightened maternal stress scores related to pandemic preparedness and COVID-19 infection were significantly associated with infant weight extremes (**Table 5**; OR = 1.60 (95% CI [1.10, 2.31], p = 0.01) and 1.50 (95% CI [1.05, 2.12], p = 0.02), respectively). There was no association between increased positive appraisal perception of the COVID-19 pandemic and infant IGA (Table 4; OR = 1.01 (95% CI [0.70, 1.47], p = 0.94)).

There was no interaction between FI and heightened stress relating to pandemic preparedness or infection on either GWG outside the recommended ranges (p = 0.16 and 0.76, respectively), nor on infant birthweight extremes IGA infants (p = 0.44 and 0.89, respectively). Similarly, no interaction was found between FI and heightened stress related to pandemic infection on GWG outside the recommended ranges (p = 0.76) and IGA infants (p = 0.89).

Table 5. GWG and infant birth weight categories according to maternal stress score

	Pandemic-Related Pregnancy Stress Scale (PREPS) subscales			
	N	**PREPS – Preparedness**	**PREPS – Infection**	**PREPS- Positive Appraisal**
IOM gestational weight gain category[l]		p = 0.42	p = 0.22	p = 0.50
- Within Recommended, n (%)	47	3.19 ± 0.14	3.50 ± 0.15	2.60 ± 0.15
- Outside Recommended, n (%)	155	3.07 ± 0.07	3.31 ± 0.07	2.50 ± 0.07
Infant birthweight category[m]		**p = 0.01**	**p = 0.02**	p = 0.94
- Appropriate birthweights (AGA) (10-90th centile), n (%)	94	2.88 ± 0.10	3.15 ± 0.10	2.40 ± 0.10
- Inappropriate birthweights (IGA) (<10th centile or >90th centile), n (%)	46	3.33 ± 0.14	3.58 ± 0.16	2.41 ± 0.14

Values are means ± SEM. Statistically significant values are bolded.

[l] sample size n =202 due to missing data

[m] sample size n =140 due to missing data

3.5 Discussion

The primary aim of the current study was to identify the SDH factors of health associated with pandemic-related FI and heightened maternal stress, and to explore the relationships between these adverse gestational exposures and the maternal-infant health outcomes, including maternal GWG and newborn birth weight, in a Canadian pregnant cohort. The main findings of the study included the identification of several psychosocial and economic (income, education, living place) determinants that were associated with FI, heightened maternal stress, or both during the COVID-19 pandemic. These included being a single-parent, a renter, belonging in the

lower income bracket, younger age group (24-29 years), increased number of children in the household, LGBTQ+ identity, and unplanned pregnancy. While gestational stress measures were associated with inappropriate infant birth weight, it was not related to inappropriate maternal GWG, and no associations were observed between FI and the two measured health outcomes. Further, no interactions between the measured exposures on the outcomes of interest were identified.

FI during pregnancy is a public health concern that poses significant risks for both maternal and fetal health outcomes. Canadian national average household FI reached a peak of 23% in 2022 (Statistics Canada, 2024). Interestingly, the prevalence of household FI in our Canadian pregnant sample was more than twice the national average (household FI prevalence, 55.7%). It was also higher than the prevalence rates reported in the United States during the COVID-19 pandemic (2019-2022), where estimates ranged from 11 to 21% among pregnant and postpartum participants (Shriver et al., 2023; Ujah et al., 2023). These discrepancies may be the result of oversampling of high-risk populations from the targeted study advertisement at food banks, community centres, and programs that focus on vulnerable and food-insecure populations (notably partners from the Canada Prenatal Nutrition Program). The financial incentive for study completion may also have attracted more economically vulnerable populations with a higher prevalence of FI. However, FI was also higher in the high-income (100-149K) households of our sample. This aligns with previous research showing that factors like home ownership, relationship status, region of residence, household size, and the presence of chronic conditions like gambling or addiction can mediate FI even in high-income households (Olabiyi & McIntyre, 2014). This evidence showed that a large proportion all food insecure households in Canadian surveys were not income poor, with greater than 15% reporting household incomes over 60 000

CAD (Olabiyi & McIntyre, 2014). We also observed that many high-income households experiencing FI had other related factors, such as a high number of children, urban residency, and single-parent leadership, which may help explain their vulnerability to FI despite their high income. Our findings further revealed that even food-secure households experienced disruptions in both the quality and quantity of food during COVID-19, indicating that the COVID-19 pandemic's impact extended beyond traditionally food-insecure populations. Our measured FI prevalence was, however, aligned with prevalence estimates for pregnant populations carried out by international research groups, which have reported global FI prevalence among pregnant individuals and mothers of children below 2 years of age ranging between 40-57%. However, these estimates include pregnant populations in low and middle-income countries (Azevedo et al., 2023; dos Santos et al., 2024).

Although several observational studies have produced varying findings on the relationship between FI during pregnancy and maternal GWG over the years (Cheu et al., 2020; de Abreu Rodrigues et al., 2021; Sparks et al., 2024), a systematic review by Arzhang et al. (2022) confirmed an association between FI and both inadequate and excessive GWG (Arzhang et al., 2022). There is also sufficient evidence supporting the relationship between FI during pregnancy and adverse infant health outcomes, such as inappropriate birthweights, both before and during the pandemic (Borders et al., 2007; de Freitas Rocha et al., 2024; Victor et al., 2023). However, our current study did not find significant associations between FI and inappropriate maternal GWG or infant birthweights during the pandemic. This lack of association may be due to the general complexities of FI, and our limited study methodology that lacked a proper temporal component to capture the potential fluctuations of FI during the COVID-19 pandemic as a result of the distinct pandemic-related measures and lockdowns set by each Canadian

province and territory. The COVID-19 pandemic introduced unique challenges in food accessibility and availability, access to healthcare services, social support, and overall household financial needs (Eliason et al., 2024). FI encompasses more than just the financial inability to access an adequate diet, as typically measured, but extends to include various coping mechanisms and behavioural adaptations by pregnant individuals, such as prioritizing essential food or seeking alternative food sources. For example, FI may have occurred at different times during pregnancy and for varying durations—such as brief instances due to supermarket shortages for wealthier families versus more chronic, severe FI for underprivileged families. These differences in exposure and severity likely influenced health outcomes in distinct ways, presenting a potential limitation in assessing the overall impact of FI. Furthermore, some study participants may have been food insecure, as reflected in their questionnaire responses, but still nutrient and/or caloric sufficient, which could explain the observed lack of association with the adverse health outcomes.

The lack of association may also be the result of the various forms of support provided by the Canadian Prenatal Nutrition Program, through which much of our targeted recruitment happened (Government of Canada, 2010). The Canadian Prenatal Nutrition Program collaborates with each province and territory to ensure that infants are born with healthy birthweights by offering various maternal programs and services, including food and nutrition supplements (Muhajarine et al., 2012). Additionally, our food insecure participants, being fairly educated, coming from mostly middle- and high-income urban households, with a culturally and geographically diverse background, might have had variations in food utilization practices, access to prenatal care, social support, or general health-related resources during the pandemic, potentially buffering against negative maternal-infant health outcomes. Overall, this finding

highlights the need to explore the broader and multifaceted aspects of FI (accessibility, availability, utilization, and stability), especially for vulnerable pregnant individuals who experience trimester-specific physiological and behavioural changes, on top of the increased energy demands.

A wide body of literature has shown that going through a disastrous experience or state of emergency while pregnant is associated with increased emotional stress, a known adverse gestational exposure (Brooks et al., 2020; Field, 2017; Glynn et al., 2001). The prevalence of heightened gestational stress related to concerns over COVID-19 infection (33.7%) and pregnancy preparedness (19.7%) among our study participants somewhat differs from studies conducted globally, with the highest scores found in cohorts in the United States (29% & 27%) and Poland (26% & 39%), and the lowest in Germany (12% & 16%), and Italy (10% & 9%) (Ilska et al., 2021; Penengo et al., 2021; Preis, Mahaffey, & Lobel, 2020; Schaal et al., 2021). Despite variations in prevalence across cohorts, these results underscore the consistent trend of elevated maternal stress during the pandemic (Agho & Van Der Pligt, 2023; Johnson, 2021; Taylor et al., 2021). This can likely be attributed to several factors, including the demographic characteristics cited above, as well as access to social support and healthcare services, all of which are associated with increased financial vulnerability and/or heightened stress levels. The increased maternal stress could equally be attributed to elevated vaccine safety concerns and/or infant formula shortages that were being reported during the COVID-19 pandemic (Asiodu, 2022; Reifferscheid et al., 2022; Sylvetsky et al., 2024). Furthermore, pandemic-induced food insecurity and changes in dietary habits experienced by our participants directly reflect the broader economic hardships and instabilities resulting from COVID-19 and its associated lockdowns (Burki, 2020; Roberton et al., 2020; Zinga et al., 2022).

