Investigating Sugar and Non-nutritive Sweetener Intake in Young Children
and Associations of Sugar Intake with Sociodemographic Indicators and
Anthropometric Measures

by
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A Thesis
presented to
The University of Guelph

In partial fulfilment of requirements
for the degree of
Doctor of Philosophy
in
Human Health and Nutritional Sciences

Guelph, Ontario, Canada

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ABSTRACT

INVESTIGATING SUGAR AND NON-NUTRITIVE SWEETENER INTAKE IN YOUNG CHILDREN AND ASSOCIATIONS OF SUGAR INTAKE WITH SOCIODEMOGRAPHIC INDICATORS AND ANTHROPOMETRIC MEASURES

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Excessive sugar intake in children is a public health concern as this can contribute to unhealthy dietary patterns later in life and increase the risk of excess weight gain and dental caries. There is limited research available on the consumption of sugar in young children in relation to sociodemographic characteristics and anthropometric measures. There is also limited data on the consumption of sugar alternatives such as non-nutritive sweeteners. Thus, the current dissertation aims to comprehensively examine total, free, and added sugar intake in young children (aged 1.5 to 5 y) enrolled in the Guelph Family Health Study. The dissertation initially reviews the complexity of multiple definitions of sugar, health recommendations, and implications for lifelong health of young children. The third chapter then examines how sociodemographic characteristics may predispose young children to higher sugar intake. Specifically, the associations are examined between child age, child sex, child ethnicity, parent number of years living in Canada, annual household income, parent education and parent marital status with total, free and added sugar intakes in young children. In this chapter, child age, child ethnicity and annual household income are found to be crucial influencers of sugar intake in young children. The subsequent chapters focus on a detailed analysis of the effects of sugar intake on anthropometric measures (including body weight, waist circumference, BMI Z-scores and percent fat mass) in young children (1.5 y to < 8 y).
cross-sectionally and longitudinally. These chapters report that young children are exceeding current World Health Organization’s recommendations for sugar intake. No statistically significant associations are observed between sugar intake and anthropometrics of young children. Given the efforts to reduce sugar intake using alternatives to sugar and sugar substitutes, this dissertation ends by evaluating the intake of non-nutritive sweeteners in young children. These are found to be low in the diets of young children currently. In conclusion, it is recommended that further research is warranted, especially longitudinal studies to better understand the long-term impact of total, free, and added sugar consumption and non-nutritive sweetener intake in young children.
DEDICATION

This thesis is dedicated to my father,

(Late) Mr. Himanshu Rai.
ACKNOWLEDGEMENTS

“Gratitude makes sense of our past, brings peace for today and creates a vision for tomorrow”- Melody Beattie

First and foremost, I dedicate this doctoral dissertation journey to my late father, Mr. Himanshu Rai, who has been my constant source of strength and inspiration throughout my life. His guidance has been precious, and though he passed away on April 15, 2022, his impact on my journey remains profound.

I extend my heartfelt gratitude to my PhD supervisors, Dr. David W.L. Ma (primary supervisor) and Dr. Jess Haines, for providing me with the wonderful opportunity to be a part of the Guelph Family Health Study (GFHS) at the University of Guelph. Their unwavering support, constant encouragement, and pearls of wisdom such as "There is always a solution to a problem" will forever resonate with me. I also want to thank the advisory committee supervisors, Dr. Alison M. Duncan and Dr. Andrea C. Buchholz for their valuable feedback on my work. I am truly grateful for the exceptional guidance from this incredible team. Thank you to Dr. Gerarda Darlington and Michael Prasad, whose statistical support, review, and input greatly improved my research. Thank you to Dr. Laura Forbes and Dr. Nana Gletsu Miller for serving on my examination committee panel. I greatly appreciate your time to review my thesis and for your feedback.

To my family, thank you for standing by me throughout the challenges of my graduate program. My husband, Sumeet Dhawan, a wonderful father to my children, my strongest supporter has been my rock. My mother, Renu Rai, with her numerology expertise, has always been there for me. My beautiful babies, Kiera Rai-Dhawan, Keeyaan Rai-Dhawan, and Kaden Rai-Dhawan, along with my sister and her family, Deeksha Rai Chawla, Kierti Chawla, and Kabier Chawla, have given me joy, love and motivation. You all believed in me more than I did in myself, and for that I am deeply thankful.
I owe a debt of gratitude to my aunts, Dr. Savita Verma and Dr. Kusum Kapur, and uncle, Ajay Gupta, for supporting my journey to Canada for my undergraduate education and providing me with a comfortable home to live in. Their help allowed me to begin my career in nutrition.

To my amazing mentor, Dr. Ananya T. Banerjee, thank you for your guidance in preparing for my PhD applications and supporting me every step of the way. Thank you to Dr. JoAnne Arcand and Dr. Russell de Souza for the amazing support during my PhD.

I want to express my sincere appreciation to all the wonderful investigators on the GFHS team, as well as my GFHS teammates and supporters, including Dr. Jessie Burns, Dr. Lisa Tang, Dr. Maude Perrault, Dr. Valerie Hruska, Dr. Amar Laila, Sabrina Douglas, Sandhya Sahye-Puderuth, Rahbika Ashraf, Cody Lust, Jessica Yu, Jaimie Hogan, Katherine Eckert, Alyssa Vets, Nicholas Carroll, Kira Jewell, Hillary Lo and Alicia Martin. You all have been incredible, and your support and willingness to answer my questions have been invaluable. I have made wonderful friends in this program, and I am grateful for the statistics study group with Sarah Wedde and Alyssa Ramschuk, who taught me so much during our meetings. I also want to thank all the students of the Ma Lab, Haines Lab, and GFHS teammates for making the meetings and learning so enjoyable.

A special thank you goes out to the amazing Ma Lab and GFHS staff Lyn Hilyer, Angela Annis, and Madeline Nixon, for their tireless efforts in answering questions, supporting students, collecting data, and supporting the GFHS families.

Thank you to the Human Health and Nutritional Sciences department, the Chair, Dr. Coral Murrant, the Faculty and the administration staff for all their amazing support during my PhD years.

I am deeply grateful to all the participating GFHS families and funding partners, the Heart and Stroke Foundation of Canada and Canadian Institute of Health Research, for making my doctoral dissertation possible.
To my friends, colleagues and managers at the University Health Network and Oakville Trafalgar Memorial Hospital (Halton Healthcare), thank you for your support and encouragement throughout my graduate journey.

A heartfelt thank you goes to my network of supportive friends, especially Rina Vohra and Rachael Bhakta, who have been by my side during my undergraduate and graduate years. Your help in quizzing me for my qualifying exam, providing me with delicious food, and being there for my family, will always be remembered. Many thanks go to Tasneem Essaji and her entire family for being a wonderful and caring friend along with constantly supporting my family during my PhD years.

I also want to express my gratitude to my friends Monica Dogra, Leena Trivedi, Rosanna Fisico, Dr. Anjali Sharma, Dr. Chetan Mehta and to the entire Younis family who have always provided me with amazing perspectives and a lot of encouragement. Thank you to the rest of my friends and relatives for their ongoing support.

Each of you has played a wonderful and important role throughout my PhD journey, and I am immensely thankful for your support and presence in my life.
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ABBREVIATIONS

%FM: percent fat mass
95% CI: 95 percent confidence interval
ASA24: Automated Self-Administered 24-Hour Dietary Assessment Tool
BIA: bioelectrical impedance analysis
BMI: body mass index
CRP: C-reactive protein
DEXA: dual X-ray absorptiometry
ESHA: Elizabeth Stewart Hands and Associates
FFQ: food frequency questionnaires
GEEs: generalized estimating equations
GFHS: Guelph Family Health Study
HDL-c: high density lipoprotein
HOMA-IR: Homeostatic Model Assessment for Insulin Resistance
IOM: Institute of Medicine
Kcal: kilocalories
LDL-c: low density lipoprotein
NNS: non-nutritive sweetener
SD: standard deviation
SE: standard error
SES: socioeconomic status
SSB: sugar sweetened beverages
WC: waist circumference
WHO: World Health Organization
CHAPTER 1
Review of the Literature

Title: Sugar research in preschoolers: Methodological, genetic, and cardiometabolic considerations

Author names: Jessica Yu, Rahbika Ashraf*, Anisha Mahajan*, Gerarda Darlington, Andrea C. Buchholz, Alison M. Duncan, Jess Haines, and David W.L. Ma, on behalf of the Guelph Family Health Study *Both authors contributed equally.

Note: This chapter, in part, has been accepted/in press in the journal, Reviews in Cardiovascular Medicine as part of a special issue, Vehicle for Cardiovascular Translational Research: Nutrition, presented here with permission and formatting modifications. The sections submitted to the journal include:

- 1.5 Sugars intake of preschool-aged children,
- 1.5.3 Sugars from sugar-sweetened beverages and cardiometabolic health in preschool-aged children and
- Table 1.3: Sugar intake in preschool-aged children and sugar intake impacts on cardiometabolic risk studies.
1.1 Introduction

The World Health Organization (WHO) suggests that excessive consumption of free sugar is a major public health concern (WHO, 2015). The WHO released a document on “Sugar intake for adults and children” in 2015 that recommends limiting free sugar to 10% of total energy intake in adults and children and ideally up to 5% of total energy intake (WHO, 2015). A substantial body of evidence indicates that overconsumption of sugar increases energy density by providing “empty calories” leading to increased body weight and obesity (DC, 2016; Keller & Bucher Della Torre, 2015; Lieffers, Ekwaru et al., 2018). This can also result in possible nutritional inadequacies, displacement of nutrient dense foods such as dairy products, and accelerate the development of early childhood caries (DC, 2016; Keller & Bucher Della Torre, 2015; Lieffers et al., 2018). Furthermore, high sugar intake can also cause elevated blood pressure, altered lipid metabolism with an increase in low density lipoprotein (LDL-c) and a decrease in high density lipoprotein (HDL-c) in children (Herrick, Fryar et al., 2020), that can lead to increased risk of chronic disease including type 2 diabetes, cardiovascular disease, and cancer. These chronic conditions in adults are responsible for billions of dollars of direct and indirect costs to the Canadian healthcare system (Lieffers et al., 2018). Chronic diseases such as type 2 diabetes are now presenting at a younger age and more often than previously seen in children (Skinner, Perrin et al., 2015). Moreover, dietary patterns that begin in childhood, can continue into adulthood, underscoring the need to understand sugar intake among young children (Mikkila, Rasanen et al., 2005).

Currently, there is moderate quality evidence linking sugar intake to the development of type 2 diabetes, heart disease, and hypertension in all age groups (DC, 2016). Most of the research is focused primarily on adults and there is little known about the association between sugar intake, risk factors, and chronic disease development in children. In particular, there is sparse research
investigating sugar intake in preschool-aged children, including, how sociodemographic characteristics influence sugar intake (Jarman, Edwards et al., 2022). Given concerns about excess energy from sugar intake, non-nutritive sweeteners (NNS) have been marketed in the Canadian food supply as a “healthier” alternative for sugar (Andrade, Lee et al., 2021). However, health concerns have been raised about the long term exposure to NNS intake in children (Azad, Abou-Setta et al., 2017). Thus, further research is warranted, and evidence is needed to understand the impact of sugar during the preschool-aged years to establish nutrition policies, early life intervention programs, and dietary guidance to promote healthy eating habits early in life. Therefore, this review of the literature serves as a foundation for a multidimensional view of sugar intake in young children. This includes current definitions of sugar; sociodemographic influences on sugar intake in young children; associations between sugar intake and anthropometric measures and subsequent health markers in young children; and a review of alternatives to sugar intake such as non-nutritive sweeteners.

1.2 Types of dietary sugar and labelling

The chemical formula for glucose is: C₁₂H₂₂O₁₁ and there are various types of sugar available in foods such as granulated or white or refined sugar; coarse sugar; superfine sugar; pearl sugar; liquid sugar; liquid invert sugar; brown sugar, demerara sugar; icing sugar; muscovado sugar; turbinado-style sugar; organic sugar; golden syrup; molasses; raw sugar or evaporated cane juice (CSI, 2023). The most common sugar additive is high-fructose corn syrup. These are referred to as simple sugars and can be used in foods for flavor, preservation, palatability, and taste (CSI, 2023). Added sugars are listed under carbohydrates and include a percent daily value (%DV) in nutrition labels on packaged foods in the Canadian food supply (GC, 2015b). Thus, the word “sugar” can
refer to any form of the above stated types of sugar. The next section discusses the different definitions of sugar described in research.

1.3 Definitions used to describe sugar

There are different types of sugars including total, free, and added sugars in research studies and varied definitions are used by organizations (summarized in Table 1.1 and 1.2). The majority of the research from the United States focuses on the definition of added sugars, which includes honey and syrups. This is different from the definition of added sugars by the WHO that does not include honey, syrups and 100% fruit juice. In contrast, research from around the world has focused on total and free sugars. In general, research has also investigated the different types of sugar (e.g., “fructose” and not “glucose”) to understand the impacts on hypertension and metabolism (Ha, Sievenpiper et al., 2012; Hannou, Haslam et al., 2018). Nutrition guidelines from the WHO and Health Canada include “free sugars” (which includes added sugars, 100% fruit juice, honey and syrups) whereas the Dietary Guidelines for Americans are based on “added sugars”. This has created ambiguity and confusion for consumers and researchers (Table 1.2). Due to these multiple definitions and the different types of sugars researched, further controversies have arisen with the focus on the nutrient “sugar” in diet and not on the entire dietary pattern or total daily energy intake (Khan & Sievenpiper, 2016). Despite this consumer and research confusion, intake of added sugar and sugar sweetened beverages (SSB) have been declining in Canada and worldwide (Jones et al., 2019; Marriott et al., 2004). However, the focus of nutrition research remains on SSB owing to the energy density of these liquid sugars. Due to the considerable attention on SSB intake, free and added sugar definitions have not been considered as a focus in research. Thus, knowledge gaps exist regarding our understanding of the associations between different types and sources of sugar on health outcomes in young children.
Table 1.1 Sugar definitions from different organizations

<table>
<thead>
<tr>
<th>Type of Sugar</th>
<th>Definition/Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sugar</td>
<td>Sugar: Can come from cane juice or sugar beet juice (GC, 2019).</td>
</tr>
<tr>
<td>Natural Sugar</td>
<td>Naturally occurring sugars in “intact or cut fruit and vegetables” and unsweetened dairy such as plain milk and yogurt (GC, 2019).</td>
</tr>
<tr>
<td>Added Sugar</td>
<td>Includes all sugars added to foods and beverages during processing and preparation. All added sugars are the same as free sugars (GC, 2019).</td>
</tr>
<tr>
<td>Free Sugar</td>
<td>Includes added sugars and sugars naturally present in honey, syrups, fruit juices and concentrate (GC, 2019).</td>
</tr>
<tr>
<td>Total Sugar</td>
<td>Total sugars include the total sugars present in a food or beverage. Total sugars include both free sugars and natural sugars (GC, 2019).</td>
</tr>
<tr>
<td>Extrinsic and Intrinsic Sugars</td>
<td>Intrinsic sugars are sugars “present within the cell wall of the plants”; Extrinsic sugars are found in “fruit juice, honey, syrups and added to processed foods” (Vos, Kaar et al., 2017).</td>
</tr>
</tbody>
</table>

Table 1.2: Recommendations for free and added sugar intake from various organizations.

<table>
<thead>
<tr>
<th>Organization</th>
<th>Sugar Recommendations</th>
</tr>
</thead>
<tbody>
<tr>
<td>World Health Organization, 2015 (WHO, 2015)</td>
<td>“WHO guideline recommends adults and children reduce their daily intake of free sugars to less than 10% of their total energy intake (strong recommendation). A further reduction to below 5% or roughly 25 grams (6 teaspoons) per day would provide additional health benefits (conditional recommendation)” –throughout the life span</td>
</tr>
<tr>
<td>Health Canada, 2019 (GC, 2019)</td>
<td>“Free sugars &lt;10% of total energy” for ≥2 y</td>
</tr>
<tr>
<td>Heart and Stroke Position Statement, 2014 (HSF, 2014)</td>
<td>“The Heart and Stroke Foundation recommends that an individual’s total intake of free sugars not exceed 10% of total daily calorie (energy) intake, and ideally less than 5%.”</td>
</tr>
<tr>
<td>Diabetes Canada, Position Statement on Sugars, 2022</td>
<td>“Limit their intake of free sugars to less than 10% of total daily calorie (energy) intake. This is approximately 50g (12 teaspoons) of free sugars consumption per day based on a 2000-calorie diet” (DiabetesCanada, 2022)</td>
</tr>
<tr>
<td>Scientific Advisory Committee on Nutrition (UK), 2015</td>
<td>“≤5% of energy from free sugars” – for &gt;2 y</td>
</tr>
<tr>
<td>European Society for Paediatric Gastroenterology, Hepatology and Nutrition, 2017 (Fidler Mis, Braegger et al., 2017)</td>
<td>“Intake of free sugars should be reduced and minimized with a desirable goal of &lt;5% energy intake in children and adolescents ≥2 to 18 years. Intake should be probably even lower in infants and toddlers &lt;2 years”</td>
</tr>
</tbody>
</table>
Institute of Medicine, 2005 (IOM, 2005)  
“Although there were insufficient data to set a UL for added sugars, a maximal intake level of 25 percent or less of energy is suggested to prevent the displacement of foods that are major sources of essential micronutrients”

American Heart Association-Scientific update, 2017 (Vos et al., 2017)  
“Committee recommends: 6tsp/100kcal/≤25g added sugars per day for children and no added sugars for children ≤2y of age”

Dietary Guideline Advisory Committee (USA), 2020 (DGA, 2020)  
“Added sugars - Less than 10 percent of calories per day starting at age 2”


1.4 Sociodemographic characteristics

Understanding the impact of various biological, behavioral, parental, and sociodemographic influences on eating patterns in preschool-aged children is crucial for informing interventions to influence eating habits (Anstruther, Barbour-Tuck et al., 2021; Jarman et al., 2022; Kranz & Siega-Riz, 2002). For children, the biological and behavioral factors that may impact intake include birth weight, health status, gender, and self-regulation abilities. The characteristics of food that also effect dietary patterns including access to food, energy density, palatability, or flavor (Scaglioni, De Cosmi et al., 2018). Other influences can include community, sociodemographic or socioeconomic status (SES) including income, ethnicity, screen time, parent education, parent nutrition knowledge, and family structure (Scaglioni et al., 2018). Sociodemographic or SES of families and children predicts the emergence of health disparities in populations and can subsequently impact health outcomes (IOM, 2006). These health disparities appear when there is an occurrence of disease due to differences in an exposure to a stressor that could stem from historical, social, and colonial reasons (Thurber, Long et al., 2020). Sociodemographic differences in population groups include household income, parental education, and occupation. Thus, to understand dietary patterns or intakes of specific nutrients, consideration of health disparity and health equity as an outcome in
research is key. In recent years the impact of SES on dietary patterns in children has been in the initial investigation stages (Hinnig, Monteiro et al., 2018). Furthermore, in high income countries, education has been inversely associated with unhealthy dietary patterns and an association between higher income and healthy dietary patterns has been observed (Hinnig et al., 2018). In medium and low-income countries, no clear associations have been established (Hinnig et al., 2018). The next section examines current research on the impact of child and adult sociodemographic characteristics on sugar intake in young children.

1.4.1 Sociodemographic characteristics, food patterns, and added sugars intake in preschool-aged children

Initial research suggests that the primary sociodemographic indicators of wealth and success, household income and parental education, were linked to desirable dietary patterns (Hinnig et al., 2018). A systematic review by Hinnig and colleagues was unable to confirm the associations of unhealthy dietary patterns in children and adolescents (2 to 19 y) with higher income and education (Hinnig et al., 2018). However, a scoping review found that both maternal and paternal education had a positive impact on healthful dietary patterns of preschool-aged children (aged 2 to 5 y) (Anstruther et al., 2021). This review recommended that interventions should target nutrition education to parents with lower education (Anstruther et al., 2021). Furthermore, this review had inconclusive findings regarding the role of income in shaping preschool-aged children’s dietary patterns (Anstruther et al., 2021).

Limited studies have examined sugar intake and sociodemographic characteristics in infants and toddlers. One study by Brekke and colleagues from Sweden discussed the implications of 1 y old infants consuming sugar enriched and low nutrient foods (Brekke et al., 2006). Based on survey questionnaires from parents of infants after delivery (n=16070) and subsequently at a one year
follow-up (n=10762) (Brekke, van Odijk et al., 2007), the investigators found that 24% of infants were consuming high sugary foods such as sweets and pastries. This was significantly and inversely associated with parent education level among other maternal factors such as mother’s young age, mother’s intake of sweets or pastries during pregnancy, mother’s living alone, and the child having older siblings (Brekke et al., 2007). Also, there was a decrease in nutrient dense foods with the increase in consumption of sugary foods (Brekke et al., 2007). This study highlights that parental sociodemographic characteristics play a significant role in infants being exposed to food items containing sugar at very young ages. Another study out of the Avon Longitudinal Study of Pregnancy and Childhood from the United Kingdom explored sociodemographic characteristics and differing dietary patterns for toddlers aged 3 y (n=10,139) and utilized self-reported questionnaires with parents as a proxy (North & Emmett, 2000). This study found that children consuming processed foods including sweets, biscuits, chocolate, and fizzy drinks (along with high fat foods) was associated with mothers who had low education levels and higher financial difficulty (North & Emmett, 2000).

Across different countries and ethnicities, low SES has been consistently associated with greater sugar intake. In a Canadian study of children aged 4 and 5 y (n=1760), households with lower SES (RR=1.17; 95% CI: 0.98, 1.4) and boys, were more likely to consume sugary soft drinks within the last week (Pabayo, Spence et al., 2012). A cross-sectional study from the USA set out to determine the sociodemographic characteristics for added sugar intakes for children aged 2- to 5-y olds (Kranz & Siega-Riz, 2002). Overall, older children had significantly higher added sugar intake than younger children; Hispanic children consumed less added sugar than other ethnicities; children with a female head of household who had at least 12 y or more of schooling had higher added sugar intake compared to less added sugar in children with a female head of household having less than
12 y of schooling (Kranz & Siega-Riz, 2002). A German study by Schneider and colleagues (2013), investigated sugar intake through sweets consumption in preschool-aged children (n=900 and aged 3 to 6 y) and its associations with sociodemographic factors. Preschool-aged children were found to consume sweets 9.7 ± 6.2 times per week and that sweet consumption was associated with different sociodemographic characteristics including parent immigrant background (i.e., Turkish and Arabic children consumed higher levels of sugar than German children) (Schneider, Jerusalem et al., 2013). In another study that explored the effects of colonialism (Thurber et al., 2020) on Indigenous children aged 0 to 3 y living in Australia (n=933), it was observed that half of the children consumed SSB, and that child SSB consumption was lower for families with high SES that were characterized by adequate financial security, employment, and having housing in urban areas (Thurber et al., 2020). Thus, these studies consistently suggest that SES has an influence on sugar intake in young children.

The research on sociodemographic characteristics and sugar intake in preschool-aged children is limited in the Canadian context. These studies have produced inconsistent findings, suggesting that additional research examining the association between sociodemographic factors and sugar intake in the Canadian context is needed.

1.5 Sugar intake of preschool-aged children

Overconsumption of free and added sugars has been shown to increase the risk of developing chronic diseases such as such as type 2 diabetes and cardiovascular disease in all population groups (Fidler Mis et al., 2017; WHO, 2015). Dietary patterns are well-established as young as 3 y of age and these habits can extend into adulthood (Mikkila et al., 2005). It is known that added sugar intake increases with age and can be significantly higher in older boys (Davis & Lee, 2014; WHO, 2015). Currently, free and added sugar intake from all food sources in preschool-
aged children (<6 y of age) and their association with the development of cardiometabolic risk (CMR) factors have not been well-researched, although there has been focused attention on sugar-sweetened beverage (SSB) intake in children (Davis & Lee, 2014). To our knowledge, most studies have examined sugar intake in older children but do not examine all food sources of free and added sugar intake in preschool-aged children. Thus, based on existing research, development of CMR in preschool-aged children needs to be further explored to implement early life interventions and inform policies for this age group. This can further assist with improved health outcomes in adolescence and adulthood. The following section reviews the current cross-sectional studies on free and added sugar intake along with the different food sources of sugar that preschool-aged children are consuming.

A study of preschool-aged children (n=5437) between 2 to 5 y old from the National Health and Nutrition Examination (NHANES) dietary data (1988-1992) reported that 11% of participants (2 to 3 years) and 12% of participants (4 to 5 y) consumed more than 25% energy intake (EI) per day from added sugar (Kranz, Smiciklas-Wright et al., 2005). In addition, 72% of the participants aged 2 to 3 years and 79% of those aged 4 to 5 y, exceeded 10% EI per day from added sugar (Kranz et al., 2005). Participants of this study were from the USDA Continuing Survey of Food Intakes by Individuals (United States Department of Agriculture Continuing Survey of Food Intake by Individuals) study (Kranz et al., 2005). In this study, two 24-hour diet recalls were completed to assess dietary intakes on two non-consecutive days and % EI from added sugar was determined. Results showed that 11% of participants aged 2 to 3 y and 12% of participants aged 4 to 5 y consumed more than 25% EI per day from added sugar (Kranz et al., 2005). The study authors concluded that the intake of added sugars in this population of preschool-aged children was high
and exceeded current recommendations from the Institute of Medicine and the WHO (Kranz et al., 2005).

Examination of free sugar sources has revealed important trends and insights into sugar intake in children. A study by Pawellek and colleagues (2017) highlighted that boys had statistically significant higher intake of total sugar (P=0.003) when compared with girls – 2.95 (−4.84, −1.07, g/day). An Irish study of free sugar intake in 3-year-old children including two national data sets (Growing Up in Ireland n=9793, 51% male; National Preschool Nutrition Survey n=126, 48% male) (Crowe, O'Sullivan et al., 2020) found that 75% of the preschool-aged children had free sugar above the 10% EI recommended by the WHO and less than 4% of the study sample attained the 5% of the EI WHO recommendation. It was noted that the median frequency of free sugar consumption was 4.0 (range of 3.0–5.0) times per day. Similarly, the SMILE study, which used dietary data from 2-year-old Australian children (n=1043) found that 71% of the children exceeded the lower <5% EI WHO recommendation of free sugars and 38% exceeded the higher <10% EI WHO recommendation (Devenish, Golley et al., 2019).

Overall, these cross-sectional studies in multiple countries reveal that young children exceed current global and national recommendations for free and added sugar intake and are consuming sugars from a variety of food sources. However, there is limited research among children in the Canadian context. Table 1.3 summarizes the research studies for young children.

1.5.1 Food sources of sugar in preschool-aged children

Several recent international research studies have confirmed that preschool-aged children consume dietary sugar from various food sources. For example, a study in Ireland explored sources of free sugar intake in 3-year-old children and found that fruit juice and smoothies, dairy products, confectionary, and soft drinks were key sources of free sugar (Crowe et al., 2020). Similarly, in the
SMILE cohort, the primary sources of free sugar were fruit juices, biscuits, cakes, desserts and confectionery, with yogurt and non-dairy milk alternatives (Devenish et al., 2019). A European study reviewed total sugar intake and sources of sugar from ages 1 to 8 y at eight time points (n=995) (Pawellek, Grote et al., 2017). This study revealed that primary food sources of sugar included dairy, fruits, confectionary items, breads and cereals, and SSBs (Pawellek et al., 2017). Additionally, a US study indicated that the primary sources of added sugar in 2 to 3 y old and 4 to 5 y old children were fruit drinks (such as lemonade, juices with 10% fruit juice), high-fat desserts (such as ice cream, pies, cookies, cakes), and regular soft drinks (Kranz et al., 2005). This study also noted that as added sugar levels increased in the dietary pattern, intake of all other macro and micronutrients (except for carbohydrates and vitamin C) decreased. If the intake of added sugar was >25% of the total energy, it was observed that these children had lower intakes of fibre, protein, and fat and higher intake of carbohydrates (Kranz et al., 2005). Thus, the above studies suggest that young children are consuming free and added sugars from several food sources other than SSB and are doing so in excess of recommendations worldwide.

1.5.2 Sugar intake and weight and BMI outcomes in children: Inconclusive evidence

There is a concern that overconsumption of dietary sugar above the WHO guidelines can contribute to increased weight and BMI in young children. A cross-sectional study examined the association of SSBs (specifically packaged drinks, including fruit drinks and fruit juices, and soft drinks) intake in obese children (n=1823) aged 4 to 5 y (Gonzalez-Palacios, Navarrete-Munoz et al., 2019). This study found a high prevalence of obesity ranging from 5.9% to 9.3% within the study cohort that was mostly mediated by the intake of packed juices (p=0.03) (Gonzalez-Palacios et al., 2019). Children who consumed more than 1 serving of SSB (of both packaged drinks and soft drinks) per day (1 serving=175mL/6fl oz) had a higher prevalence of obesity (OR=3.23;
95% CI 1.48-6.98) (Gonzalez-Palacios et al., 2019). This suggests that a link between added sugars and SSBs intake in children can be associated with obesity in children aged 4 to 5 y.

In contrast, other studies have found no statistically significant associations between dietary sugar intake and anthropometric measures. A cross-sectional data analysis of the National Health and Nutrition Examination Survey (NHANES) (1971 to 1975; 1988 to 1994) enrolled children (n=20,000) aged 1 to 18 years and found no association between total and added sugar with BMI (Song, Wang et al., 2012). This study suggested that total energy intake, rather than a specific nutrient, had a greater impact on children’s BMI. Additionally, the NHANES data, from 1999 to 2002 for children aged 2 to 5 years (n=1160; 50% male), did not find a statistically significant increase in BMI with intake of SSBs (O’Connor, Yang et al., 2006). Another study found no association between SSBs consumption and changes in weight and BMI at 6 months and at a 12 months follow-up (Newby et al., 2004). This study was conducted in n=1345 children in the North Dakota Special Supplemental Nutrition Program for Women, Infants, and Children group (Newby, Peterson et al., 2004) Considered together, there is a lack of consistent findings which may be due to differing methodology to measure anthropometry, cross-sectional associations, and use of self-reported data. Therefore, further long-term research studies which address these methodological shortcomings, are needed.