While there was mostly reported maternal stress associated with pandemic preparedness and COVID-19 infection in our study, over one tenth of study participants (13%) reported high levels of positive appraisal of the pandemic, indicating a more adaptive and opposing view from most people. Preis et al. found that this positive perspective was associated with personal growth and resilience, reflecting a copying mechanism among pregnant individuals during global crises, such as the pandemic (Preis, Mahaffey, & Lobel, 2020). This coping mechanism may have reduced the worry related to pandemic social isolation, disrupted healthcare, or birthing plans for some participants. It demonstrates how individuals adapt differently, and how some might gain confidence from overcoming catastrophes, highlighting the need for tailored approaches when it comes to equitable social policy.

Despite the high prevalence of heightened pandemic-related maternal stress experienced by our study participants, there was no significant association observed with inappropriate GWG. Previous studies, including those conducted during the pandemic, have predominantly demonstrated a link between elevated stress levels and inadequate GWG. For instance, in a study examining the impact of the initial COVID-19 lockdown in New York on GWG, Collins-Smith et al. found that the lockdown period was associated with lower-than-recommended weight gain during pregnancy (Collins-Smith et al., 2022). In a prospective study of 60 pregnant participants, Picone et al. reported a link between heightened stress, measured by the Holmes-Rahe life events questionnaire, and inadequate GWG, independent of nutrient or caloric intake (Picone et al., 1982). Similarly, Brawarsky et al., using the Perceived Stress Scale (PSS), observed inadequate GWG in participants with higher reported stress during pregnancy (Brawarsky et al., 2005). Orr et al. also found an association between elevated stress levels, assessed through the Prenatal Social Environment Inventory (PSEI), and inadequate GWG (Orr et al., 1996). Likewise,

Kominiarek et al. reported that higher stress, as measured by life-changing events during pregnancy, was associated with inadequate GWG, emphasizing the negative impact of gestational stress on weight gain (Kominiarek et al., 2018). In contrast, only a few studies have found associations between stress and excessive GWG. In a large population-based study in the United States, Mehta-Lee et al. reported a link between psychosocial stress, particularly financial stress, and an increased risk of excessive GWG (Mehta-Lee et al., 2024). Similarly, in a more recent multicenter observational cohort study, Abdelwahab et al. found that simply being pregnant and delivering during the pandemic was associated with higher odds of excessive GWG and lower odds of inadequate GWG (Abdelwahab et al., 2024). Comparable findings were also observed in a cross-sectional study by Cao et al. conducted during the pandemic (Cao et al., 2022). However, these studies may have been inconsistent due to the different scales and methods used to quantify stress as an adverse gestational exposure or the unique conditions present during events like the [pandemic]. Overall, there are mixed findings in relation to stressful exposures during pregnancy and GWG, which might explain the lack of association in our current study, as combining the two GWG extremes into one category to compensate for the small sample size, may have obscured the potential association favoured by one GWG extreme. Further obscuring of our measured association might have been due to the absence of measures related to timing and severity of maternal stress across gestation. In fact, Braig et al. found a statistically significant positive association between chronic psychosocial stress and body weight only when the stress was experienced specifically within the first trimester of pregnancy (Braig et al., 2020). Similarly, Zhu et al. concluded that only stressful exposures during the first trimester were associated with changes in maternal GWG (Zhu et al., 2013). Considering this observed time-specific effect, it is important to consider the temporal phases of heightened

infections and societal restrictions experienced during the COVID-19 pandemic, that importantly varied by region of residence. As such, the variable timing of critical windows of exposure (conception and first trimester) along with the variable timing of heightened pandemic-related restrictions across participants may also contribute to lack of significant findings. Larger cohorts that can explore these important variables are needed to specifically answer this question.

The observed independent association between heightened maternal stress and infant birthweight extremes, known for being predictive metrics for an infant's adverse long-term health outcomes, is consistent with what has been described in the literature (Khashan et al., 2009, 2009; M. Li et al., 2020; Littleton et al., 2010). More specifically, our findings are in line with previous experiences of other stressful exposures in Canada, such as the 1998 North American Ice storm, that has documented associations between elevated maternal stress and several adverse infant health outcomes, including shorter gestational lengths and predicted birth weights among participants exposed during earlier pregnancy phases (Dancause et al., 2011), increased offspring cortisol and HPA Axis reactivity (Yong Ping et al., 2020), elevated childhood BMI and adiposity (Liu et al., 2016), externalizing behaviours and aggression (Jones et al., 2019; Nguyen et al., 2018), and autism phenotype in these young adults (X. Li et al., 2023). Furthermore, a large body of evidence has shown that disaster-related or perceived stress from extreme pregnancy experiences (i.e., experiencing a public health emergency, bereavement or domestic violence), may negatively impact infant health outcomes including fetal growth profiles (Harville et al., 2010; László et al., 2013, 2020; Shah & Shah, 2010; Su et al., 2021). Similar findings of adverse fetal health outcomes have been documented from maternal mood-related disorders, like anxiety and depression (Bergeron et al., 2023; Howard & Khalifeh, 2020; Khashan et al., 2014; Mélançon et al., 2020). Elevated circulating maternal cortisol levels have

been postulated as a causal mechanism, promoting vasoconstriction of the uterine artery and decreased blood flow to the developing feto-placental unit (Shriyan et al., 2023).

While our observed associations between elevated maternal stress and altered fetal growth profiles align to those described in fetal programming literature (Davis & Narayan, 2020), they were somewhat at odds with a recent meta-analysis that examined the effect of the COVID-19 pandemic on neonatal birth weight (Yao et al., 2023). In this review, a comparison of neonatal birth weight between the pandemic and pre-pandemic periods, irrespective of maternal stress levels, demonstrated a pandemic-associated increase in mean birth weight and decrease in VLBW infants, with no observed effect on low birth weight, SGA, LGA, and macrosomia (Yao et al., 2023). It is important to recognize that while the authors of this analysis assume that maternal stress levels would be heightened during the pandemic period, no assessments of maternal stress or associations between maternal stress levels and infant birthweights were completed. Further, it is well documented that the prevalence of other adverse pregnancy health outcomes, including preterm delivery, maternal death, stillbirths, and ruptured ectopic pregnancies, were increased during the COVID-19 pandemic period (Chmielewska et al., 2021; Gholami et al., 2023; Khalil et al., 2020; Rao et al., 2022). This emphasizes the need for more research on all kinds of gestational stress and maternal-infant health outcomes.

Strengths and limitations

This study has several strengths and limitations that should be considered when interpreting the findings. Strengths of our study include a population-based cohort that covered all Canadian provinces and territories, and the online format of the survey that allowed for broader recruitment of culturally and socially diverse participants. This format also allowed for anonymous participant inclusion, an important consideration when asking questions related to

sensitive topics such as food insecurity, GWG and maternal mental health. We must also acknowledge the limitations of the current study, that should serve to inform future research endeavours on this topic. First, our study relied on subjective, self-reported measures, which are less accurate than objective ones and have previously been reported as having low validity (Brenner & DeLamater, 2016; Rosenman et al., 2011). This may have influenced the associations we observed or the absence of them. Second, this study relied on a single, retrospective assessment of data which is subjected to recall biases, as participants might have falsefully recalled some information between the time of actual experience and the time of questionnaire completion. In addition, our study asked for data during the pandemic without any temporal consideration; specifically, whether our identified exposures (FI and maternal stress) occurred or changed temporally across pregnancy, according to critical developmental milestones in fetal development (Harville et al., 2010; Schriger, 2008). The exclusion of participants due to missing data, particularly on maternal obstetric outcomes, led to a significantly reduced sample size, particularly for birth outcome measures. This reduction may have limited the statistical power of our study, potentially impacting the generalizability of the results and the ability to detect significant associations. Finally, the absence of information on physical activity during pregnancy presents a potential limitation, as it could have obscured some associations, or even contributed the observed prevalence of inappropriate GWG observed. Hence, the lack of association between heightened maternal stress or even FI and GWG could be further explained by the protective effects of physical activity, provided some participants exercised. Evidence has shown that physical activity during gestation is associated with reduced risks of adverse maternal-infant health outcomes such as inappropriate GWG, birthweight, preterm birth, preeclampsia, and gestational diabetes (Moyer et al., 2016). On the other hand, the

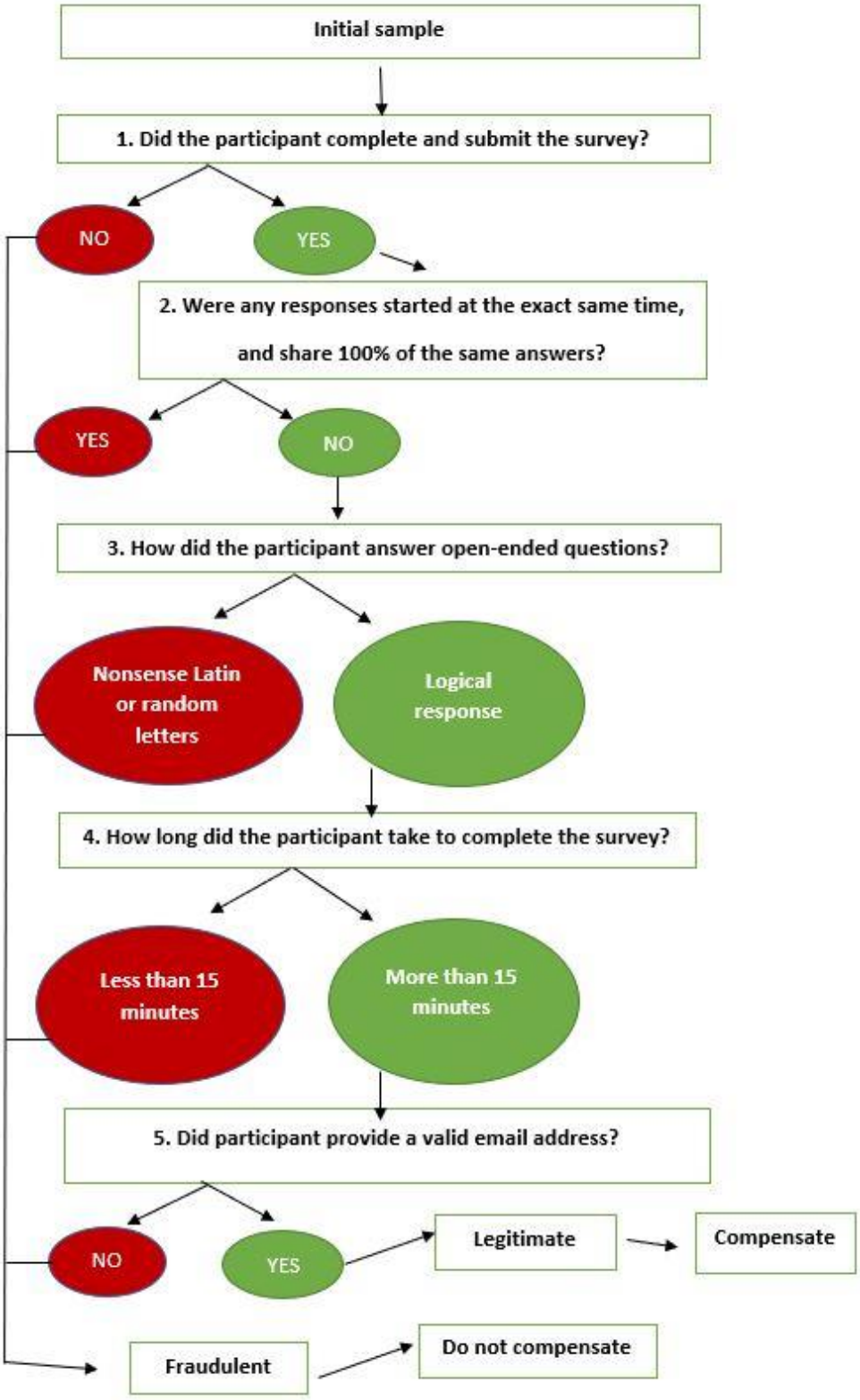
elevated prevalence of inappropriate GWG could be linked to increased sedentary behavior during the pandemic as a result of the lockdowns and different restrictive regulations put in place (Chandrasekaran & Ganesan, 2021; Runacres et al., 2021).

Conclusion

Adverse gestational exposures, such as FI and elevated maternal stress, were heightened during the COVID-19 pandemic, albeit experienced to varying degrees across the Canadian population. Within a DOHaD context, having a clearer understanding the population characteristics associated with adverse environmental exposures during pregnancy is important in allowing us to specifically identify distinct groups of pregnant individuals and their children who may be at highest risk for chronic disease in later life (King et al., 2012; King & Laplante, 2005). Emphasizing the importance of social determinants of health to pregnancy and offspring health outcomes, particularly in the context of natural disaster and emergency settings, helps identify target populations that would benefit most from additional supports and public policy reforms during these unexpected events.

3.6 Supplemental Material

Participant Response Filtering Methodology



CHAPTER 4: DISCUSSION

4.1 Summary of findings

Given the unprecedented nature of the COVID-19 pandemic and its associated lockdowns, there were numerous disruptions in everyday life, including compromised access to food and increased stress levels. Vulnerable populations, including those that were pregnant at the time, were considerably impacted by these disruptions (Azevedo et al., 2023; Wall & Dempsey, 2023). This study aimed to identify relevant social determinants of health associated with pandemic-related FI and heightened maternal stress and to explore the relationship between these adverse pregnancy exposures and maternal GWG and newborn birth weight in a pregnant Canadian cohort. In our study, various SDH factors—such as household type, sexual orientation, housing status, age group, household income, number of children, and unplanned pregnancies—were linked to FI among our study participants. Additionally, heightened stress was associated with all the above SDH factors, except for age and housing status. Although relationships were expected between these adverse exposures and health outcomes, the only significant finding observed was a positive association between heightened pandemic-related maternal stress and inappropriate for gestational age infant birthweights, a health outcome known to predict adverse long-term health in these offspring (Ong & Dunger, 2004; Smith et al., 2016). This thesis employed a more intricate, interdisciplinary approach to build on the core principles of bioscience in health and disease. These principles were examined as mechanisms underlying the exposure-outcome relationship, with a focus on incorporating biopsychosocial factors that can reduce harmful exposures and outcomes, ultimately aiming to address health inequities.These needed investigations into adverse early life exposures in the context of the COVID-19 pandemic, specifically those applying a social determinants' framework, are required to identify

and characterize pregnant individuals and their children at highest risk to be most adversely impacted in times of emergencies or natural disasters.

4.2 Limitations

In Chapter 3 a brief discussion of study limitations was provided, which I have further expanded upon below. A considerable unexpected hurdle that was faced in the completion of this study was the vulnerability of our online survey to 'bot attacks' and fraudulent responders who may have been motivated by the financial compensation provided upon study completion. Within 48 hours of launching our online survey, we received 3,500 responses, with a total of 2,759 completed surveys. Many of these were immediately suspicious due to unusually fast completion times, identical responses, or nonsensical answers to open-ended questions. None the less, we were left with the daunting and time-consuming task of determining which survey responses were in fact legitimate and eligible to be included in our data analysis. In light of this challenge, we were forced to pause recruitment, take the survey offline and develop an efficient and sensitive filtering methodology to sort through the survey responses to flag fraudulent responses (see 3.6 Supplemental Materials). After completing our screen of this first batch of responses, it was determined that 98% of these initial responses (n=2707/2759) were very likely fraudulent in nature. We also needed to revisit our online survey design and implement a number of safety measures prior to survey relaunch, to prevent future bot attacks and fraudulent responses. These measures were informed by current literature and expert advice related to online survey design (Chmielewski & Kucker, 2020; Moss, 2018; Simone, 2019), and included the completion of a screening captcha, flagging respondents who completed the survey materials impossibly fast, tracking study time stamps for impossible dates and times (e.g., bundles of participants beginning and ending the survey at the same exact time), and analysing open ended

questions for non-sense/illegitimate short answers. These measures were found to be slightly successful, as an additional 32 responses were received in the 48 hours upon survey relaunch, with a 10% positive yield. While this experience was very time consuming and frustrating, it did provide our team with considerable insight of important consideration for online survey design in the current online social climate.