1.5.3 Sugars from sugar-sweetened beverages and cardiometabolic health in preschool-aged children

A large body of research has focused on SSB consumption due to the large amounts of sugar present in these drinks (Table 1.3). Thus, SSB acts as a convenient proxy for overall sugar intake in most studies due to its energy density from sugar amounts.
A cross-sectional analyses of NHANES (1994 to 2004) data including children (n=4880) aged 3 to 11 years found that the highest tertile of SSB consumption (4.39±1.71 SSB servings or 35 oz daily) was positively associated with the C-reactive protein (CRP) and waist circumference (WC) and negatively associated with high density lipoprotein (HDL-c) (Kosova, Auinger et al., 2013). A subgroup analysis of children aged 3 to 5 years found a positive association between SSB intake and LDL-c (Kosova et al., 2013). In both boys and girls aged 3 to 11 y, SSB intake was positively associated with CRP (Kosova et al., 2013). In girls (aged 3 to 11 y), SSB intake was inversely associated with HDL-c and positively associated with low density lipoprotein (LDL-c) (Kosova et al., 2013). Furthermore, in both non-Hispanic black and white groups, a significant inverse association was noted between SSB intake and HDL-c. In the non-Hispanic black group, SSB intake was significantly positively associated with TG and CRP levels (Kosova et al., 2013).

A longitudinal follow-up study conducted in Amsterdam, further highlighted the association between SSB intake and blood pressure in children (de Boer, de Rooij et al., 2018). This study examined the longitudinal association of intake of SSB and blood pressure (BP) in children aged 5 to 6 y or 11 to 12 y (de Boer et al., 2018). The study found an average intake of 2.6 servings of SSB per day. There were no associations found between SSB and BP for children aged 5 to 6 y however, as the number of servings increased in older children (11 to 12 y), the association between SSB and BP became positive and significant (de Boer et al., 2018). Similar results were seen in the Early Childhood Longitudinal Birth-Cohort study in the US, where SSB intake in children aged 2 to 5 y (n=9600) were examined (DeBoer, Scharf et al., 2013). The study participants that consumed higher SSB were seen to have higher BMI Z-scores at age 4 y and 5 y and not at 2 y (DeBoer et al., 2013). By 5 y of age, regular SSB drinkers had an increased odds of obesity (DeBoer et al., 2013). Another longitudinal study investigating Dutch children with a median age of 5.9 y (n=2045) found
that high SSB consumption in boys was significantly associated with CMR at age 6 y (Leermakers, Felix et al., 2015). In another longitudinal study from Québec, Canada, children between the ages of 2.5 to 3.5 y (n=2103) who consumed a higher number of SSBs had more than three times the odds of being overweight at 4.5 y (Dubois, Farmer et al., 2007).

Studies that have examined changes over time in SSB intake from infancy onward have revealed similar outcomes. For example, a longitudinal study of SSB intake in children (n=1189) in the United States from infancy to 6 y of age showed that infants exposed to SSB were twice as likely to be obese when compared with infants who were not (Pan, Li et al., 2014). It was also noted that the likelihood of consuming SSB at age 6 y was 71% higher for children who consumed SSBs at infancy and 92% higher for those children who consumed SSB before 6 months of age (Pan et al., 2014). Another study found that excess intake of added sugars (from dairy products, baked goods, sweets and spreads) consumed in the first two years of life were associated with an increased BMI at age 7 y in a subset of the longitudinal Dortmund Nutritional and Anthropometric Longitudinally Designed study (n=216; 111 boys and 105 girls) (Herbst, Diethelm et al., 2011).

A cross-sectional study linking SSB intake with cardiometabolic risk (CMR) factors in 1778 participants between the ages of 3 to 6 y (Eny, Jeyakumar et al., 2020) highlighted that SSB consumption was positively associated with CMR biomarkers, specifically lower HDL-c and higher TG. This study utilized the CMR scores as described by the American Academy of Pediatrics and included SBP, triglycerides (TG), WC, glucose, and HDL-c (Eny et al., 2020). The authors demonstrated that with every 1 cup of SSB intake per day, there was a significant increase in the CMR score by 0.05 SD units (Eny et al., 2020). It was also noted that 100% fruit juice was not significantly associated with the CMR biomarkers, except lower HDL-c was reported (Eny et al., 2020).
Overall, research to date from cross-sectional and longitudinal studies suggests that SSB intake starting from the first few years of life can predispose preschool-aged children towards higher CMR. However, there is limited research in Canadian preschool-aged children. While broad generalizations can be made, Canadian studies are needed given differences in the food supply, lifestyle, and food and marketing regulations.

1.6 Non-nutritive sweeteners (NNS)

NNS are defined as compounds that impart sweetness to a food item, do not have calories (such as non-caloric sweeteners) or are limited in calories (such as sugar alcohols) (Rios-Leyvraz & Montez, 2022). This also includes natural extracts that may not be chemically modified (GC, 2010; Rios-Leyvraz & Montez, 2022). In Canada, the following NNS are permitted to be added to food items: advantame, acesulfame potassium, calcium saccharin, erythritol, aspartame, cyclamate, hydrogenated starch hydrolysates, isomalt, lactitol, maltitol, maltitol syrup, mannitol, monk fruit extract, neotame, potassium saccharin, sorbitol, saccharin, sodium saccharin, sorbitol syrup, steviol glycosides, sucralose, and thaumatin (GC, 2010, 2023). NNS can include both artificially or naturally derived compounds and are generally considered safe for consumption in the adult population or during pregnancy and lactation, based on the acceptable daily intake (ADI), as indicated by Health Canada (GC, 2010, 2023). NNS are not recommended for children <2 y as these may replace nutritious foods and impact self-regulation of consumption of sweet foods (AHS, 2020; Gil-Campos, Gonzalez et al., 2015).

NNS are perceived and marketed as a healthier alternative to sugar (Rios-Leyvraz & Montez, 2022; Shum & Georgia, 2021; Sylvetsky, Rother et al., 2011). Some children may have high affinity for sweetness and based on evolution there could be an innate preference for sweet taste that may be attributed to genetics (Fitch, Keim et al., 2012; Garavaglia, Rodriguez Garcia et al., 2018). NNS first came into circulation into the North American food supply in the 1800s to add
to palatability without adding calories (Baker-Smith, de Ferranti et al., 2019). NNS have been widely and globally been used as a tool for childhood obesity, as they are being used as an alternative to added sugar intake. NNS are found in Jell-o™, diet jams, and bubble gums that are frequently consumed by children (Baker-Smith et al., 2019; Foreyt, Kleinman et al., 2012; Rios-Leyvraz & Montez, 2022). There is sparse knowledge on the current intake of NNS and possible CMR of NNS intake in preschool-aged children (Andrade et al., 2021; Rios-Leyvraz & Montez, 2022). Additionally, information from various health authorities such as the Academy of Nutrition and Dietetics (AND) and Institute of Medicine (IOM) have provided conflicting messaging on consumption of these for the general population (Archibald, Dolinsky et al., 2018; Sylvestsky et al., 2011). The IOM does not promote the consumption of NNS in children due to limited long-term evidence of effectiveness and safety, and due to the fact that these can displace milk consumption (Sylvestsky et al., 2011). On the other hand, the AND encourages NNS as part of a healthy diet for individuals of all ages (Sylvestsky et al., 2011). The latest Canada’s Food Guide (GC, 2019) does not recommend the consumption of artificial or naturally sourced NNS due to lack of well-documented health benefits for the general population. Additionally, there are concerns reported from the American Academy of Pediatrics (AAP) suggesting that amounts of NNS in the food supply are ever increasing and that not all parents have adequate knowledge about the various types of NNS and their mode of action (Baker-Smith et al., 2019). Thus, consumption of NNS in young children is concerning in the absence of short and longer-term research on the impact of NNS intake in children.

1.6.1 NNS intake in preschool-aged children

NNS intake has been evaluated in several countries and the data from US shows that intake of NNS intake in children aged (2 to 18 y) has risen by 200% over the past 20 years (Young et al.,
2019). This is likely owing to the rise of NNS in the food supply, and this intake is mostly prevalent in children living with obesity (Sylvetsky et al., 2011; Young, Conway et al., 2019).

A study conducted in Buenos Aires in 2011, including n=2664 children between the ages of 2 to 18 y and using a 24-hr recall, found that 44% of the preschool-aged children and 53% of the school-aged children were consuming foods that contained NNS (Garavaglia et al., 2018). The most frequently consumed NNS in children and adolescents were found to be aspartame and acesulfame K and the sources for these included beverages such as powdered juice, concentrated juice, canned or bottled juice, flavored waters, and soft drinks (Garavaglia et al., 2018). Similarly, in a study from Chile conducted in preschool-aged children aged 4 to 6 y (n=959) coming from low to medium household income, a 24-hour dietary recall showed that NNS intake including aspartame, sodium cyclamate, and steviol glycosides were the most consumed in this group (Venegas Hargous, Reyes et al., 2020). Dietary sources of NNS included beverages as the highest contributors for aspartame and acesulfame potassium, candies for cyclamate, and saccharine and dairy products for sucralose (Venegas Hargous et al., 2020).

While studies have identified types of NNS and dietary sources and express concerns due to their presence, there are others that have suggested that young children are getting limited exposure to NNS. An Irish study determined NNS intakes including acesulfame-K, aspartame, saccharin, and sucralose in preschool-aged children (n=500) aged 1 to 4 y (Martyn, Nugent et al., 2016). It found that children consuming all these sweeteners were below the acceptable daily intake (ADI) with the top contributor being flavored beverages (Martyn et al., 2016). Another study from Chile evaluated NNS consumption in children aged 6 to 12 y (n=250) after front of package labeling was established (Martinez, Zapata et al., 2020). Prior to the introduction of labelling requirements, all children consumed foods and beverages containing NNS predominantly from sucralose,
acesulfame-K, stevia, and aspartame (Martinez et al., 2020). After the front of package labelling regulation was introduced, the study authors concluded that NNS intake did not exceed the ADI including 13.9 mg for acesulfame-K and 12.4 mg for sucralose when compared with 15 mg/day for both.

Another US study highlighted that NNS consumption can also be attributed to limited disclosures of NNS amounts listed on packaged foods, while creating ambiguity and misperceptions for parents of young children aged 1 to 5 y (Harris & Pomeranz, 2021). The study authors used a survey-based method design to gather information on parent’s ability (n=2591 participants) to identify NNS ingredients from labels on packaged foods (Harris & Pomeranz, 2021). There was 88% retention rate for the study participants and it was noted that 53 to 58% of the participants could not correctly identify the NNS type in beverages (Harris & Pomeranz, 2021). In Canada, manufacturers do not need to disclose NNS amounts on packaged foods, making it challenging to quantify the amounts that adults and children may be consuming. Thus, parents may not have all the information on packaged foods to limit intake of NNS entirely.

1.6.2 Intake of NNS and health outcomes findings from reviews

A few review papers have been published on NNS intake and various health outcomes in young children. A review published in Brazil in 2018, explored benefits and risks of consumption of NNS in all population groups (Duran Aguero, Angarita Davila et al., 2018). This paper urged health professionals to assess NNS consumption based on these population groups before use (Duran Aguero et al., 2018). This review found 3 studies (one study from Ireland, one from Chile and one from Argentina) examining sweeteners and dietary intake. Two of these studies suggested that children were meeting the ADI for NNS. However, one study suggested that the population of children and adolescents exceeded the ADI for cyclamate. Children in this study consumed NNS
through soft drinks, powdered and packaged juices (Duran Aguero et al., 2018). The study highlighted the role of NNS in the regulation of adipogenesis. In addition, this study found mixed and inconclusive evidence of the impact of NNS intake on body weight and obesity for children and adolescents. A few studies have showed positive associations between NNS and an increase in BMI; a cross-sectional study (Chilean school children aged 10 to 16 y) suggested no association and a meta-analysis indicated reduction of body weight with NNS intake (Duran Aguero et al., 2018). This study suggested that NNS research is being investigated with early onset of menarche, increased risk of illness, using NNS as a reward, and an increase in oral intake with increased NNS intake. Research is also being conducted on saccharin altering gut microbiota causing glucose intolerance (Duran Aguero et al., 2018).

A review by Young et al., 2019 investigated studies on NNS intake in relation to weight, appetite regulation, and long-term metabolic health. This review included cross-sectional, prospective cohort studies and randomized controlled trials (Young et al., 2019). The study concluded that there is limited information available to make any recommendations of NNS as an effective alternative for weight loss despite being deemed toxicologically safe in children by health authorities (Young et al., 2019). This study further posits that the current information does not differentiate between the physiological impacts of the various NNS (Young et al., 2019). Thus, this area is under-researched and needs further analysis prior to recommending NNS intake in children.

A recent systematic review published by the WHO has suggested that NNS research is sparse and the impacts of NNS intake and the outcomes such as adiposity are inconclusive (Rios-Leyvraz & Montez, 2022). This review found 4 randomized controlled trials (RCTs) using parallel-arm design (followed from 6 weeks to 18 mo) and 15 cohort studies (followed from 8 mo to 10 y) in children aged birth to 18 y (Rios-Leyvraz & Montez, 2022). This review explored outcomes in
children (<18 y of age) including adiposity and cardiometabolic risk (Rios-Leyvraz & Montez, 2022). A large RCT was included in this review and conducted in children between the ages of 4 y and 11 y and did not report any significant decrease in body weight, BMI Z-scores, WC or % fat mass (de Ruyter, Olthof et al., 2012; Rios-Leyvraz & Montez, 2022). For children (between the ages of 12 to 18 y old), no difference on CMR factors such as total cholesterol, HDL-c, LDL-c or TG were seen for chronic NNS consumers versus non-consumers of NNS (Rios-Leyvraz & Montez, 2022).

Considered together, the above reviews indicate that the role of NNS intake and health outcomes in children is limited, inconsistent, and inconclusive. Further longitudinal and good quality studies are needed to confirm any conclusions of short-term and long-term impact of NNS intake on health outcomes. In the absence of strong evidence and ever-increasing presence of food items in the Canadian grocery stores, continuous monitoring of NNS intake in young children is recommended.

Overall, studies show that preschool- and school-aged children in many countries consume NNS, but depending on labelling requirements, actual intake may be poorly understood. While regulatory bodies have established safe levels for acute intake, there remains a concern about the long-term effects of chronic exposure, especially in children, for which there is no research. Currently, precise understanding of NNS intakes in Canada are lacking due to limited information regarding NNS amounts on packaged foods It is unknown whether Canadians exceed current ADI levels for different NNS. The ADI levels vary from 4 mg to 40 mg/kg body weight of intake per day based on the type of NNS consumed. In addition, current research does not differentiate between the impact of artificially sweetened versus natural NNS (e.g., sucralose and aspartame.
when compared with naturally occurring NNS such as stevia). Thus, further long-term research and
good quality studies with a large sample size in young children is warranted.
Table 1.3: Studies investigating sugar intake in preschool-aged children and impacts on cardiometabolic risk

<table>
<thead>
<tr>
<th>Authors</th>
<th>Type of Study</th>
<th>Participants</th>
<th>Methods used to collect dietary and/or anthropometric data</th>
<th>Primary Findings</th>
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<tbody>
<tr>
<td>(Kranz et al., 2005) USA</td>
<td>-Cross-sectional study: The goal was to examine added sugar intakes in preschool-aged children and how these compare with Dietary Reference Intakes.</td>
<td>N=5437; ages 2 to 5 y.</td>
<td>-Energy sources were divided into 5 categories ≤10% of energy from added sugar; 11-15%; 16-20%; 21-25% and &gt;25%. -Used 2-day dietary intake data that was collected using the multiple-pass approach.</td>
<td>-Most children consumed less than 25% of energy from added sugar. -Main sources of sugars included: fruit, regular soft drinks, and high-fat desserts.</td>
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<tr>
<td>(Crowe et al., 2020) Ireland</td>
<td>-Secondary data analysis: 2 national surveys in Ireland: Growing up in Ireland (GUI) and National Preschool Nutrition Survey (NPNS). The aim was to quantify the total sugar and free sugar intakes for preschool-aged children.</td>
<td>GUI= N=9793; NPNS= N=126; age = 3 y.</td>
<td>-Utilized semi-weighted food diaries and short food questionnaires. -Data mapping for matching covered and non-covered GUI and NPNS food data.</td>
<td>-Free Sugar= 40 ± 23.5 g/day and contributed to (mean and std. dev) 14.1% ± 5.81 total energy intake; 75% of the 3 y old children consumed more than 10% total energy intake as free sugar. -Main food sources of free sugar included: fruit juice and smoothies, dairy products, confectionary, and soft drinks.</td>
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</table>
(Devenish et al., 2019) Australia
- Participants recruited from the SMILE cohort study. The goal of this study was to determine free sugar intakes, sources and determinants of high intakes in preschool-aged children.

N=938 participants were 2 y old.

- Food frequency questionnaire contained 89 items and were semi-quantitative. These were emailed or posted to parents when their child reached 2 y.

- Mean intake of free sugar was 29.3g/day providing a total of 10% of Estimated Energy Requirements (EER). 71.1% of the children exceeded 5% of their EER and 38.4% of children exceeded 10% of their EER.

- Main food sources of free sugar intake: cereal-based products and dishes, non-alcoholic beverages, milk products and dishes, infant formula and foods, sugar products and dishes, confectionery, and cereal nut/fruit/seed bars.

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<tr>
<th>Sugar intake associations with anthropometric measures and cardiometabolic risk factors in preschool-aged children</th>
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</table>
| (Eny et al., 2020) Canada | Cohort study- TARGet Kids! repeated measures study examining sugar sweetened beverage (SSB) consumption (including 100% fruit juice) and cardiometabolic risk outcomes in preschool-aged children (2008-2017). | Children under 6 y recruited between 2008 to 2017 during well child physician visits from 11 primary care practices. | Canadian Community Health Survey included a question on frequency of consumption (i.e., “how many drinks of each drink your child has in a typical day in cups?”). 
- Trained research staff measured systolic blood pressure and waist circumference (WC), high density lipoprotein cholesterol (HDL-c) and higher triglycerides (TG). 
- 100% fruit juice and SSB intake was associated with lower HDL-c. 
- For every 1 cup increased SSSB intake, the cardiometabolic risk score increased by 0.05 SD units. | Higher sugar sweetened beverages (SSB) intake was associated with higher cardiometabolic risk score, lower high density lipoprotein cholesterol (HDL-c) and higher triglycerides (TG). |
and child’s birthweight were reported by their parents.

<table>
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<tr>
<th>(Kosova et al., 2013) USA</th>
<th>Cross-sectional analysis of US NHANES data (1994 to 2004). The aim of this study was to assess the association between SSB intake and cardiometabolic risk markers in young children.</th>
<th>N=4880; ages: 3 to 11 y.</th>
<th>Home interviews were completed by trained staff. In addition, participants were asked to visit the examination centre to complete a physical examination, provide blood and urine samples and complete questionnaires.</th>
<th>Overall results for 3 to 11 y- Increased SSB was independently associated with increased CRP concentrations (P=0.003), increased WC (P=0.04), low HDL-c (P&lt;0.001) except for a positive association between SSB and LDL-c cholesterol levels in the 3 to 5 y age group.</th>
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<tr>
<td>(de Boer et al., 2018) The Netherlands</td>
<td>Cross-sectional study data collected in 2008-2010. The study aim included to examine the associations between SSB intake, blood pressure, and autonomic nervous system in young children.</td>
<td>Ages 5 to 6 y (N=2519) or 2015-2016 at age 11 to 12 y (N=769).</td>
<td>SSB intake at 5 to 6 y of age was reported by the main caregiver. SSB intake at 11 to 12 y of age was self-reported by the child. Systolic blood pressure (SBP), diastolic blood pressure (DBP) and autonomic nervous system were measured in supine position.</td>
<td>For the 5 to 6 y age group: Consumed on an average 2.6 SSB servings daily. No associations were found between SSB and blood pressure (BP) after full adjustment of covariates. For the 11 and 12 y age group: Consumed on an average 4.4 SSB servings daily. For every one consumption of SSB serving increase/day, this was associated with</td>
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<tr>
<td>Study (Year)</td>
<td>Country</td>
<td>Type of Study</td>
<td>Participants</td>
<td>Data Collection</td>
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<tr>
<td>(Leermakers et al., 2015) Netherlands</td>
<td>The Netherlands</td>
<td>Longitudinal cohort study</td>
<td>N=2045 Dutch children with median age of 5.9 y.</td>
<td>Semi quantitative food frequency questionnaires (FFQ) (211-item) was completed by parents at age 13 mo. Trained staff measured children’s height and weight at the research centres and gathered this data. Information from 13 mo to 48 mo. The children visited the research centre at age 6 y– body fat was measured using dual x-ray absorptiometry (DEXA) scans. Percent body fat mass was calculated.</td>
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<tr>
<td>(Dubois et al., 2007) Canada</td>
<td>Canada</td>
<td>Longitudinal Study of Child development in Quebec (1998 to 2002). The goal of this study was to investigate the relationship between SSB intake between meals at 2.5 y, 3.5 y and 4.5 y with</td>
<td>N=2,103 children born in 1998 in Quebec, Canada and n=1944 children of 4 to 5 y that participated in the study. Self-administered FFQ completed by children’s mother when children were aged at 2.5 y, 3.5 y and 4.5 y and a 24 h recall was completed by the research team for children at 4.5 y. This information helped to determine frequency of SSB intake in between meals.</td>
<td>Regular SSB intake between meals can lead to young children being at greater risk of being overweight. Children that were regularly consuming SSB (versus those not consuming SSB regularly), at 2.5 y, 3.5 y and 4.5 y were overweight at 4.5 y (15% overweight for regular SSB</td>
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<tr>
<td>Study</td>
<td>Country</td>
<td>Study Design</td>
<td>Objective</td>
<td>Methods</td>
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<tr>
<td>(Pan et al., 2014)</td>
<td>USA</td>
<td>Longitudinal cohort study</td>
<td>Goal was to examine association of SSB intake at infancy with obesity at 6 y of age.</td>
<td>N=1189 American children that were recruited for the Infant feeding practices Study II (2005-2007) were followed from 10 to 12 mo up to 6 y of age.</td>
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<tr>
<td>(Herbst et al., 2011)</td>
<td>Germany</td>
<td>Longitudinal Study</td>
<td>This study evaluated associations between added sugar intake in early childhood and BMI/Body fat at 7 y of age.</td>
<td>N=216 (111 boys; 105 girls) recruited in the Dortmund Nutritional and Anthropometric Longitudinally Designed Study</td>
</tr>
<tr>
<td>Study (DeBoer et al., 2013) USA</td>
<td>Longitudinal and cross-sectional study to examine association of SSB intake with weight status for children aged 2 to 5 y.</td>
<td>N=9600 children in the Early Childhood Longitudinal Survey Birth Cohort.</td>
<td>Parents were interviewed by trained staff to review children’s SSB intake. Trained staff measured height and weight of children. These evaluations were completed at 2, 4 and 5 y of age.</td>
<td>SSB consumption was low at 2 y of age and increased at 4 and 5 y of age. The study demonstrated that those children that consumed SSB compared to those that didn’t have a higher BMI z score i.e. ≥1 SSB serving daily at 2 years had a greater increase in BMI z-score at 4 y of age. By age 5 y regular SSB drinkers had higher adjusted odds of obesity (1.43; P&lt;0.01).</td>
</tr>
</tbody>
</table>
CHAPTER 2
Thesis Rationale and Objectives
2.1 Rationale and Overall Objective

Dietary patterns are established early in life as these carry on into adulthood and reduced intake of refined sugar in young children has been highlighted as being crucial for positive health outcomes (Mikkila et al., 2005). Overconsumption of free and added sugar intake in children can increase risk of weight gain, provide empty calories, and lead to dental caries (Herrick et al., 2020). This can in turn increase risk of chronic disease such as type 2 diabetes and cardiovascular disease (Herrick et al., 2020). While there is growing knowledge about the effects of sugar in older children and adolescents, little is known in preschool-aged children. Thus, this thesis aims to investigate the association between total, free, and added sugar intake from all food sources in preschool-aged and young children with sociodemographic characteristics and anthropometrics. This thesis also explores the current consumption patterns of non-nutritive sweeteners (NNS) in preschool-aged and young children. To address this aim, four independent studies have been completed and are detailed as follows.

2.2 Study rationale and objectives:

Study 1 (Chapter 3): Sugar intake among preschool-aged children in the Guelph Family Health Study: Associations with sociodemographic characteristics

Study rationale: The thesis begins with an examination of the association between sociodemographic characteristics and sugar intake in young children and their parents. It is important to first consider that access to food is determined in part by sociodemographic characteristics. Currently, there is a paucity of research related to sociodemographic characteristics in Canada that may shed light on factors contributing to the access of sugar containing foods.
The specific objective of this study was to:

- Investigate the associations between preschool-aged children’s intake of total, free, and added sugar and parent and child sociodemographic characteristics including child age, child sex, child ethnicity, years the family has lived in Canada, annual household income, parent education, and parent marital status.

Study 2 (Chapter 4): Dietary sugar intake among preschool-aged children: a cross-sectional study

Study rationale: Study 1 highlighted how sociodemographic characteristics are associated with sugar intake in young children. Study 2 transitions to focus on dietary aspects of sugar intake and health implications. Previous research has focused primarily on SSB intake in all children and adolescents. Therefore, this study explored current Canadian consumption patterns of sugar intake specifically in young children from all food sources and the associations between the total, free, and added sugar intake in preschool-aged and young children with anthropometrics.

The specific objectives of this study were to:

1. Investigate the daily intakes of total sugar, free sugar, and added sugar in preschool-aged children.

2. Determine the key food sources (by category) of free and added sugar among a sample of preschool-aged children.

3. Investigate cross-sectional associations between intakes of total, free, and added sugar, and anthropometric measures, including body weight, BMI Z-scores, body weight, waist circumference, and percent body fat in preschool-aged children.
Study 3 (Chapter 5): Dietary sugar and anthropometrics among young children in the Guelph Family Health Study: Longitudinal associations

Study rationale: Study 2 concluded that longer term data is needed to understand the impact of early life intake. Therefore, Study 3 investigated the longitudinal associations of total, free, and added sugar intake with anthropometrics in young children after 18 months of follow-up.

The specific objective of this study was to:
- Investigate longitudinal associations between baseline intakes of total, free, and added sugars and anthropometric measures (body weight, BMI Z-scores, percent fat mass, and waist circumference) at 18 months among young children (aged 1.5 to <8 y) in the Guelph Family Health Study (GFHS) pilot families.

Study 4 (Chapter 6): Non-nutritive sweetener intake is low in preschool-aged children in the Guelph Family Health Pilot Study

Study rationale: Study 4 investigated current consumption patterns of non-nutritive sweetener (NNS) intake in preschool-aged children. This study was explored as NNS are currently marketed as a healthy alternative to sugar intake and the Canadian supply for the food sources containing NNS is increasing rapidly with limited information available on these packaged foods.

The specific objectives of this study were to:

1. Determine NNS intake among preschool-aged children.
2. Determine the key food sources and types of NNS consumed by preschool-aged children.
3. Determine the frequency of consumption of NNS food sources by preschool-aged children.
CHAPTER 3 RATIONALE

There is limited knowledge on how sociodemographic characteristics are associated with young children’s sugar intake. None of the previous research studies on this topic have taken the different types of sugar (total, free, and added sugar) into consideration. Since dietary patterns are established by the age of 5 y, the formative period is critical for establishing healthy lifestyle patterns. Excessive intake of energy dense and processed foods such as those with refined sugars can predispose young children to chronic disease later in life. Therefore, examining a variety of sociodemographic characteristics such as child age, child sex, child ethnicity, parent years living in Canada, annual household income, parent education, and parent marital status, can help identify various determinants that can drive sugar intake patterns in young children. Gaining insights into this information can aid in reducing health disparities in specifically identified communities and enable targeted interventions focused on reducing sugar intake in children. Thus, the aim of this cross-sectional study was to examine associations between child and parent sociodemographic characteristics and children’s sugar intake using baseline data from the GFHS.
CHAPTER 3

Study 1: Sugar intake among preschool-aged children in the Guelph Family Health Study: Associations with sociodemographic characteristics

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This chapter has been published in the Children, MDPI journal, presented here with permission and references and table/figure numbers are formatted for this dissertation for consistency.

3.1 Abstract:

3.1.1 Simple Summary: Sociodemographic characteristics of a parent and child may predispose young children to excessive dietary sugar intake; however, there is limited research available on this topic. The aim of this cross-sectional analysis was to examine the impact of sociodemographic characteristics such as child age, child sex, child ethnicity, parent number of years living in Canada, annual household income, parent education and parent marital status on total, free and added sugar intake in young children. Dietary and sociodemographic data including 267 children from 210 families participating in the Guelph Family Health Study were examined. The results indicate that child age, child ethnicity and annual household income can play a crucial role in shaping sugar intake in young children. This research may help inform future research and program interventions early in life along with guiding parents to decrease sugar intake in young children.

3.1.2 Abstract: Background: It is crucial to develop strategies targeted to promote healthy eating patterns in vulnerable populations, especially young children from diverse sociodemographic groups. Thus, this study objective was to investigate the associations between child age, child sex, child ethnicity, parent number of years living in Canada, annual household income, parent education and parent marital status with total, free and added sugar intakes in young children. Methods: This cross-sectional study was a secondary analysis of data gathered in the Guelph Family Health Study. The study included 267 children (129M; 138F) from 210 families aged 1.5 to 5 years. Parents completed questionnaires for children on sociodemographic characteristics and an online 24-hr diet recall. The associations between sociodemographic characteristics and sugar intakes were determined using generalized estimating equations applied to linear regression models. Results: The mean age of the children was $3.5 \pm 1.2$ years (mean $\pm$ std dev.). As children’s age increased, there was higher intake of free and added sugar ($\hat{\beta}=8.6$, $P=0.01$, 95% CI=2.4 to 14.7
and $\hat{\beta}=6.5$, $P=0.03$, 95% CI = 0.8 to 12.2, respectively). Those children who identified as white had a higher total sugar intake than children of other ethnicities ($\hat{\beta}=31.0$, $P=0.01$, 95% CI=7.2 to 54.7). Additionally, higher annual household income was associated with lower free sugar intake in children ($\hat{\beta} = -2.4$, $P=0.02$, 95% CI= -4.5 to -0.4). Conclusions: This study underscores the significant influence of multiple sociodemographic characteristics on sugar intake in young children, providing valuable insights for public health policy and nutrition interventions. Moreover, this study highlights the need for early behaviour interventions focusing on reducing sugar intake in young children while considering sociodemographic factors.

**Keywords:** sugar intake, children, preschooler, toddler, parent, sociodemographic.
3.2 INTRODUCTION

Overconsumption of sugar in children can diminish diet quality, provide high energy content, and lead to excess weight gain and dental caries (Brekke et al., 2007; WHO, 2015). Research studies have indicated that preschool-aged children are exceeding World Health Organization (WHO) guidelines for free sugar intake (WHO, 2015) and consume free and added sugars from a variety of sources (Mahajan, Yu et al., 2021; Ricciuto, Fulgoni et al., 2022). Excess sugar intake can also be the precursor for chronic conditions such as type 2 diabetes and metabolic syndrome later in life (Mazarello Paes, Hesketh et al., 2015).