Our current study did not consider the different provincial and territorial variations in measures and policies implemented, including lockdowns, mandatory masking, social distancing, and reduced social activities to address the COVID-19 pandemic (Wood et al., 2021). These regional variations might have intensified or affected the timing of the FI and stress exposures among the pregnant Canadians. For instance, the experience of FI during the COVID-19 pandemic might have varied in ways which the HFSSM was not designed to capture, as it was specifically designed to measure the household level experience of FI in the last 12 months prior to completion. Furthermore, while the HFSSM has been widely validated for measuring FI in the general population, it has not necessarily been robustly validated for pregnancy, as there are different trimester specific energy requirements. In fact, the questionnaire contains a question on weight loss, which is not entirely appropriate for this population. Finally, our study did not measure dietary intake, making it difficult to determine FI translated into compromised diets among participants. This gap may explain the lack of association between FI and maternal-infant health outcomes, as participants might have been concerned about food security—evidenced by the high prevalence—yet still maintained an adequate diet.

4.3 Areas of future research

Our findings underscore the need for follow-up studies using animal models and human observational studies to investigate the potential hormonal mechanisms involved in prenatal stress and birthweight relationships. For example, studies could be focused on better understanding the role of maternal and fetal cortisol signalling and subsequent fetal development following a natural disaster/pandemic-driven stressful event. Further, a better understanding of critical windows of adverse exposures in this context is needed; are there specific periods in pregnancy in which exposure to these types of environmental events might have the most detrimental impacts on fetal growth and development? Further, using animal models, the detailed mechanistic interaction between nutritional deprivation and maternal stress can be better explored, allowing us to ask questions related to causality. Further, due to the shorter gestational period and life span of many animal models, these experiments would also permit us to better explore the types of long-term health impacts these adverse in utero exposures might have on the offspring, advancing the field of DOHaD.

In the context of pandemics and natural disasters, which often occur without predictable timing and result in stringent public health measures, understanding the dose-response relationship and effect of timing between gestational exposures and outcomes is crucial. This understanding can help identify critical exposure levels and the precise timing when an exposure such as stress or FI happens, especially during vulnerable periods like pregnancy, which can impact health outcomes. Policymakers could then better predict how varying interventions might influence health outcomes under different scenarios, helping in the development of relevant support programs aimed at mitigating risks in vulnerable populations. Additionally, the HFSSM measure should be adapted and validated for use in pregnancy, accounting for maternal physiological and psychological changes and energy demands essential for fetal development. Future studies

should consider measuring FI with respect to the four dimensions of accessibility, availability, utilization, and stability as described by FAO (Leroy et al., 2015). Finally, to address the limitations of our small sample size, future studies should incorporate more prospective measurements, and involve larger, more diverse cohorts in terms of sociodemographic characteristics and regional representation to better reflect the pregnant Canadian population.

4.4 Interdisciplinarity of study

Despite its long and predominant use in healthcare and scientific research, the biomedical model puts little to no emphasis on the social, psychological, environmental, and behavioural aspects of health and well-being of a population (Engel, 1977). Given the significant increase in global mortality and morbidity from controllable factors, non-communicable diseases, general rise in healthcare expenditure, and persisting health inequity (Mathers & Loncar, 2006; Msemburi et al., 2023; Ortiz-Ospina & Roser, 2024; Scambler, 2012; WHO, 2018), there is a need for a more comprehensive and inclusive approach to healthcare, clinical practice, and scientific research, such as the biopsychosocial model. This model goes beyond the mere biomedical thinking to include interconnected determinants that might render a specific population more vulnerable than another (CDC, 2014; Dam et al., 2008; Engel, 1977; Ortiz-Ospina & Roser, 2024; WHO, 2024). Suggesting that an entire population's long-term health outcomes could be significantly improved by shifting further from a curative to a preventative model might seem skeptical, however, this shift could contribute to the discovery of innovative methods for exploring, measuring, and addressing complex health issues at all stages of life, with a particular focus on vulnerable developmental periods such as the perinatal window.

The preventative approach in healthcare generally aims to foster healthier communities, environments and innovative social programs and policies that might play an important role in determining long-term health outcomes, especially when it comes to critical windows of development, as postulated by the developmental origins of health and disease (DOHAD) paradigm (Dowe, 2001; Fuller, 2022; Heindel & Vandenberg, 2015; National Collaborating Centre for Determinants of Health, 2016). This thesis applied a more intricate and interdisciplinary approach to expand upon the foundational principles of bioscience in health and disease. These principles were identified as mechanisms that facilitate the exposure-outcome relationship, with the aim of integrating biopsychosocial factors that could mitigate adverse exposures and outcomes, thereby addressing inequities in health. Evidence indicates that individuals living in disadvantaged circumstances experience worse health outcomes compared to their more advantaged counterparts, highlighting the need for equitable approaches to perinatal healthcare (CDC, 2024; National Collaborating Centre for Determinants of Health, 2016).

This study purposely targeted vulnerable pregnant populations across the country in order to understand the various biopsychosocial aspects related to their experience of both FI and pandemic-related stress, and how these adverse exposures might affect their pregnancy health outcomes. As a result, this study incorporated aspects of epidemiology, biology, SDH, nutrition, psychology, and obstetrics in the hope of influencing public health policy. The epidemiological aspects came in through studying the distribution and determinants of health during an unprecedented public health crisis caused by the COVID-19 pandemic. This provided a glance of how the pandemic and its indirect consequences, such as the associated lockdowns, affected the availability of food or accessibility of healthcare and prenatal services. The social aspect of the

study came from the exploration of relevant SDH factors, like socioecomic, education, housing, or social support status, ultimately allowing for the identification of critical risk factors which place specific pregnant populations at higher risk for adverse fetal programming events. These social determinants might have influenced the general nutritional habits or food utilization, given that the eating habits might vary by an individual's family composition, food knowledge or available resources (Lewin, 1943). Further, the psychosocial health of individuals during the pandemic might have varied by the amount of social support available or availability of a copying mechanism because of the pandemic-related stress (Chankasingh et al., 2022; Kim et al., 2024; H. Yu et al., 2020). The above social determinants might have influenced the pregnancy behaviour patterns, including whether an individual chose to give birth at home or in hospital, or abstained from social visits to limit potential COVID-19 exposure to them and their fetus/infant (Cheng et al., 2022; Childress et al., 2023). Identification of populations at highest risk and gaining insight into what rendered them more vulnerable compared to others, can drive conversations pertaining to targeted public health policy and public health programming unique to emergency or natural disaster planning. Overall, by leveraging knowledge and expertise in these various fields, we were able to design and execute an important first step research project that has provided unique insight into the various biopsychosocial aspects that underpin food security and gestational stress, and ultimately maternal-infant health outcomes, in the context of a public health emergency.

4.5 Conclusion

Our study contributes to an important gap in the literature on FI and maternal stress during pregnancy, particularly within the context of public health emergencies such as the

COVID-19 pandemic in Canada. Specifically, key SDH indicators—including household type, sexual orientation, housing status, age group, household income, number of children, and unplanned pregnancies—were identified as significant risk factors for FI, stress, or both during pregnancy. Further, this study identified an increased risk of inappropriate fetal growth trajectories associated with heightened COVID-19 related prenatal stress, with increased observations of birthweight extremes. Considering the entire prenatal period, identifying the concrete needs and challenges faced during pregnancy, which were exacerbated during the COVID-19 pandemic, could inform targeted interventions and programs aimed at alleviating the potential short- and long-term adverse health outcomes of social and material deprivation during critical windows of early life development.