It is widely recognized that early life intervention strategies are critical for establishing healthy eating habits that can continue throughout life. Investigating the various environmental factors that can contribute to the establishment of dietary patterns is a complex process. Young children’s dietary intake is influenced by numerous factors including those at the level of the child, parent, household and childcare (Jarman et al., 2022; Mazarello Paes et al., 2015). In high income countries that sociodemographic characteristics especially of the parents can have a significant impact on the diet quality of both younger and older children (Anstruther et al., 2021). Research has found that energy intake is higher among children from families with low maternal education, parental unemployment and greater number of siblings (Pabayo et al., 2012). Furthermore, individuals of lower socioeconomic status (SES) can have an increased chronic disease burden later in life (Northstone & Emmett, 2005). A scoping review on socioeconomic determinants of food intake patterns in young children (2 to 5 y) highlighted that the current knowledge base in this area for young children is sparse (Anstruther et al., 2021). Emerging evidence highlights that diet-related disparities attributed to sociodemographic characteristics may appear in children as early as 4 y of age (Dubois et al., 2007). Investigating sociodemographic characteristics of both
children and parents in association with intake of sugar in young children may help inform early life diet interventions, nutrition messaging to parents and the development of nutrition policy focused on dietary sugars (Jarman et al., 2022; Kranz & Siega-Riz, 2002; Rashid, Engberink et al., 2018).

There is limited research on how dietary intake of sugar among young children may differ by sociodemographic characteristics. Income and parental education are major indicators driving high sugar intake in many families that have been extensively studied (Hinnig et al., 2018). However, there is heterogeneity in the results and a wide range of other sociodemographic characteristics that have been shown to influence sugar intake including child ethnicity, child immigration status, child age and sex. A German study found that the intake of sweets (including gummies, chocolate and cookies) was higher among preschool-aged children (ages 3 to 6 y) whose families had immigrated to Germany and was inversely associated with parent education level (Schneider et al., 2013). Similarly, a study from United Kingdom found an association between toddlers (3 y) consuming sweets, biscuits and chocolate with low maternal education levels and higher financial difficulty (North & Emmett, 2000). Another study conducted in Canada in children aged 4 and 5 years (n=2114), observed that child sex and age were important considerations when investigating sociodemographic differences in sugar intake in young children (Pabayo et al., 2012). Specifically, boys from low SES consumed higher servings of regular soft drinks when compared to girls; also, children aged 5 years were more likely to consume regular soft drinks when compared with children aged 4 years (Pabayo et al., 2012).

Most studies have focused only on sugar sweetened beverage (SSB) consumption in relation to sociodemographic characteristics of an individual (Anstruther et al., 2021; Pabayo et al., 2012). Given the wide range of sources of sugar in children’s diets, exploring overall sugar
intake, as well as free and added sugars, may provide a more complete picture of associations between sociodemographic variables and children’s sugar intake. Moreover, there is high variability in the sociodemographic characteristics examined to-date, where some studies have focused solely on parent-level determinants whereas others have explored child-level determinants (Anstruther et al., 2021). Thus, it is crucial to examine multiple sociodemographic characteristics, including both child and parent-level characteristics, to understand their impact on dietary patterns, specifically sugar intake in young children. These results may help to identify which families to target for interventions designed to reduce children’s sugar intake. Therefore, this study investigated the associations between child and parent sociodemographic characteristics and intakes of total, free and added sugar among preschool-aged and young children.

3.3 METHODS

3.3.1 Study Design, Setting, Participants and Enrollment

This cross-sectional study used baseline data from the Guelph Family Health Study (GFHS), an ongoing family-based obesity prevention intervention (Haines, Douglas et al., 2018). This study began in 2017 and is ongoing and includes 246 families at baseline (Haines et al., 2018). Participants met the inclusion criteria for the study if were residing within the Guelph-Wellington area and were not planning to move within one year, if had at least one child 1.5-5 years old, and were able to complete a survey in English (Haines et al., 2018). Families were recruited through Family Health Teams, Community Health Centres and Ontario Early Years Centres using social media posts, posters and in-person recruitment (Haines et al., 2018). The families were given grocery gift cards to recognize the time for participating in the study. The study was approved by the University of Guelph Research Ethics Board (REB#17-07-003).

3.3.2 Data Collection

3.3.2.1 Dietary assessment
Dietary data were obtained through one 24-hour recall using the Automated Self-Administered 24-h Dietary Assessment Tool (ASA24)- Canadian version completed by the parent (ASA24, 2018). Parents of the children completed the 24-hour diet recall online and were instructed to provide the typical eating pattern of the children. Participants that were breast fed (n=15) or with incomplete data (n=28) or with errors in the data (n=12) were excluded. Our final analytic sample included 267 preschool-aged children (138 females; 129 males) from 210 families.

3.3.3 Outcome Variables

The outcome variables included baseline total, free and added sugar intakes of preschool-aged children.

3.3.3.1 Total, Free and Added Sugar Calculations

This study included a comprehensive evaluation of all three types of dietary sugars namely total, free and added sugars. The study team used sugar definitions as adopted by Health Canada where total sugars includes free and naturally occurring sugars and free sugars includes added sugars and naturally occurring sugars in fruit juices where added sugars include all sugars added to foods during processing or preparation (GC, 2019).

Data extraction for sugar intakes followed a standard operating procedure to maintain consistency (Yu, Mahajan et al., 2023). The dietary data were checked by two data analysts to ensure data quality. Total, free and added sugar intakes were expressed as kcal of sugar per 1000 kcal/day (Mahajan et al., 2021). The study calculations have been described elsewhere (Yu et al., 2023). In brief, for this study, total sugar intakes were directly extracted from the ASA24 (Canadian version) nutrient results. Added sugar intakes were manually calculated from ASA24 results using 37 United States Department of Agriculture’s food patterns groups as listed within the Food Patterns Equivalent Database (Bowman, 2017; Yu et al., 2023). Added sugars from ASA24 results were converted from teaspoon equivalents to grams and then to kcal whereas, free
sugar intakes (including added sugars and 100% fruit juice) were calculated based on whether a listed item contained 100% fruit juice.

3.3.4 Predictor Variables (Sociodemographic characteristics)

Sociodemographic data for the study were gathered from the baseline survey completed by parent 1, who was the first parent to enroll in the study (91% mothers in the overall sample). Sociodemographic characteristics included: child age, child sex, child ethnicity, parent number of years living in Canada, annual household income, parent education and parent marital status. Child age was captured in years and coded as a continuous variable. Child sex was coded as “male” or “female”. Child ethnicity was collected using the question, “How would you describe (child's name) ethnicity/race?” Due to sparseness in the data across all ethnicities except for white participants, child ethnicity was coded “white” or “other”. Parent number of years in Canada was captured with the question asked as, “How long have you lived in Canada?” For this category, there were 7 response options ranging from “Less than 1 year” to “Greater than 20 years” and this characteristic was coded as a continuous variable by calculating the midpoint of each category. Annual household income was asked as the following question: “What is the total annual income of your household before taxes?” There were 12 response options ranging from <$10,000 to >$150,000 (CAD). The mid-point for each quantitative category was calculated to create a continuous variable for household income. Parent education was asked as, “What is the highest grade or degree you completed in school?” There were 10 response options ranging from “8th grade” or “less to postgraduate training or degree”, which were subsequently collapsed into 3 categories of High school, College or University degree and Postgraduate degree. Parent marital status was assessed using the item, “What best describes your current marital status?” Response options included married, not married but living with a partner, single (never married), divorced, separated, widowed. These categories were subsequently collapsed to “married” (2-parent home-
married or common-law) or “not married” (includes single and never married; not married but living with a partner; divorced; separated and widowed).

3.3.5 Data Analysis

Descriptive statistics were used to describe child and parent characteristics. Linear regression models were fitted using generalized estimating equations (GEE) to estimate associations between sociodemographic characteristics including child age, child sex, child ethnicity, household income, parent years in Canada, parent education, parent marital status, and total, free and added sugar. The variable, parent education was coded into 3 categories: high school, university or college and postgraduate degree. A nested modelling approach, performed in R-Studio, was used to globally assess the association between parent education with total, free and added sugar. The GEE approach was utilized to account for siblings in the data (Liang & S.L., 1986). For this study data analysis, R (RCoreTeam, 2022) was used within RStudio 2021.09.0 Build 351 Version 3.

3.4 RESULTS

3.4.1 Sugar intake in preschool-aged children and sociodemographic characteristics

Table 3.1 provides information on baseline total, free and added sugar intake in grams/day (mean ± SD) for preschool-aged children, as well as child and parent sociodemographic characteristics. The analytic sample included 267 children from 210 families (Female: 138; Male: 129). The average age of the children was 3.5 ± 1.2 y. There were 205 children (77%) that identified as white and 55 children that identified as other ethnicities. The majority, 177 children, had a parent who was married, and 33 children had a parent who was not married. Household income included 110 families (52%) reporting incomes over $100,000 (CAD).

3.4.2 Associations between sociodemographic characteristics and sugar intake of children
A higher total sugar intake was seen in children who were white compared to children of other ethnicities ($\hat{\beta}=31.0$; $P=0.01$; 95% CI=7.2 to 54.7; Table 3.2). There was a positive association between child age and free sugar ($\hat{\beta}=8.6$; $P=0.01$; 95% CI = 2.4 to 14.7; Table 3.3) and added sugar ($\hat{\beta}=6.5$; $P=0.03$; 95% CI = 0.8 to 12.2; Table 3.4) intakes in the study sample. This meant that with every 1-year increase in age there was an estimated 8.6 kcal increase in free sugar intake and a 6.5 kcal increase in added sugar intake per 1000 kcal/day. Annual household income was inversely associated with free sugar intake ($\hat{\beta}=-2.4$; $P=0.02$; 95% CI= -4.5 to -0.4). No other statistically significant associations between sociodemographic characteristics and total, free and added sugar intakes were observed. For parent education, there was no association with total sugar (df=2; P-value =0.77; $\chi^2=0.53$); free sugar (df=2; P-value=0.05; $\chi^2=5.9$) and added sugar (df=2; P-value= 0.12; $\chi^2=4.3$) in the overall model.

3.5 DISCUSSION

To date, limited research has examined how sociodemographic characteristics may influence young children’s sugar intake. This study found that child age, ethnicity, and annual household income are associated with sugar intake in preschool-aged children. These results advance our fundamental understanding of sociodemographic characteristics that may influence intake of sugar in young children.

Study results suggest that as children age, they eat higher amounts of free and added sugar. These findings are paralleled by studies examining overall diet quality and age in children. Furthermore, a study investigating added sugar intake in preschoolers between the ages of 2 to 5 y in North Carolina, USA, found that older children consumed more added sugar than younger children as likely older children consume greater energy daily (Kranz & Siega-Riz, 2002).
Similarly, across major cohort and longitudinal studies from US, UK, Netherlands and Australia, a recent scoping review found that child age was negatively associated with diet quality (Jarman et al., 2022). Taken together, these results suggest that interventions in early life should be targeted to parents for children as young as infants as evidence suggests that intake of added sugars advances with age.

Differences in sugar intake by ethnicity is inconsistent in the research literature. Child ethnicity was found to be a determinant of sugar intake in the present study and children that identified as white had higher total sugar intake than other ethnic groups. In contrast, a US study of 3 y old children (n=898) showed that black and Hispanic children consumed greater median intakes of sugar-sweetened beverages (SSB) when compared to white children (p<0.001) (de Hoog, Kleinman et al., 2014). However, the study by Kranz and Siega-Riz, showed that children (n=5,652) of Hispanic descent consumed less added sugar than children of other non-Hispanic black or white ethnicities (Kranz & Siega-Riz, 2002). These differences may be due to the varied racial-ethnic make-up of these American samples compared to our sample from Southwestern Ontario, Canada, which was primarily white with few children identifying as black or Hispanic. Nevertheless, differences in sugar intake by ethnicity among more diverse racial-ethnic Canadian populations warrants further investigation given its potential impact.

Annual household income was inversely associated with free sugar intake, which is consistent with multiple studies that have highlighted diet-related disparities in relation to income (Brekke et al., 2007; Coles, Cheyne et al., 2015; Hinnig et al., 2018). A Canadian study of children aged 4 to 5 y (n=1,760), found children living in low income neighborhoods had higher intakes of soft drinks and fruit juices ($\chi^2 = 14.14$, P<0.01) when compared to those living in high income neighborhoods (Pabayo et al., 2012). Similarly, a Portuguese study investigating multiple SES
characteristics found that annual household income was inversely related to children’s intake of SSB and sweets (Vilela, Oliveira et al., 2015). It is speculated that households with higher income may have access to healthy foods such as fruits and vegetables and that these parents also play an more active role in limiting processed sugary items for their children (Anstruther et al., 2021). The current study found that parent education was not associated with sugar intake in children. However, a Swedish study investigating the dietary pattern of infants at 1 y of age (n= 16,070) showed that parent education was inversely associated with the frequency of intake of sweets and pastries (Brekke et al., 2007). Furthermore, a longitudinal study from the UK found that from 4 to 7 y (n=9550), consumption of a dietary pattern of highly processed foods such as sweets and ice cream was associated with decreasing levels of maternal education (Northstone & Emmett, 2005). This difference is also likely due to the high proportion (>90%) of parents reporting the attainment of university or postgraduate education in the present study. Additional research among more sociodemographic diverse samples in Canada are needed to further elucidate how children’s sugar intake may differ by parental educational level.

3.5.1 Study Limitations

The present study uniquely contributes to the limited research examining sociodemographic associations with dietary intake in the preschool-age population in the Canadian context, nevertheless, there are some limitations to consider. There could be risk of selection bias during the recruitment of the study sample as families who were motivated to participate in a health-based study could have chosen. There are also many other sociodemographic variables that were not considered in the current study, such as home ownership and number of family members, which could be considered in future studies. Food intake for the study was captured using one 24-hr recall, thus may not reflect usual intake. Parent-reported diet data may be subject to social
desirability bias, which could have led to parents underreporting children’s sugar intake. This would have biased results towards the null. Ethnic diversity was limited as 77% of the children were white and over half of the children came from households with incomes greater than $100,000 (CAD). Thus, the study results may not be generalizable to diverse and lower socioeconomic populations and are specific to the families living in the Canadian context.

3.6 CONCLUSION

This study found that sugar intake was associated with sociodemographic characteristics of children. Child age was positively associated with free and added sugar intakes and annual household income was inversely associated with free sugar intake. Our data, when considered together with other research exploring these associations, suggest that multiple sociodemographic characteristics play a role in shaping dietary intake of sugar. Thus, investigation of sociodemographic characteristics is warranted in larger and more sociodemographic diverse cohorts. This information can help inform health promotion initiatives when working with varied populations and early intervention programs through education and awareness to parents to reduce sugar intake in young children.
3.7 ACKNOWLEDGEMENTS:

Author Contributions: D.W.L.M and J.H. are the Co-Directors of the GFHS and supervised this project. J.H., D.W.L.M. and A.M. conceptualized the study, J.Y. and A.M. reviewed the data, A.M. completed the data analysis and wrote the manuscript. A.C.B. supervised and was the co-advisor for the first author. G.D. was the statistical advisor. A.M.D. supervised the dietary data collection and analysis. All authors reviewed, critically analyzed the results and approved this manuscript.

Funding: Funding for this project provided by Heart & Stroke Foundation (G-18-0022070), Canadian Institutes of Health Research (376067) and Health for Life Initiative at the University of Guelph; however, none of the organizations had any role in the project design, data collection, analyses, interpretation of data, or writing of the manuscript.

Institutional Review Board Statement: The study was conducted in accordance with the Declaration of Helsinki and approved by the Institutional Review Board (or Ethics Committee) of the University of Guelph Research Ethics Board (REB#17-07-003). Approval date: August 15, 2017.

Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

Data Availability Statement: The GFHS welcomes external collaborators. Interested investigators can contact GFHS investigators to explore this option, which preserves participant confidentiality and meets the requirements of our Research Ethics Board, to protect human subjects. Due to Research Ethics Board restrictions, we do not make participant data publicly available.

Acknowledgements: The authors would like to extend their thanks and gratitude to the participating families and to Angela Annis, Madeline Nixon, Adam Sadowski and Michael Prasad
for their support in facilitating this research. The authors acknowledge Wellington-Dufferin-Guelph Public Health and the Guelph Family Health Team for their collaborative support of this work.

**Conflict of Interest:** The authors declare that there are no competing interests.
Table 3.1: Characteristics of parents and children participating in the Guelph Family Health Study at baseline. Children participants (n=267) and families (n=210)

<table>
<thead>
<tr>
<th>Type of Sugar*</th>
<th>Daily intake (g, mean ± SD)*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Sugar</td>
<td>84.1±33.9</td>
</tr>
<tr>
<td>Free Sugar</td>
<td>37.4±26.8</td>
</tr>
<tr>
<td>Added Sugar</td>
<td>33.4±23.5</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Number</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Child</strong></td>
<td></td>
</tr>
<tr>
<td>Sex</td>
<td></td>
</tr>
<tr>
<td>Male</td>
<td>129 (48.3)</td>
</tr>
<tr>
<td>Female</td>
<td>138 (51.7)</td>
</tr>
<tr>
<td>Age, years, mean ± standard deviation</td>
<td>3.5 ± 1.2 y</td>
</tr>
<tr>
<td><strong>Ethnicity</strong></td>
<td></td>
</tr>
<tr>
<td>White</td>
<td>205 (76.8)</td>
</tr>
<tr>
<td>Other**</td>
<td>55 (20.6)</td>
</tr>
<tr>
<td><strong>Parent</strong></td>
<td></td>
</tr>
<tr>
<td>Parent number of years living in Canada</td>
<td></td>
</tr>
<tr>
<td>Greater than 20 years</td>
<td>184 (88.0)</td>
</tr>
<tr>
<td>Less than 20 years</td>
<td>25 (12.0)</td>
</tr>
<tr>
<td><strong>Household income</strong></td>
<td></td>
</tr>
<tr>
<td>&lt;$60,000</td>
<td>33 (15.7)</td>
</tr>
<tr>
<td>$60,000 to $99,999</td>
<td>56 (26.7)</td>
</tr>
<tr>
<td>$100,000 to $149,000</td>
<td>63 (30)</td>
</tr>
<tr>
<td>≥$150,000</td>
<td>47 (22.4)</td>
</tr>
<tr>
<td><strong>Parent education</strong></td>
<td></td>
</tr>
<tr>
<td>High school graduate</td>
<td>13 (6.2)</td>
</tr>
<tr>
<td>University and College graduate</td>
<td>94 (44.8)</td>
</tr>
<tr>
<td>Postgraduate training</td>
<td>103 (49)</td>
</tr>
<tr>
<td><strong>Parent marital status</strong></td>
<td></td>
</tr>
<tr>
<td>Married</td>
<td>177 (84.3)</td>
</tr>
<tr>
<td>Not Married</td>
<td>33 (15.7)</td>
</tr>
</tbody>
</table>

* Average intakes in grams of total, free and added sugar in preschool-aged children.

**Other ethnicities included West Asian (Arab, Iranian, Afghan); Latin American; Chinese; South Asian (East Indian, Pakistani, Sri Lankan); Korean or Japanese; Southeast Asian (Vietnamese, Cambodian, Filipino, Malaysian, Laotian) and Aboriginal/First Nations peoples.
Table 3.2: Association between child age, child sex, child ethnicity, parent years living in Canada, household income, parent marital status with total sugar intake in preschool-aged children

<table>
<thead>
<tr>
<th></th>
<th>$\hat{\beta}$</th>
<th>SE</th>
<th>P-value</th>
<th>95% CI low</th>
<th>95% CI high</th>
</tr>
</thead>
<tbody>
<tr>
<td>Child age*</td>
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*Child age, Parent years living in Canada and Annual household income were coded as continuous variables.

**Child ethnicity was coded as white or other; Parent marital status was coded as married or other.
Table 3.3: Association between child age, child sex, child ethnicity, parent years living in Canada, household income, parent marital status with free sugar intake in preschool-aged children

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*Child age, Parent years living in Canada and Annual household income were coded as continuous variables.

**Child ethnicity was coded as white or other; Parent marital status was coded as married or other.
Table 3.4: Association between child age, child sex, child ethnicity, parent years living in Canada, household income, parent marital status with added sugar intake in preschool-aged children

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*Child age, Parent years living in Canada and Annual household income were coded as continuous variables.

**Child ethnicity was coded as white or other; Parent marital status was coded as married or other.
CHAPTER 4: RATIONALE

The results from Study 1 (Chapter 3) identified several sociodemographic characteristics including child age, child ethnicity, and annual household income having a significant influence on the intakes of total, free, and added sugar in young children. These results provide critical insights into the variations in sugar intake among different segments of the population. These results can help inform public health interventions. Dietitians and other healthcare professionals can use this information when counselling parents of young children and tailor their recommendations based on sociodemographic characteristics.

The findings of Study 1 (Chapter 3) highlight that sociodemographic characteristics are an important determinant for food access. Building on these findings, the next phase focused on examining consumption patterns of total, free, and added sugar intake in young children, identifying primary sources of free and added sugars in their diets and the impact of sugar intake on child anthropometrics such as body weight, waist circumference, percent fat mass and, BMI Z-scores.
CHAPTER 4

STUDY 2: Dietary sugar intake among preschool-aged children: A cross-sectional study

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Competing Interests: None declared

Funding agencies: This research was funded by Heart and Stroke Foundation of Canada, Canadian Institutes of Health Research (CIHR) and Health for Life Initiative at the University of Guelph; however, neither of the organizations had any role in the project design, data collection, analyses, interpretation of data, or writing of the manuscript.

This chapter has been published in the CMAJ OPEN journal, presented here with permission and references and table/figure numbers are formatted for this dissertation for consistency.

4.1 Abstract

4.1.1 Background: Excessive intake of sugar in young children is a public health concern. Study objectives were to examine preschool-aged children’s intakes of total, free and added sugar and to investigate their associations with body weight, BMI Z-scores, percent fat mass and waist circumference.

4.1.2 Methods: The cross-sectional cohort study included preschool-aged children between 1.5 to 5 years of age, enrolled in pilot studies of the Guelph Family Health Study. Total sugar daily intake was determined using a food processor software; free and added sugar daily intakes and food sources were determined through manual inspection of 3-day food records. Anthropometric measures were completed by trained research staff. We used linear regression models with generalized estimating equations were used to estimate associations between sugar intakes and anthropometric measures.

4.1.3 Results: We included 109 children (55 girls and 54 boys) in 77 families. Mean daily intakes were 86 (standard deviation [SD] 26) g for total sugar, 31 (SD 15) g for free sugar and 26 (SD 13) g for added sugar. Of participants, 80% (n = 87) had intakes of free sugar greater than 5% of their daily energy intake. The most frequent food sources of free and added sugar were bakery products. A weak inverse association between free sugar intake (kcal/1000 kcal) and waist circumference (cm) (β = –0.02, 95% confidence interval –0.04 to –0.0009) was found but no significant associations were noted between sugar intake and other anthropometric measures.

4.1.4 Interpretation: Most children in this study had free and sugar intakes that exceeded current recommendations; overall, their total, free and added sugar intakes were not associated with the
anthropometric measures. This study can be used to inform policy development for sugar intake in young children and apprise early intervention programs.

4.2 Introduction

Dietary patterns begin in early childhood and can continue into adulthood. Thus, early years are crucial for nutrition interventions and habit formation (Mikkila et al., 2005). Infants have a natural affinity towards sweet foods overall and pre- and post-natal exposures of added sugar are important (Fidler Mis et al., 2017; Herbst et al., 2011). Genetic, environmental and cultural influences can increase preferences for sugary foods in children (Fidler Mis et al., 2017). However, there is a lack of high quality research data on the dietary intake of sugars among young children, especially among infants and toddlers (Herrick et al., 2020). Given that cardiometabolic risk markers may begin to emerge as young as 3 years of age (Skinner et al., 2015), it is important to understand the sugar intake patterns and explore associations between intake of sugar and cardiometabolic risk markers (including anthropometric measures) in early life. This information can help inform policy development and behavior change intervention programs focused on early prevention.

Adverse effects of excessive sugar intake are a cause for global public health concern in all age groups (WHO, 2015). Overconsumption of sugar has been associated with increased risk of excessive weight gain, dental decay, poor diet quality and nutritional inadequacy in children and adolescents under the age of 19 y (Elfassy, Adjoian et al., 2019; Herrick et al., 2020; Keller & Bucher Della Torre, 2015). Excessive sugar intake has also been implicated in the development of high blood pressure and lipid abnormalities in children (Herrick et al., 2020), which can lead to earlier presentation of chronic diseases in children than seen in previous generations (Skinner et al., 2015).
In most studies, sugar sweetened beverages (SSB) are the primary source of dietary sugar intake among children and adolescents (Davis & Lee, 2014). One study found that SSB consumption in the first year of life was associated with a 13% increase in risk of being overweight at 8 years of age (Blum, Jacobsen et al., 2005). Recently, a study found that higher intakes of SSB and 100% fruit juices are associated with increased risk of cardiometabolic risk factors in preschool-aged children (Eny et al., 2020). Moreover, there are studies that have found no significant associations between SSB intake and body weight or body mass index (BMI) Z-scores in preschool-aged and school children (Davis & Lee, 2014; Newby et al., 2004). Given these mixed findings and the primary focus on SSB, we embarked on our research study using detailed dietary assessments to broadly examine sources of sugar intake and investigate associations between dietary sugar intake and anthropometric measures in preschool-aged children.

There are multiple sugar definitions in the research literature for added, free and total sugar. The World Health Organization (WHO) and Health Canada defines added sugar as any type of dietary sugar that is added in processing or preparation of foods (e.g., sugars added when manufacturing sugar sweetened beverages and sweet treats such as lollipop, candies and fruit snacks) (GC, 2019; WHO, 2015). The term “free sugar” is a broader definition which includes added sugar and sugars that are naturally occurring in honey, syrups, fruit juices and fruit juice concentrates (GC, 2019; WHO, 2015). Total sugars include free, added and natural sugars found in fruits, vegetables and unsweetened milk (GC, 2019).

Our study objectives were two-fold. Firstly, to examine the daily intakes of total sugar, free sugar and added sugar, and the key food sources (by category) of free and added sugar among a sample of preschool-aged children. Our research study has adopted these definitions from the WHO and Health Canada for free and total sugar. However, the present study used a more common
definition of added sugar used in the research literature, which includes sugars added during manufacturing, honey and syrups (Bailey, Fulgoni et al., 2018; Louie, Moshtaghian et al., 2015). Our second objective was to explore cross-sectional associations between intakes of total, free and added sugar with anthropometric measures, including body weight, BMI Z-scores, body weight, waist circumference and percent body fat. We hypothesized that free and added sugar intake in preschool-aged children will be positively associated with anthropometric measures.

4.3 Methods

4.3.1 Study Design

The study is a cross-sectional secondary data analysis of a sample of preschool-aged children from the Guelph Family Health Study. This research investigates the amount of total, free and added sugar intake, the associations with anthropometric measures and the key food sources of free and added sugar intake.

4.3.2 Settings and Participants

The GFHS is a family-based lifestyle obesity prevention study, initiated in 2014 at the University of Guelph, Ontario, Canada. The current cross-sectional cohort study includes data gathered from preschool-aged children from the GFHS pilot studies at baseline from 2014 to 2016 (Haines et al., 2018). The purpose of the pilot studies was to test the feasibility and acceptability of our study methods.

Families with at least one child aged 1.5 to 5 years, who were not planning to move within the next year were recruited from the Guelph-Wellington area through the Guelph Family Health Team, Guelph Community Health Centre and Ontario Early Years Centres (Haines et al., 2018). Our recruitment strategies were targeted, far-reaching and included the use of study Facebook posts that were widely shared by community partners, the University of Guelph and
Guelph Family Health Study websites. Posters and rack cards were displayed at the above community agencies and also at local recreation centers, libraries and other locations that provide services to young families. The participants completed an eligibility screener either online or over the phone with the study coordinator (Haines et al., 2018). Appendix (4.8) provides more details on the ongoing GFHS. A gift card was provided to participants to acknowledge the time required.

**4.3.3 Study Measures**

**4.3.3.1 Intake and Sources of Sugar**

Total, free and added sugar intakes were assessed from the analysis of 3-day food records (2 weekdys and 1 weekend day). Parents were given paper food record forms, on which they recorded their child(ren)’s food and drink consumption, including amount and occasion of consumption, brand names of products, and recipes for mixed foods. Food record data were entered into the ESHA Food Processor software for analysis of 3-day average nutrient intakes (Version 11.6.441, Salem, OR, 2015). Total sugar intake was analyzed by the ESHA Food Processor; however, added and free sugar intakes were determined through manual calculations and review of product and SMART LABEL websites. We adapted the algorithm of Louie and colleagues (Louie et al., 2015), which included a standardized, objective and stepwise approach to calculate content of added sugar (including honey and syrups) and free sugar (including foods with added sugar and 100% fruit juice and concentrates) (Louie et al., 2015). This calculation has been used in other studies that investigated free sugar intake in preschool-aged children (Crowe et al., 2020; Devenish et al., 2019). These calculations were performed by two data analysts to assure data quality. The data analysts followed a standard operating procedure to complete the calculation and worked closely together to ensure data consistency. There are limitations in the research literature such as inconsistent definitions of free and added sugar (Fidler Mis et al., 2017) and limited food
composition databases that calculate added and free sugar amounts (Crowe et al., 2020). Total, free, and added sugar intakes were normalized to kcal per 1000 kcal/day for ease of comparison in the regression analysis. To identify free and added sugar sources, we adapted the categorization system used by Bernstein and colleagues (Bernstein, Schermel et al., 2016). Approximately 17 broad free and added sugar food categories were used to classify the sources consumed by our study population (Bernstein et al., 2016). The food records were reviewed to classify combined or stand-alone food items into free and added sugar food categories. Our data analysts did not note any free sugar and added sugar items in the food records for the Vegetables or Fish and Seafood food categories. The following are examples of the items included in the prominent food categories seen in our study. Bakery Products included items such as all breads and sweet breads, muffin, granola bars, pancakes and cookies. Beverages included both sweetened and unsweetened beverages such as juices and sweetened milk. Cereals and Grain Products included both hot and cold cereal options. Dairy products and substitutes included sweetened yogurts. Desserts included ice cream, frozen popsicles and Jell-O™. Sugars and Sweets included marshmallows, candies, syrups, fruit candies and sweetened jams.

4.3.3.2 Anthropometrics

Anthropometric outcome variables included waist circumference (WC), height, body weight, percent fat mass and BMI Z-scores. The following were the means noted for the above anthropometrics: body weight 16.2 (standard deviation [SD] 3.6) kg, BMI Z-score 0.6 (SD 1.0), waist circumference 50.8 (SD 4.6) cm and percent fat mass 29.8% (SD 5.2%). Repeated anthropometric measures were completed by trained research staff. Participants were instructed to remove any footwear and outer garments before measurements were taken. WC was measured at the top of the iliac crest of participants’ bare abdomen, using a non-elastic tape measure (Gulick
II™, Country Technology Inc., Gay Mills, Wisconsin). Height (cm) was measured using a child stadiometer. Height and WC were measured in duplicate; if the values were within 0.5 cm, then a mean value was calculated. Otherwise, a third measurement was taken and the mean of the two closest values was calculated. Body weight (kg) was measured using an electronic weighing scale. BMI Z-scores were calculated using the R package zscorer. Percent fat mass was assessed using supine tetrapolar bioelectrical impedance analysis (BIA). Participants were instructed to avoid food/drink and vigorous physical activity for 30 minutes prior to the BIA assessment. Percent fat mass was calculated using Kushner and colleagues’ total body water formula (Kushner, Schoeller et al., 1992) and Fomon and colleagues’ hydration constants (Fomon, Haschke et al., 1982). Inter- and intra-rater reliability of the BIA were previously determined in a sample of six children within the GFHS (Jewell, 2019). The inter-rater coefficient of variation (CV) and reliability coefficient were 1.8 and 0.79, respectively (Jewell, 2019). Moreover, the intra-rater CV for the first observer was 0.05 and second observer was 0.15 (Jewell, 2019). The intra-rater reliability coefficients for first observer was 0.05 and second observer was 0.15 (Jewell, 2019).

4.3.3.3 Statistical Analysis

Data were analyzed using SAS® University Edition version 9.4 (SAS Institute Inc., Cary, NC). We used descriptive statistics were used to summarize children’s sugar intake. Linear regression models using generalized estimating equations were fitted to estimate associations between sugar intake and anthropometric measures. We used generalized estimating equations GEE’s to account for any dependence between sibling participants (Liang & Zeger, 1986), and to attain 95% confidence intervals for categories of sugar sources. The variables age and sex were identified as potential confounders and controlled for in the models that explored associations between sugar intake and children’s body weight, fat mass, and waist circumference.
4.3.3.4 Ethics Approval

The study was approved by the University of Guelph Research Ethics Board (REB#14AP009).

4.4 Results

A total of n=117 (83 families) participants were enrolled in the pilots. Participants were excluded from analyses if food records were incomplete (n=4) or if breastfeeding replaced a meal and/or exceeded 50 mins or >625mL of breastmilk per day (n=4). Thus, our final analytic study sample included 109 preschool-aged children (55 females; 54 males) from 77 families.

4.4.1 Demographic characteristics

Among our sample of 109 children, the mean age was 3.6 (SD 1.2) years and 84% (n=92) of the participants were white. A total of 61% (n=47) of parents reported their annual household income >$80,000, and 41% (n=32) had completed postgraduate training or degrees (Table 1).

4.4.2 Sugar intake amounts and percent of total energy

Mean daily intakes were 86 (SD 26) g (21.5 teaspoons) for total sugar, 31 (SD 15) g (7.8 teaspoons) for free sugar and 26 (SD 13) g (6.5 teaspoons) for added sugar (Figures 1 and 2). Of participants, 80% (n = 87) had intakes of free sugar that exceeded 5% of their daily energy intake (Figure 1).

4.4.3 Food sources of free and added sugar intakes

We noted that 100% (n=109) of the children in our study were consuming free and added sugar from bakery products, 77% (n=84) from sugars and sweets, and 72% (n=78) from cereals and grains (Table 2). For free sugar intake, the top three food sources included bakery products (9.1 g; 95% CI 8.0, 10.2), sugars and sweets (7.5 g; 95% CI 6.3, 8.7), similar consumption of cereals and grain products (4.2 g; 95% CI 3.2, 5.1) and beverages (10.5 g; 95% CI 8.0, 12.9).
added sugars, the top three food sources included bakery products (9.1 g; 95% CI 8.0, 10.2), sugars and sweets (7.5 g; 95% CI 6.3, 8.6), cereals and grains (4.2 g; 95% CI 3.2, 5.1) (Table 3).

4.4.4 Cross-sectional associations between sugar intakes and anthropometric measures

Overall, children’s total, free, and added sugar intakes were not associated with the anthropometric measures explored (Table 4). Our study did find a significant but weak inverse association between free sugar intake and waist circumference (cm) (β = -0.02, 95% CI -0.04, -0.0009; p-value < 0.05) (Table 4).

4.5 Interpretation

Our study investigated daily intakes of total, free and added sugar along with key food sources among preschool-aged children in the GFHS pilot studies. In addition, we examined cross-sectional associations between total, free and added sugar and anthropometric measures. To our knowledge, this is the first Canadian study to examine cross-sectional associations between dietary sugar intake and anthropometric measures among preschool-aged children.

Children’s intake of total sugars (86 g/day) in our sample was below the 2015 Canadian average of 101 g/day or 24 teaspoons for children 2 to 8 y (Langlois, Garriguet et al., 2019). This age range might be too large for comparison as intake of total sugars may change markedly between toddlers, preschoolers and children. The average added sugar intake of 6.5 teaspoons/day in our sample exceeds the American Heart Association (AHA) Scientific Statement, which recommends <6 teaspoons / day for children older than 2 y, and limiting or avoiding added sugar for children younger than 2 y (Vos et al., 2017). The World Health Organization recommends reducing free sugar intake to less than 10% of total energy intake but suggests further reducing this limit to below 5% Health Canada recommends the 10% limit (WHO, 2015). Health Canada recommends the 10% limit (GC, 2019). These recommendations and guidelines are also endorsed
by Heart and Stroke Foundation of Canada (HSF, 2014). Furthermore, 20.2% of children had added sugar intake that exceeded the 10% limit as recommended by the American Heart Association (AHA) Scientific Statement (Vos et al., 2017) and the Dietary Guidelines for Americans 2015-2020 (DGA, 2015) (Appendix 4.8).

The Institute of Medicine recommends a 25% upper limit of total energy for added sugars (IOM, 2005). Kranz and colleagues (2005) analyzed added sugar consumption for 2 to 5 year old American children through the Continuing Survey of Food Intake (Kranz et al., 2005). In this study, the majority of participants consumed <25% of energy from added sugar, similar to our study sample (Kranz et al., 2005). Among this US sample, the top food sources were fruit drinks, high fat desserts and soft drinks (Kranz et al., 2005), whereas in our sample bakery products were the top food source. Data from population-based surveys in Canada and the US suggest that intake of SSB has decreased over the past 10 years, which may explain the differences in top food sources of sugar intake in our study versus earlier studies with preschool-aged children (Jones, Kirkpatrick et al., 2019; Marriott, Hunt et al., 2019).

A total of 80% of preschool-aged children in our study had a free sugar intake that exceeded the 5% recommendation and 32%, that exceeded the 10% recommendation set by the WHO (WHO, 2015). These results are similar to research by Devenish and colleagues who analyzed free sugar intake among 2-year-old children in Australia (Devenish et al., 2019). In this study, 71.1% of children exceeded the 5% of total energy recommendation and 38% exceeded the less than 10% recommendation (Devenish et al., 2019). The main free sugar sources found in their sample were fruit juice, biscuits, cakes, desserts and confectionery, which were similar to the main free sugar sources we found in our study (Devenish et al., 2019).
Examination of the cross-sectional associations between total, free and added sugar and anthropometric measures showed a small but significantly negative association between free sugar and waist circumference (Table 4). This result was normalized per 1000 kcal for each participant and therefore, may appear small and not clinically relevant. Considering a clinical scenario, the estimated mean difference in waist circumference for two children differing in free sugar intake by 2 SD (100 kcal) and assuming a 1000 kcal diet, would be -2 cm with a confidence interval (CI) that goes as low as -4 cm (-2.21; 95% CI -4.32, -0.09; p-value < 0.05). In this manner, a 2 cm decrease in waist circumference is clinically interpretable, however, there is no research to date that suggests consuming more sugar results in a reduction in waist circumference. Interpreting these data within the context of other measures in this study including non-significant associations for fat mass, BMI Z-scores and body weight, suggest that effects of free sugar on waist circumference are not likely plausible. Nevertheless, given the cross-sectional nature of these analyses, it does not rule out potential long-term effects that require further follow-up.

Research studies linking sugar intake with weight gain and obesity in children are conflicting as seen in systematic reviews (WHO, 2015). For instance, The Dortmund Nutritional and Anthropometric Longitudinally Designed (DONALD) Study of 216 participants (0.5 to 7 y) found that a high added sugar intake in the first 2 y of life was associated with an increased BMI by the age of 7 y (Herbst et al., 2011). By contrast, using NHANES data (1971-1975; 1988-1994) from children aged 1 to 18 y, no association was found between total and added sugar with BMI (Song et al., 2012). This study suggested that total energy intake, rather than a specific nutrient, had a greater impact on children’s BMI (Song et al., 2012).

There is a paucity of literature on sugar intake and anthropometric measures in preschool-aged children. Although overall, the research examining dietary sugar intake has been mixed in
children, evidence shows SSB intake is associated with cardiometabolic risk factors that include waist circumference and BMI Z-scores in preschool-aged children (Kosova et al., 2013; Seferidi, Millett et al., 2018). This is likely due to the increased energy density in the overall dietary pattern with SSBs intake. Our findings indicated a statistically significant negative association between free sugar intake and waist circumference (that is not clinically relevant due to the small regression coefficient estimate) and do not suggest any other associations of sugar with anthropometric measures.

4.5.1 Limitations

Some limitations should be considered when interpreting our results including that our study sample consisted of 84% Caucasians and over 61% of participants had an annual household income over $80,000 CAD. Thus, our results may not be generalizable to children from diverse ethnic or low socio-economic populations. A sample size calculation was not needed for the study as this was a feasibility study and all the available data were analyzed. Owing to the small sample size, there is a risk of type 2 error (false negatives) and thus, there is a need for replication in larger cohorts. Parent-reported food records were used to collect dietary data which may be underreporting children’s sugar intake data owing to social desirability bias or errors in the reporting of children’s intake. In Canada, it is not required that companies identify the proportion of added and naturally occurring sugars on nutrition labels. This meant that for some products, such as in infant formula, we were unable to differentiate the free and added sugars in the product. Our added sugar definition was adapted from Louie and colleagues (Louie et al., 2015) and includes honey and syrups. While this definition is aligned with other research in this field (GC, 2019; Louie et al., 2015) it has been debated (Khan & Sievenpiper, 2016; Mela & Woolner, 2018) as it is not consistent with current WHO and Health Canada definitions (WHO, 2015). Lastly,
while a gift card was provided in our study, it was a token amount meant to acknowledge participants’ time and not to be considered a limitation.

4.6 Conclusion

Our study found that young children are exceeding current Canadian and WHO recommendations for dietary sugar intake. Preschool-aged children are consuming free and added sugar from many food sources. Overall, there was no association with dietary sugar intake and anthropometric measures in our study participants. The study findings support current recommendations that preschool-aged children should limit free and added sugar intake to establish healthy dietary patterns early in life. Although our study does not provide evidence linking sugar intakes and anthropometric measures, most children exceeded the WHO recommendations for free sugar intake.

This study can inform health care professionals and policymakers about the current consumption patterns of sugars in young children, as there is currently limited research available for this age group. Our data regarding key food and beverage sources of sugar intake among preschool-aged children can be used to guide dietary and policy advice for preschool-aged children. Given the limited research examining sugar intake among young children and the impact on cardiometabolic risk factors in early years, further investigation of dietary sugar intake (amount and sources) and longitudinal associations with anthropometric measures are warranted in preschool-aged children.

4.7 ACKNOWLEDGEMENTS

Contributors: Anisha Mahajan conducted and interpreted the data analysis and wrote the manuscript. David Ma and Jess Haines are co-directors of the Guelph Family Health Study (GFHS) and supervised this project. Gerarda Darlington was the statistical advisor. Andrea Buchholz
supervised body composition measurements for the study, and Alison Duncan supervised the
dietary data collection and analysis. Both were co-advisors for this project. These authors critically
evaluated the results of this project. Angela Annis assisted with data acquisition, and Jessica Yu,
Jaimie Hogan, Kira Jewell, Alex Carriero and Adam Sadowski assisted with data cleaning and
data review. All authors reviewed and revised the manuscript,
gave final approval of the version to be published and agreed to be accountable for all aspects of
the work.

**Funding:** This research was funded by the Heart and Stroke Foundation of Canada, the Canadian
Institutes of Health Research and the Health for Life Initiative at the University of Guelph. None
of the organizations had any role in the project design, data collection, analyses, interpretation of
data or writing of the manuscript.

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**Data sharing:** The GFHS welcomes external collaborators. Interested investigators can contact
GFHS investigators to explore this option, which preserves participant confidentiality and meets
the requirements of our research ethics board, to protect human subjects. Owing to research ethics
board restrictions, we do not make participant data publicly available.

**Acknowledgements:** The authors acknowledge Wellington-Dufferin-Guelph Public Health and
the Guelph Family Health Team for their collaborative support of this work.
### Tables and Figures:

**Table 4.1**

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>No. (%)†</th>
</tr>
</thead>
<tbody>
<tr>
<td>Household income, Can$</td>
<td></td>
</tr>
<tr>
<td>Did not answer</td>
<td>3 (4)</td>
</tr>
<tr>
<td>&lt; 39 000</td>
<td>5 (6)</td>
</tr>
<tr>
<td>40 000–49 999</td>
<td>6 (8)</td>
</tr>
<tr>
<td>50 000–59 999</td>
<td>5 (6)</td>
</tr>
<tr>
<td>60 000–69 999</td>
<td>5 (6)</td>
</tr>
<tr>
<td>70 000–79 999</td>
<td>6 (8)</td>
</tr>
<tr>
<td>80 000–89 999</td>
<td>10 (13)</td>
</tr>
<tr>
<td>90 000</td>
<td>37 (48)</td>
</tr>
<tr>
<td>Parent education</td>
<td></td>
</tr>
<tr>
<td>Postgraduate training or degree</td>
<td>32 (42)</td>
</tr>
<tr>
<td>University graduate</td>
<td>30 (39)</td>
</tr>
<tr>
<td>College graduate</td>
<td>7 (9)</td>
</tr>
<tr>
<td>Some university, some college or technical school</td>
<td>8 (10)</td>
</tr>
<tr>
<td>Child ethnicity</td>
<td></td>
</tr>
<tr>
<td>White</td>
<td>92 (84)</td>
</tr>
<tr>
<td>Other</td>
<td>17 (16)</td>
</tr>
<tr>
<td>Child age, yr, mean ± SD</td>
<td>3.7 ± 1.2</td>
</tr>
<tr>
<td>Child sex</td>
<td></td>
</tr>
<tr>
<td>Male</td>
<td>54 (50)</td>
</tr>
<tr>
<td>Female</td>
<td>55 (50)</td>
</tr>
</tbody>
</table>

Note: SD = standard deviation.
*Children participants (n = 109) and families (n = 77).
†Unless stated otherwise.
Figure 4.1: Percent of preschool-aged children in the GFHS pilot studies consuming free sugar

Figure 4.1: Percentages of preschool-aged children in the Guelph Family Health Study pilot studies (n = 109) consuming free sugars in the amounts of 0% to < 5%, ≥ 5% to < 10%, ≥ 10% to < 25%, and ≥ 25% of total energy.
Figure 4.2: Percent of preschool-aged children in the GFHS pilot studies consuming added sugar

Figure 4.2: Percentages of preschool-aged children in the Guelph Family Health Study pilot studies (n = 109) consuming added sugars in the amounts of 0% to < 5%, ≥ 5% to < 10%, ≥ 10% to < 25%, and ≥ 25% of total energy. Percentages do not sum to 100 because of rounding.
Table 4.2