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APPENDICES

Appendix A: Ethics certificate

14/11/2022

Université d'Ottawa
Bureau d'éthique et d'intégrité de la recherche

University of Ottawa
Office of Research Ethics and Integrity

CERTIFICAT D'APPROBATION ÉTHIQUE | CERTIFICATE OF ETHICS APPROVAL

Numéro du dossier / Ethics File Number	H-07-22-8071
Titre du projet / Project Title	Food insecurity, maternal stress and maternal/infant health outcomes during the COVID-19 pandemic: a DOHaD framework
Type de projet / Project Type	Thèse de maîtrise / Master's thesis
Statut du projet / Project Status	Approuvé / Approved
Date d'approbation (jj/mm/aaaa) / Approval Date (dd/mm/yyyy)	14/11/2022
Date d'expiration (jj/mm/aaaa) / Expiry Date (dd/mm/yyyy)	13/11/2023

Équipe de recherche / Research Team

Chercheur / Researcher	Affiliation	Role
Landry KALEMBO	École interdisciplinaire des sciences de la santé / Interdisciplinary School of Health Sciences	Chercheur Principal / Principal Investigator
Shannon BAINBRIDGE-WHITESIDE	École interdisciplinaire des sciences de la santé / Interdisciplinary School of Health Sciences	Superviseur / Supervisor
Bénédicte FONTAINE-BISSON	École des sciences de la nutrition / School of Nutrition Sciences	Co-superviseur / Co-supervisor
Sagni KUMA	École interdisciplinaire des sciences de la santé / Interdisciplinary School of Health Sciences	Assistant de recherche / Research Assistant

Appendix B: Copy of study questionnaire

Thank you for taking the time to complete the **food access and stress in pregnancy during the CovId-19 pandemic (ORIGIN) Survey**. Your answers will help us understand the concrete needs and challenges faced by pregnant individuals of varying sociodemographic backgrounds, and how they were affected by food insecurity and heightened stress during the pandemic. This survey is being used to collect information on your personal characteristics (e.g. age, gender, ethnicity, immigration status, education, income), dietary habits, lifestyle, living conditions, stress, pregnancy experience, and the impact of COVID-19 during your pregnancy.

For the purposes of this survey when we say "during your pregnancy" we are referring to your most recent pregnancy that took place during the COVID-19 pandemic (since March 2020). If you are currently pregnant, please refer to your previous pregnancy that took place during the pandemic.

Please complete the following questions to the best of your ability. You are not required to answer any question that makes you uncomfortable. You will be able to indicate "prefer not to answer" or skip to the next question if this is the case.

This survey is broken down into 12 sections and contains 100-159 questions depending on which ones apply to you. The survey will take approximately 30 minutes to complete. Please note that you can save your answers and complete the survey later.

Thank you!

Section 1 – Sociodemographic Information

In this section you will be asked questions about your background (such as your gender, marital status, ethnicity, education, immigration status, etc.). Note that a $25 electronic gift card ***or interact e-transfer*** will be offered upon completion of the survey.

1. **Where did you live during your pregnancy? Select all that apply.**
    - Newfoundland and Labrador
    - Prince Edward Island Île-du-Prince-Édouard
    - Nova Scotia
    - New Brunswick
    - Québec
    - Ontario
    - Manitoba
    - Saskatchewan
    - Alberta
    - British Colombia Colombie-Britannique
    - Yukon
    - North-West Territories
    - Nunavut
    - 14, I prefer not to answer

2. **What was your marital status during your pregnancy? Were you…?**
    - Married
    - Living common law
    - Widowed
    - Separated
    - Divorced
    - Single, never married
    - I prefer not to answer

3. **Do you live with your partner/significant other?**
    - 1 : Yes
    - 2 : No
    - 3 : Not applicable – I did not have a partner/significant other
    - 4 : I prefer not to answer

4. **How would you describe your gender identity? Select all that apply**
    - Woman

- Man
- Gender fluid - A person who does not identify with a single fixed gender or has a fluid or unfixed gender identity
- Genderqueer - Used to describe someone who typically rejects notions of categories and embrace fluid gender identity
- Intersex - An umbrella term used to describe bodies that fall outside of male/female categories (e.g., chromosome differences, ambiguous genitalia, internal organ differences)
- Non-binary - An umbrella term referring to anyone who is not cis-gendered and is inclusive of identities such as trans-woman and trans-man
- Questioning - A term used to describe people who are in the process of exploring their sexual orientation or gender identify
- Transgender - An umbrella term for people whose gender identity and/or expression is different from sex assigned at birth
- Two-spirit - Refers to a person who identifies as having both a masculine and a feminine spirit, and is used by some Indigenous people to describe their sexual, gender and/or spiritual identity.
- I don't know
- I prefer not to answer
- I prefer to self-describe

4. b Please self describe

5. How would you describe your sexual orientation? Select all that apply.

- Asexual - A person who does not experience sexual attraction
- Bisexual - A person emotionally, romantically, or sexually attracted to more than one sex, gender, or gender identity though not necessarily simultaneously, in the same way or to the same degree. Sometimes used interchangeably with pansexual.
- Gay - A sexual orientation towards people of the same sex/gender Heterosexual/straight - A person whose primary sexual orientation is towards people of the opposite sex/gender
- Lesbian - A woman whose primary sexual orientation is towards people of the same sex/gender
- Pansexual - Potential for emotional, romantic, or sexual attraction to people of any gender though not necessarily simultaneously, in the same way or to the same degree.
- Queer - An inclusive term used to express a spectrum of identities and orientations
- I don't know
- I prefer not to answer
- I prefer to self-describe

5 b. Please self describe

6. Where were you born?

- Born in Canada
- Born outside Canada
- I prefer not to answer

7. When did you move to Canada?

- In the last 1 year
- In the last 1-5 years
- In the last 5-10 years
- In the last 10+ years
- I prefer not to answer

8. Are you now, or have you ever been a Permanent Resident?

- Yes
- No
- I prefer not to answer

9. In what year did you first become a Permanent Resident?

10. Do you identify as Indigenous; that is First Nation (North American Indian), Métis, or Inuk (Inuit)?

- Yes
- No
- I prefer not to answer

10 b. Please select the option that best describes you:

- First Nations
- Métis Inuk (Inuit)
- I prefer not to answer

11. Do you identify as a member of a visible minority? Note: Visible minority includes persons who are non-Caucasian in race or non-white in colour and who do not report being Indigenous.

- Yes
- No
- I prefer not to answer

11 b. Please select the option that best describes you.

- Arab
- Black
- Chinese

- Filipino
- Japanese
- Korean
- Latin American
- South Asian (e.g., East Indian, Pakistani, Sri
- Lankan, etc.)
- Southeast Asian (e.g., Vietnamese, Cambodian,
- Laotian, Thai)
- West Asian (e.g., Iranian, Afghan)
- I prefer not to answer
- I prefer to self-describe

11 c. Please self describe

12. What language do you speak most often at home?

- English
- French
- Other
- I prefer not to answer

13. Select your age group (years old):

- 18-23
- 24-29
- 30-34
- 35-39
- 40-44
- 45-49
- 50+
- I prefer not to answer

14. Do you consider where you live to be:

- Urban area (large city) (population >1 million)
- Suburban (smaller city or region outside an urban
- area) (population >10,000 to < 1 million)
- Rural area (population < 10,000)
- I prefer not to answer

15. Did you graduate from high school (secondary school)?

- Yes
- No
- I prefer not to answer

16. What is the highest degree, certificate, or diploma you have obtained?

- No post-secondary degree, certificate, or diploma
- Trade certificate or diploma from a vocational
- school or apprenticeship training
- Non-university certificate or diploma from a
- community college, CEGEP, school of nursing, etc.
- University certificate below bachelor's level
- Bachelor's degree
- Graduate degree (e.g. Msc, MD, PhD etc.)
- I prefer not to answer

17. During your pregnancy, were you attending a school, college, CEGEP, or univsersity?

- Yes
- No
- I prefer not to answer

18. During your pregnancy, were you enrolled as a full-time or part-time student?

- Full-time student
- Part-time student
- I prefer not to answer

Section 2 – General Health & Health Behaviour

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1. In general, during your pregnancy, how was your physical health?

- Excellent
- Very good
- Good
- Fair
- Poor
- I prefer not to answer

2. In general, during your pregnancy how was your mental health?

- Excellent
- Very good
- Good
- Fair
- Poor

- I prefer not to answer

3. Including the pregnancy that you are referring to in this survey, how many times have you been pregnant? (This includes pregnancies ending in miscarriage, abortion, ectopic pregnancy, stillbirth, and live birth.)

- 1
- 2
- 3
- 4
- ≥ 5
- I prefer not to answer

4. Thinking about the amount of stress in your life, how would you describe most of your days during your pregnancy?

- Not at all stressful
- Not very stressful
- A bit stressful
- Quite a bit stressful
- Extremely stressful
- I prefer not to answer

5. During your pregnancy, did you develop any new medical conditions or have preexisting health problems that required you to take medication for more than 2 weeks, have special care, or extra tests?

- Yes
- No
- I prefer not to answer

5 b. Please specify

6. At any point during your pregnancy, did you smoke daily, occasionally, or not at all?

- Daily
- Occasionally
- Not at all
- I prefer not to answer

7. During your pregnancy, was there any period of time when you lived with someone who smoked?

- Yes
- No
- I prefer not to answer

8. After you realized you were pregnant, how often did you drink alcoholic beverages?

- Was not drinking at the time/stopped drinking
- Less than once a month
- Once a month
- 2 to 3 times a month
- Once a week
- 2 to 3 times a week
- 4 to 6 times a week
- Everyday
- I prefer not to answer

9. After you realized you were pregnant, did you use illicit drugs and/or misuse prescription drugs?

- Never
- Less than once a month
- 1 to 3 times a month
- Once a week
- More than once a week
- Everyday
- I prefer not to answer

10. After you realized you were pregnant, did you use cannabis?

- Never
- Less than once a month
- 1 to 3 times a month
- Once a week
- More than once a week
- Everyday
- I prefer not to answer

Section 3 – Maternal & Infant Health Outcomes

---

1. What was the sex of your child?

- Male
- Female
- I prefer not to answer

2. Was the pregnancy planned?

- Yes
- No
- I prefer not to answer

3. What month was your child born?

- Jan
- Feb
- Mar
- Apr
- May
- Jun
- Jul
- Aug
- Sept
- Oct
- Nov
- Dec
- I prefer not to answer

4. What year was your child born?

- 2020
- 2021
- 2022
- 2023
- I prefer not to answer

5. Was you child born preterm?

- Yes
- No
- I don't know
- I prefer not to answer

6. Was your child diagnosed as growth restricted?

- Yes
- No
- I don't know
- I prefer not to answer

7. Was your child admitted to the Neonatal Intensive Care Unit (NICU) after birth?

- Yes
- No
- I don't know
- I prefer not to answer

8. How was your child delivered?

- Vaginal
- C-section
- I prefer not to answer

9. Would you like to report this child's birth weight in grams (g) or pounds (lbs) and ounces (oz)?

- Grams (g)
- Pounds (lbs) and ounces (oz)?
- I do not know my child's birth weight
- I prefer not to answer

9 b. What was your child's birth weight? (grams) _____

9 c. What was your child's birth weight? (pounds and ounces) _____

10. Would you like to report this child's length at birth in centimeters (cm) or inches (inch)?

- Centimeters (cm)
- Inches (inch)
- I do not remember
- I prefer not to answer

10 b. What was your child's length at birth? (cm)

10 c. What was your child's length at birth? (inch)

11. Please specify what type of pregnancy this was (i.e. how many babies were delivered?)

- Single (1 baby)
- Twins (2 babies)
- Triplets (3 babies)
- More than 3 babies
- I prefer not to answer

12. What week gestation was your child born? _____

13. Would you like to report your height in centimeters (cm) or feet (ft)?

- Centimeters (cm)
- Feet (ft)

- I don't know
- I prefer not to answer

13 b. What is your height? (cm) _____

13 c. What is your height? (ft) _____

14. Would you like to report your weight in kilograms (kg) or pounds (lbs)?

- Kilograms (kg)
- Pounds (lbs)
- I prefer not to answer

14 b. Just before your pregnancy, how much did you weigh? (kg). Please report on your average for the 6 months prior to the pregnancy. _____

14 c. Just before your pregnancy, how much did you weigh? (lbs). Please report on your average for the 6 months prior to the pregnancy. _____

15. What was your actual weight gain during the pregnancy? (kg)

15 b. What was your actual weight gain during pregnancy? (lbs)

16. What do you consider to be a healthy weight gain for you in pregnancy? Please enter a single amount (kg)_____

16 b. What do you consider to be a healthy weight gain for you in pregnancy? Please enter a single amount (lbs)_____

17. Did your healthcare providers talk to you about your weight and/or your weight gain limits?

- Yes
- No
- I prefer not to answer

18. Did you make a focused effort to stay within the weight gain limits given to you by your health care provider?

- Never
- Rarely
- Sometimes
- Most of the time
- Always
- I prefer not to answer

19. During your pregnancy, what did you believe were the challenges to gaining within a targeted weight?

- Lack of support from family or friends

- Lack of guidance from health care professional
- Weight gain during pregnancy is beyond control of
- the mother
- It is difficult to exercise during pregnancy
- It is difficult to eat healthy during pregnancy
- I don't believe there are any barriers to gaining
- a healthy amount of weight during pregnancy.
- Other
- I prefer not to answer
- Not applicable

Section 4 – Housing Status/Living Arrangement & Transportation

---

1. During your pregnancy, how many children did you have (under the age of 18)?

- 0
- 1
- 2
- 3
- 4
- 5 or more
- I prefer not to answer

2. During your pregnancy, how many people usually lived at your address including yourself?

- 0
- 1
- 2
- 3
- 4
- 5 or more
- I prefer not to answer

3. During your pregnancy, did you (or any member of your home) own or rent your dwelling?

- Owner (even if you are still paying the mortgage)
- Tenant (even if no cash rent is paid)
- I prefer not to answer

4. Was this dwelling (home) subsidized?

- Yes
- No
- I prefer not to answer

5. During your pregnancy, did you own a car?

-
- Yes
- No
- I prefer not to answer

6. Did you have access to a car when you needed one?

- Yes
- No
- Sometimes
- I prefer not to answer

7. Did you have a bus or train stop that was within a 15-minute walk of your home?

-
- Yes
- No
- I do not know
- I prefer not to answer

8. During your pregnancy, which mode of transportation did you overall use mostly?

- Car
- Bus
- Bicycle
- By foot
- Train or tramway
- I prefer not to answer

Section 5 – Food Insecurity

---

1. Which of the following statements best describes the food eaten in your household during your pregnancy?

- You and other household members always had enough of the kinds of foods you wanted to eat
- You and other household members had enough to eat, but not always the kinds of food you wanted
- Sometimes you and other household members did not have enough to eat
- Often you and other household members didn't have enough to eat
- Don't know / refuse to answer

2. You and other household members worried that food would run out before you got money to buy more. Was that often true, sometimes true, or never true during your pregnancy?

- Often true
- Sometimes true
- Never true
- I prefer not to answer

3. The food that you and other household members bought just didn't last, and there wasn't any money to get more. Was that often true, sometimes true, or never true during pregnancy?

- Often true
- Sometimes true
- Never true
- I prefer not to answer

4. You and other household members couldn't afford to eat balanced meals. During your pregnancy, was that often true, sometimes true, or never true?

- Often true
- Sometimes true
- Never true
- I prefer not to answer

5. You or other adults in your household relied on only a few kinds of low-cost food to feed the child(ren) because you were running out of money to buy food. Was this often true, sometimes true, or never true during your pregnancy?

- Often true
- Sometimes true
- Never true
- I prefer not to answer

6. You or other adults in your household couldn't feed the child(ren) a balanced meal, because you couldn't afford it. Was that often true, sometimes true, or never true during your pregnancy?

- Often true
- Sometimes true
- Never true
- I prefer not to answer

7. The child(ren) were not eating enough because you and other adult members of the household just couldn't afford enough food. Was this often, sometimes, or never true during your pregnancy?

- Often true
- Sometimes true
- Never true
- I prefer not to answer

8. During your pregnancy, did you or other adults in your household ever cut the size of your meals or skip meals because there wasn't enough money for food?

- Yes
- No
- I prefer not to answer

8 b. How often did this happen?

- Almost every month
- Some months but not every month
- Only 1 or 2 months
- I prefer not to answer

9. During your pregnancy, did you (personally) ever eat less than you felt you should because there wasn't enough money to buy food?

- Yes
- No
- I prefer not to answer

10. During your pregnancy, were you (personally) ever hungry but didn't eat because you couldn't afford enough food?

- Yes
- No
- I prefer not to answer

11. During your pregnancy, did you (personally) lose weight because you didn't have enough money for food?

- Yes
- No

- I prefer not to answer

12. During your pregnancy, did you or other adults your household ever not eat for a whole day because there wasn't enough money for food?

- Yes
- No
- I prefer not to answer

12 b. How often did this happen?

- Almost every month
- Some months but not every month
- Only 1 or 2 months
- I prefer not to answer

13. During your pregnancy, did you or other adults in your household ever cut the size of any of the children's meals because there wasn't enough money for food?

- Yes
- No
- I prefer not to answer

14. During your pregnancy, did any of the children ever skip meals because there wasn't enough money for food?

- Yes
- No
- I prefer not to answer

14 b. How often did this happen?

- Almost every month
- Some months but not every month
- Only 1 or 2 months
- I prefer not to answer

15. During your pregnancy, were any of the children ever hungry but you just couldn't afford more food?

- Yes
- No
- I prefer not to answer

16. During your pregnancy, did any of the children ever not eat for a while day because there wasn't enough money for food?

- Yes

- No
- I prefer not to answer

17. During your pregnancy, did the amount of food consumed (e.g. cutting portions or number of meals) change because of the pandemic?

- Yes
- No
- I prefer not to answer

17 b. During your pregnancy, did the quality of the food eaten (e.g. types of food you would normally like/expect to eat) change because of the pandemic?

- Yes
- No
- I prefer not to answer

17. c During your pregnancy, did your access to food (e.g. being able to go to the grocery store or have your order delivered) change because of the pandemic?

- Yes
- No
- I prefer not to answer

Section 6 – Dietary Habits

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1. During your pregnancy, how would you rate the quality of your diet in general?

- Excellent
- Good
- Average
- Poor
- Very poor
- I prefer not to answer

2. Healthy eating during pregnancy was? (Healthy = eating a variety of foods from all food groups that provide all the nutrients needed for pregnancy, in the recommended amounts)

- Rather easy
- Rather difficult
- I prefer not to answer

3. What was stopping you from eating "healthy" during your pregnancy (Check all that apply)

- Cravings
- Hunger
- Food aversions (disgust)
- Financial factors
- Access to healthy food
- Time constraints
- Lack of knowledge about nutritious foods
- Lack of culinary skills
- Your partner/spouse, other family members, children
- Other (please specify)
- I prefer not to answer

3 b. Please specify

4. What facilitated healthy eating during your pregnancy? (Please check all that apply)

- I did not have or did not give in to food cravings pregnancy?
- I did not have a problem with hunger (too much or too little)
- I did not have food aversions (dislikes)
- My budget allowed it
- I had access to healthy foods
- I had enough time to eat well
- I had enough knowledge about nutrition
- I had good cooking skills
- I had help from my partner/spouse, other family members
- Other (Please specify)
- I prefer not to answer

4 b. Please specify

5. Did you have any dietary restrictions due to your religious or personal beliefs?

- Yes
- No
- I prefer not to answer

6. During your pregnancy, who usually prepared the meals at home?

- You
- Another person in the household
- Another person outside the household
- I prefer not to answer

7. During the normal 7-day week, how often did you eat a commercially prepared meal? (frozen meals, ready-to-eat, etc)

- Never or very rarely
- Less than once per week
- 1-2 times per week
- 3-4 times per week
- Every day or so
- I prefer not to answer

8. In a typical 7-day week, how often did you eat at fast food restaurants? (e.g. McDonald's, Tim Horton's, Harvey's, Burger King, snack bar, etc.)

- Never or very rarely
- Less than once per week
- 1-2 times per week
- 3-4 times per week
- Every day or so
- I prefer not to answer

9. When you cooked, why did you prepare food at home? Select all that apply.

- It was better for my health
- It was better for my baby's health
- It was less expensive
- I liked to cook
- It allowed me to prepare food that I liked
- Other
- I prefer not to answer
- Not applicable (I did not cook)

10. Since you became pregnant, did you eliminate any foods or beverages from your diet that you consumed prior to becoming pregnant?

- Yes
- No
- I prefer not to answer

10 b. Please specify

11. Since you became pregnant, did you introduce any brand-new foods or beverages in your diet that you never consumed prior to becoming pregnant?

- Yes
- No
- I prefer not to answer

11 b. Please specify

12. Since you became pregnant, did you decrease your consumption of any specific foods or beverages?

- Yes
- No
- I prefer not to answer

12 b. Please specify

13. In the 3 months before your got pregnant, did you take a multivitamin containing folic acid or a folic acid supplement?

- Yes
- No
- I don't know
- I prefer not to answer

14. During the first 3 months of your pregnancy, did you take a multivitamin containing folic acid or a folic acid supplement?

- Yes
- No
- I don't know
- I prefer not to answer

Section 7 – The Pandemic Related Pregnancy Stress Scale

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1. During my pregnancy, I was concerned about going to prenatal care appointments due to COVID-19.

- Very Little
- Little
- Some
- Much
- Very Much
- **I prefer not to answer**

2. During my pregnancy, I was concerned that I would not get the prenatal care I needed because of COVID-19.

- Very Little
- Little
- Some
- Much
- Very Much
- I prefer not to answer

3. During my pregnancy, I was worried that I would get COVID-19 when I went to the hospital to deliver.

- Very Little
- Little
- Some
- Much
- Very Much
- I prefer not to answer

4. During my pregnancy, I was worried that my baby could get COVID-19 at the hospital after birth.

- Very Little
- Little
- Some
- Much
- Very Much
- I prefer not to answer

5. During my pregnancy, I felt that COVID-19 was helping me appreciate my pregnancy more.

- Very Little
- Little
- Some
- Much
- Very Much
- I prefer not to answer

6. During my pregnancy, I was worried I would not be able to have someone with me during the delivery

- Very Little
- Little
- Some
- Much
- Very Much

- I prefer not to answer

7. During my pregnancy, I was worried I would not be prepared for the birth due to the pandemic restrictions

- Very Little
- Little
- Some
- Much
- Very Much
- I prefer not to answer

8. During my pregnancy, I felt that being pregnant was giving me strength during the pandemic.

- Very Little
- Little
- Some
- Much
- Very Much
- I prefer not to answer

9. During my pregnancy, I was concerned that I was not getting enough healthy food or sleep or exercise because of COVID-19 restrictions

- Very Little
- Little
- Some
- Much
- Very Much
- I prefer not to answer

10. During my pregnancy, I was concerned that a COVID-19 infection could harm my baby.

- Very Little
- Little
- Some
- Much
- Very Much
- I prefer not to answer

11. During my pregnancy, I was concerned that a COVID-19 infection could harm my pregnancy (such as miscarriage or preterm birth)

- Very Little

- Little
- Some
- Much
- Very Much
- I prefer not to answer

12. During my pregnancy, I was worried that the pandemic could ruin my birth plans.

- Very Little
- Little
- Some
- Much
- Very Much
- I prefer not to answer

13. During my pregnancy, I was concerned about being separated from my baby after the delivery because of the pandemic.

- Very Little
- Little
- Some
- Much
- Very Much
- I prefer not to answer

14. During my pregnancy, I thought about having a baby to help me get through the pandemic hardships.

- Very Little
- Little
- Some
- Much
- Very Much
- I prefer not to answer

15. During my pregnancy, I was concerned that people wouldn't be able to help me care for my baby after birth.

- Very Little
- Little
- Some
- Much
- Very Much
- I prefer not to answer

Section 8 – Social Support

1. Were you satisfied with your social life in general before the pandemic?

- Very satisfied
- Somewhat satisfied
- Somewhat unsatisfied
- Very unsatisfied
- I prefer not to answer

2. During your pregnancy, were you satisfied with your social life in general?

- Very satisfied
- Somewhat satisfied
- Somewhat unsatisfied
- Very unsatisfied
- I prefer not to answer

3. How would you describe your sense of belonging to your local community before the pandemic? Would you say it was:

- Very strong
- Somewhat strong
- say it was Neutral
- Rather weak
- Very weak
- I prefer not to answer

4. During your pregnancy, how would you describe your sense of belonging to your local community? Would you say it was:

- Very strong
- Somewhat strong
- say it was Neutral
- Rather weak
- Very weak
- I prefer not to answer

5. How often did you feel that you lacked companionship before the pandemic?

- Almost never
- Sometimes
- Often

- I prefer not to answer

6. During your pregnancy, how often did you feel that your lacked companionship?

- Almost never
- Sometimes
- Often
- I prefer not to answer

7. How often did you feel isolated from others before the Pandemic?

- Almost never
- Sometimes
- Often
- I prefer not to answer

8. How often did you feel isolated from others since the Pandemic?

- Almost never
- Sometimes
- Often
- I prefer not to answer

9. During your pregnancy, how many people did you feel comfortable asking for advice or help with personal or family problems when you were in trouble, without fear of being judged?

- None
- 1
- 2 to 5
- 6 or more
- I prefer not to answer

10. In times of financial difficulty, I could count on the people around me to help me.

- Totally in agreement
- In agreement
- Neutral
- In disagreement
- Strongly in disagreement
- I prefer not to answer
- Not applicable

11. During you pregnancy, how often was support available to you when you needed it?

- None of the time
- A little of the time

- Some of the time
- Most of the time
- All of the time
- I prefer not to answer

12. If you had a partner during your pregnancy, how satisfied or dissatisfied were you with the support you received from them?

- Very satisfied
- Somewhat satisfied
- Neither satisfied or dissatisfied
- I prefer not to answer
- Not applicable

Section 9 – Self-esteem

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1. On the whole, I was satisfied with myself.

- Strongly Agree
- Agree
- Disagree
- Strongly Disagree
- I prefer not to answer

2. At times I thought I was no good at all.

- Strongly Agree
- Agree
- Disagree
- Strongly Disagree
- I prefer not to answer

3. I felt that I had a number of good qualities.

- Strongly Agree
- Agree
- Disagree
- Strongly Disagree
- I prefer not to answer

4. I was able to do things as well as most other people.

- Strongly Agree
- Agree
- Disagree
- Strongly Disagree
- I prefer not to answer

5. I felt I do not have much to be proud of.

- Strongly Agree
- Agree
- Disagree
- Strongly Disagree
- I prefer not to answer

6. I certainly felt useless at times.

- Strongly Agree
- Agree
- Disagree
- Strongly Disagree
- I prefer not to answer

7. I felt that I was a person of worth, at least on an equal plane with others.

- Strongly Agree
- Agree
- Disagree
- Strongly Disagree
- I prefer not to answer

8. I wished I could have more respect for myself.

- Strongly Agree
- Agree
- Disagree
- Strongly Disagree
- I prefer not to answer

9. All in all, I was inclined to feel that I was a failure.

- Strongly Agree
- Agree
- Disagree
- Strongly Disagree
- I prefer not to answer

10. I took a positive attitude toward myself.

- Strongly Agree
- Agree
- Disagree
- Strongly Disagree
- I prefer not to answer

Section 10 – Socioeconomic Status

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1. Did you work at a paid job or business at any time during your pregnancy?

- Yes
- No
- Prefer not to answer

2. Which of the following best describes your employment status during your pregnancy?

- Full-time
- Part-time
- Paid leave
- Unpaid leave
- I prefer not to answer
- Other

2 b. Please specify

3. During your pregnancy, did you change jobs?

- Yes
- No
- Prefer not to answer

4. During your pregnancy, how would you describe most days at work?

- Not at all stressful
- Not very stressful
- Somewhat stressful
- Stressful
- Extremely stressful
- I prefer not to answer

5. During your pregnancy, in which of these locations did you work the most hours?

- At a fixed location outside the home (e.g., office building, factory)
- Outside the home with no fixed location (e.g., driving, making sales calls)
- At home (e.g., main residence, cottage)
- I prefer not to answer

6. Were you an employee or self-employed?

- Employee
- Self-employed
- Working at a family business without pay

7. Did you have more than one job or business during your pregnancy?

- Yes
- No
- Prefer not to answer

8. During your pregnancy, were you concerned about job stability because of COVID-19?

- Yes
- No
- Prefer not to answer

9. During your pregnancy, what was your average total household income before taxes?

- Less than $25,000 CAD
- $25,000 to $49,999 CAD
- $50,000 to $74,999 CAD
- $75,000 to $99,999 CAD
- $100,000 to $124,999 CAD
- $125,000 to $149,999 CAD
- $150,000 CAD or greater
- I prefer not to answer

10. Thinking of total income for all members of your household, what were the sources of income or other financial support during your pregnancy? (Check all that apply)

- Salary (or self-employment income)
- Municipal or provincial social assistance or welfare benefits
- Employment insurance benefits (unemployment)
- Dividends and interest (e.g. on bonds, savings)
- Workers' compensation benefits
- Child tax benefits or family allowances
- Child or spousal support
- COVID-19 Relief benefit (CERB)

- Other (e.g. rental income, scholarship, family
- assistance)
- I prefer not to answer

Section 11 – Access to Healthcare

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1. Thinking back to your entire pregnancy, were you able to get information and care in a language you speak well enough to conduct a conversation?

- Yes
- No
- Sometimes
- I prefer not to answer

2. Was it important to you to receive perinatal services in your preferred language?

- Very important
- Important
- Neutral
- Not very important
- Not at all important
- I prefer not to answer

3. How far did you travel to receive medical care during pregnancy and delivery?

- 0-25 km
- 25-50 km
- Greater than 50 km
- I prefer not to answer

4. How many weeks pregnant were you when you had your first visit for prenatal care? This includes the first time your pregnancy was confirmed by a healthcare provider.

- First trimester (Please specify the number of weeks if you remember)
- Second trimester (Please specify the number of weeks if you remember)
- Third trimester (Please specify the number of weeks if you remember)
- I do not remember
- I prefer not to answer

4 b. Please specify

4. c Please specify

5. Did you receive prenatal care as early as you wanted?

- Yes
- No
- Prefer not to answer

6. What prevented you from getting prenatal care as early as you wanted?

- Doctor/ healthcare provider was unavailable
- Doctor/ healthcare provider would not start care earlier
- I didn't know I was pregnant
- I didn't have childcare
- I was too busy
- I didn't have transportation
- I couldn't take time off work
- Other
- I prefer not to answer

7. How many prenatal care visits did you have?

-
- 0
- 1-4
- 5-8
- 9-12
- 13 or more
- I do not remember
- I prefer not to answer

8. From which type of healthcare provider, such as an obstetrician, family doctor, or midwife, did you receive the most care?

- Obstetrician/ Gynecologist
- Family doctor/general practitioner
- Midwife
- Other (specify)
- I prefer not to answer

9. What was your level of satisfaction with the prenatal health services offered in your region?

- Very satisfied
- Satisfied
- Neutral
- Dissatisfied
- Very dissatisfied

- I prefer not to answer

10. During your pregnancy, did you attend pregnancy support programs, prenatal or childbirth education classes?

- Yes
- No
- Prefer not to answer

11. During your pregnancy, who or what were you most useful sources of information about pregnancy, labour, and birth?

- Previous pregnancy
- Family or friends
- Obstetrician/gynecologist
- Family doctor/general practitioner
- Midwife
- Nurse/nurse practitioner
- Doula
- Prenatal/childbirth classes
- Books
- Internet
- Other (specify)
- I prefer not to answer

11 b. Please specify

Section 12 – Sleep & Physical Activity

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1. Did you exercise during your pregnancy?

- Yes
- No
- I prefer not to answer

2. On a typical week, how much time did you spend in total on moderate and vigorous physical activities where your heartbeat increased and you breathed faster (e.g. brisk walking, cycling as a means of transport or as exercise, heavy gardening, running or recreational sports). Only include activities that lasted at least 10 minutes at a time.

- Less than ½ an hour (less than 30 minutes)
- 1/2 an hour - 11/2 hours (30-90 minutes)

- 11/2 - 21/2 hours (90-150 minutes)
- 21/2 hours - 5 hours (150-300 minutes)
- More than 5 hours (more than 300 minutes)
- I prefer not to answer

3. How much of the time that you spent on physical activities in a typical week, which you indicated above, did you spend in total on vigorous physical activity? This includes activities that got your heart racing, made your sweat and left you short of breath that speaking became difficult (e.g. swimming, running, cycling at high speeds, cardio training, weight lifting or team sports such as football)

- Less than ½ an hour (less than 30 minutes)
- 1/2 an hour - 11/2 hours (30-90 minutes)
- 11/2 - 21/2 hours (90-150 minutes)
- 21/2 hours - 5 hours (150-300 minutes)
- More than 5 hours (more than 300 minutes)
- I prefer not to answer

4. During your pregnancy, how many hours of actual sleep did you get at night? (This may be different than the number of hours you spent in bed)

- 1-2
- 3-4
- 5-6
- 7-8
- More than 8
- I don't recall
- I prefer not to answer

5. During your pregnancy, how would your rate your sleep quality overall? Please choose a number from 0 to 10, according to the following five categories: 0 = terrible, 1-3 = poor, 4-6 = fair, 7-9 = good, and 10 = excellent)

- Terrible (0)
- Poor (1-3)
- Fair (4-6)
- Good (7-9)
- Excellent (10)
- I prefer not to answer