<table>
<thead>
<tr>
<th>Food source category*</th>
<th>Type of sugar</th>
<th>% of free and added sugar intake†</th>
<th>No. (%) of children consuming the category‡</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bakery products</td>
<td>Free sugar</td>
<td>29.6</td>
<td>109 (100)</td>
</tr>
<tr>
<td></td>
<td>Added sugar</td>
<td>34.9</td>
<td>109 (100)</td>
</tr>
<tr>
<td>Sugars and sweets</td>
<td>Free sugar</td>
<td>18.8</td>
<td>84 (77)</td>
</tr>
<tr>
<td></td>
<td>Added sugar</td>
<td>22.1</td>
<td>84 (77)</td>
</tr>
<tr>
<td>Cereals and grain products</td>
<td>Free sugar</td>
<td>9.4</td>
<td>77 (72)</td>
</tr>
<tr>
<td></td>
<td>Added sugar</td>
<td>11.1</td>
<td>77 (72)</td>
</tr>
<tr>
<td>Beverages</td>
<td>Free sugar</td>
<td>23</td>
<td>77 (71)</td>
</tr>
<tr>
<td></td>
<td>Added sugar</td>
<td>10.5</td>
<td>51 (47)</td>
</tr>
<tr>
<td>Dairy products and substitutes</td>
<td>Free sugar</td>
<td>6.4</td>
<td>63 (58)</td>
</tr>
<tr>
<td></td>
<td>Added Sugar</td>
<td>7.5</td>
<td>63 (58)</td>
</tr>
<tr>
<td>Snacks</td>
<td>Free sugar</td>
<td>1.4</td>
<td>48 (44)</td>
</tr>
<tr>
<td></td>
<td>Added sugar</td>
<td>1.7</td>
<td>48 (44)</td>
</tr>
<tr>
<td>Sauces, dips and condiments</td>
<td>Free sugar</td>
<td>2.1</td>
<td>44 (40)</td>
</tr>
<tr>
<td></td>
<td>Added sugar</td>
<td>2.5</td>
<td>44 (40)</td>
</tr>
<tr>
<td>Desserts</td>
<td>Free sugar</td>
<td>4.1</td>
<td>29 (27)</td>
</tr>
<tr>
<td></td>
<td>Added sugar</td>
<td>4.7</td>
<td>28 (26)</td>
</tr>
<tr>
<td>Mixed dishes, sides and entrees</td>
<td>Free sugar</td>
<td>1.2</td>
<td>21 (19)</td>
</tr>
<tr>
<td></td>
<td>Added sugar</td>
<td>1.3</td>
<td>20 (18)</td>
</tr>
<tr>
<td>Meats, eggs and substitutes</td>
<td>Free sugar</td>
<td>0.3</td>
<td>17 (16)</td>
</tr>
<tr>
<td></td>
<td>Added sugar</td>
<td>0.3</td>
<td>17 (16)</td>
</tr>
<tr>
<td>Fruits</td>
<td>Free sugar</td>
<td>1.5</td>
<td>12 (11)</td>
</tr>
<tr>
<td></td>
<td>Added sugar</td>
<td>1.7</td>
<td>12 (11)</td>
</tr>
<tr>
<td>Other foods and beverages</td>
<td>Free sugar</td>
<td>1.1</td>
<td>10 (9)</td>
</tr>
<tr>
<td></td>
<td>Added sugar</td>
<td>1.3</td>
<td>10 (9)</td>
</tr>
<tr>
<td>Nuts and seeds</td>
<td>Free sugar</td>
<td>0.1</td>
<td>7 (6)</td>
</tr>
<tr>
<td></td>
<td>Added sugar</td>
<td>0.1</td>
<td>7 (6)</td>
</tr>
<tr>
<td>Fats, oils and vinegars</td>
<td>Free sugar</td>
<td>0.1</td>
<td>5 (5)</td>
</tr>
<tr>
<td></td>
<td>Added sugar</td>
<td>0.2</td>
<td>5 (5)</td>
</tr>
<tr>
<td>Soups</td>
<td>Free sugar</td>
<td>0.3</td>
<td>5 (5)</td>
</tr>
<tr>
<td></td>
<td>Added sugar</td>
<td>0.3</td>
<td>5 (5)</td>
</tr>
<tr>
<td>Vegetables</td>
<td>Free sugar</td>
<td>0</td>
<td>0 (0)</td>
</tr>
<tr>
<td></td>
<td>Added sugar</td>
<td>0</td>
<td>0 (0)</td>
</tr>
<tr>
<td>Fish and seafood</td>
<td>Free sugar</td>
<td>0</td>
<td>0 (0)</td>
</tr>
<tr>
<td></td>
<td>Added sugar</td>
<td>0</td>
<td>0 (0)</td>
</tr>
</tbody>
</table>

*The 17 categories were adapted from Bernstein et al.19
†Calculation for free and added sugar was completed by calculating the average of added/free sugar (grams) for 3 days for each participant in the specific category divided by total added/free sugar (grams) times 100.
‡Percent of children consuming the category: this is a calculation of the percent of participants who were included in each category. Total n = 109 preschool-aged children.
Table 4.3

<table>
<thead>
<tr>
<th>Food source category</th>
<th>Type of sugar</th>
<th>$n$</th>
<th>Mean intake (95% CI), g</th>
<th>Mean intake (95% CI), kcal</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bakery products</td>
<td>Free sugar</td>
<td>109</td>
<td>9.1 (8.0 to 10.2)</td>
<td>36.4 (36.0 to 40.8)</td>
</tr>
<tr>
<td></td>
<td>Added sugar</td>
<td>109</td>
<td>9.1 (8.0 to 10.2)</td>
<td>36.4 (36.0 to 40.8)</td>
</tr>
<tr>
<td>Sugars and sweets</td>
<td>Free sugar</td>
<td>84</td>
<td>7.5 (6.3 to 8.7)</td>
<td>30.0 (25.2 to 34.8)</td>
</tr>
<tr>
<td></td>
<td>Added sugar</td>
<td>84</td>
<td>7.5 (6.3 to 8.6)</td>
<td>30.0 (25.2 to 34.4)</td>
</tr>
<tr>
<td>Cereals and grain products</td>
<td>Free sugar</td>
<td>77</td>
<td>4.2 (3.2 to 5.1)</td>
<td>16.8 (12.8 to 20.4)</td>
</tr>
<tr>
<td></td>
<td>Added sugar</td>
<td>77</td>
<td>4.2 (3.2 to 5.1)</td>
<td>16.8 (12.8 to 20.4)</td>
</tr>
<tr>
<td>Beverages</td>
<td>Free sugar</td>
<td>77</td>
<td>10.5 (8.0 to 12.9)</td>
<td>42.0 (32 to 51.6)</td>
</tr>
<tr>
<td></td>
<td>Added sugar</td>
<td>51</td>
<td>6.5 (4.7 to 8.3)</td>
<td>26.0 (18.8 to 33.2)</td>
</tr>
<tr>
<td>Dairy products and substitutes</td>
<td>Free sugar</td>
<td>63</td>
<td>3.4 (2.8 to 4.0)</td>
<td>13.6 (11.2 to 16.0)</td>
</tr>
<tr>
<td></td>
<td>Added sugar</td>
<td>63</td>
<td>3.4 (2.8 to 4.0)</td>
<td>13.6 (11.2 to 16.0)</td>
</tr>
<tr>
<td>Snacks</td>
<td>Free sugar</td>
<td>48</td>
<td>1.0 (0.6 to 1.4)</td>
<td>4.0 (2.4 to 5.6)</td>
</tr>
<tr>
<td></td>
<td>Added sugar</td>
<td>48</td>
<td>1.0 (0.6 to 1.4)</td>
<td>4.0 (2.4 to 5.6)</td>
</tr>
<tr>
<td>Sauces, dips and condiments</td>
<td>Free sugar</td>
<td>44</td>
<td>1.6 (1.2 to 1.9)</td>
<td>6.4 (4.8 to 7.6)</td>
</tr>
<tr>
<td></td>
<td>Added sugar</td>
<td>44</td>
<td>1.6 (1.2 to 1.9)</td>
<td>6.4 (4.8 to 7.6)</td>
</tr>
<tr>
<td>Desserts</td>
<td>Free sugar</td>
<td>29</td>
<td>4.7 (3.6 to 5.9)</td>
<td>18.8 (14.4 to 23.6)</td>
</tr>
<tr>
<td></td>
<td>Added sugar</td>
<td>28</td>
<td>4.8 (3.6 to 6.0)</td>
<td>19.2 (14.4 to 24)</td>
</tr>
</tbody>
</table>

Note: CI = confidence interval.
*Key food sources were defined based on those categories that were consumed by at least 25% of the preschool-aged children in the pilot studies.

Table 4.4

<table>
<thead>
<tr>
<th>Type of sugar</th>
<th>Body weight (kg)$\uparrow$</th>
<th>BMI Z-scores</th>
<th>Waist circumference (cm)$\uparrow$</th>
<th>Fat mass (%)$\uparrow$</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$\beta$ (95% CI)</td>
<td>$\beta$ (95% CI)</td>
<td>$\beta$ (95% CI)</td>
<td>$\beta$ (95% CI)</td>
</tr>
<tr>
<td>Added sugar</td>
<td>-0.01 (-0.03 to 0.007)</td>
<td>-0.005 (-0.01 to 0.002)</td>
<td>-0.02 (-0.05 to 0.008)</td>
<td>-0.001 (-0.03 to 0.03)</td>
</tr>
<tr>
<td>Free sugar</td>
<td>-0.011 (-0.02 to 0.002)</td>
<td>-0.004 (-0.008 to 0.0006)</td>
<td>-0.02 (-0.04 to -0.009)</td>
<td>-0.003 (-0.03 to 0.02)</td>
</tr>
<tr>
<td>Total sugar</td>
<td>-0.004 (-0.01 to 0.006)</td>
<td>-0.001 (-0.005 to 0.002)</td>
<td>-0.009 (-0.02 to 0.007)</td>
<td>0.0009 (-0.02 to 0.02)</td>
</tr>
</tbody>
</table>

Note: BMI = body mass index.
*Units for added sugar, free sugar and total sugar are normalized to kcal/1000 kcal.
$\uparrow$Data have been presented controlling for age and sex for body weight, waist circumference and percent fat mass.
Table 4.5: National and global recommendations for free and added sugar intakes for children

<table>
<thead>
<tr>
<th>Organization</th>
<th>Free Sugar or Added Sugar Recommendations for Children</th>
</tr>
</thead>
<tbody>
<tr>
<td>World Health Organization, 2015 (WHO, 2015)</td>
<td>“WHO recommends reducing the intake of free sugars to less than 10% of their total energy intake (strong recommendation). WHO suggests a further reduction to below 5% would provide additional health benefits (conditional recommendation).”</td>
</tr>
<tr>
<td>Health Canada, 2019 (GC, 2019)</td>
<td>“Free sugars: Less than 10% of total energy”</td>
</tr>
<tr>
<td>American Heart Association-Scientific update, 2017 (Vos et al., 2017)</td>
<td>“Recommend that children consume ≤25 g (100 kcal or ≈6 teaspoons) of added sugars per day for children and to avoid added sugars for children &lt;2 years of age.”</td>
</tr>
<tr>
<td>Heart and Stroke Foundation of Canada, 2014 (HSF, 2014)</td>
<td>“In both adults and children, intake of free sugars not exceed 10% of total energy (strong recommendation). Further reduction to below 5% of total energy (conditional recommendation)”</td>
</tr>
<tr>
<td>Dietary Guidelines for Americans 2015-2020 (DGA, 2015)</td>
<td>“Consume less than 10 percent of calories per day from added sugars”</td>
</tr>
<tr>
<td>Institute of Medicine, 2005 (IOM, 2005)</td>
<td>“Although there were insufficient data to set a UL for added sugars, a maximal intake level of 25 percent or less of energy is suggested to prevent the displacement of foods that are major sources of essential micronutrients”</td>
</tr>
</tbody>
</table>
4.8 Chapter Appendix:

The Guelph Family Health Study (GFHS) is a longitudinal family-based cohort study designed to identify early life risk factors for chronic disease and to identify effective family-based health promotion strategies (Haines et al., 2018). Participants were recruited using posters and rack cards displayed at local family health team clinics and early childhood education centres as well as posts to these agencies’ websites and Facebook accounts. Families were eligible to participate if they had at least one child between 18 months and 5 y of age at the time of registration for the study, lived within the Guelph-Wellington area in Ontario and if one parent was comfortable responding in English to complete study questionnaires. The GFHS began with two pilot phases (phases 1 and 2), which started in 2014 and 2015, respectively, in advance of the launch of the full-scale study. A total of n=83 families, n= 117 preschool-aged children were enrolled at baseline in the GFHS pilots. Families were given grocery gift card incentives in recognition of their participation. Parents provided informed, written consent at their initial study visit for themselves and their children. Child dietary data were gathered using paper-based 3-day food records completed in detail by the parents. Anthropometric assessment data was measured by trained research staff including waist circumference, body fat, weight and height. The GFHS pilot studies are still ongoing and have helped inform and implement changes for the full study that began in 2017. Currently, the full GFHS study includes 246 families at baseline. Please refer to the study website for further details: https://guelphfamilyhealthstudy.com/.
CHAPTER 5: RATIONALE

The findings of Study 2 (Chapter 4), based on the cross-sectional data analysis of the GFHS pilot study, showed that young children are exceeding WHO recommendations for free sugar intake and are consuming refined sugars from a variety of food sources, rather than SSB. However, total, free and added sugar intake in young children was not associated with anthropometric data. These findings raised questions regarding the need for a long-term follow-up.

Thus, Study 3 (Chapter 5) was initiated, to examine whether the sugar intake of children at baseline was not associated with children’s anthropometric data longitudinally over 18 months. The results of this study will contribute to the existing knowledge on the long-term role of sugar intake on the growth and development of young children.
CHAPTER 5

Study 3: Dietary sugar and anthropometrics among young children in the Guelph Family Health Study: Longitudinal associations

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Alison M. Duncan PhD, RD
Gerarda Darlington PhD
Jess Haines PhD, RD
David W.L. Ma PhD
Andrea C. Buchholz PhD, RD
on behalf of the Guelph Family Health Study

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3Guelph Family Health Study, University of Guelph
4Department of Mathematics and Statistics, University of Guelph

This chapter has been submitted to the Canadian Journal of Dietetic Practice and Research and is under review. The chapter has been formatted for references and table/figure numbers for this dissertation for consistency.
5.1 ABSTRACT

Purpose: Our understanding of the influence of sugar intake on anthropometrics among young children is limited. Most existing research is cross-sectional and has focused on sugar-sweetened beverages. The study objective was to investigate longitudinal associations between young children’s total, free and added sugar intake from all food sources at baseline with anthropometric measures at baseline and 18 months.

Methods: The Guelph Family Health Study (GFHS) is an ongoing randomized controlled trial and a family-based health promotion study. Food records and anthropometric data were collected at baseline (n=109, 55 males; 3.7 ± 1.1 y, mean ± SD) and 18 months (n=109, 55 males; 5.1 ± 1.1 y) of the GFHS pilots. Associations between sugar intakes and anthropometrics were estimated using linear regression models with generalized estimating equations adjusted for age, sex, household income and intervention status.

Results: Total sugar intake was inversely associated with body weight at 18 months (P = 0.01). There was no effect of time on any other associations between total, free and added sugar intakes and anthropometrics.

Conclusions: Early life dietary sugar intakes may not relate to anthropometric measures in the short term. Further investigation into potential associations between dietary sugar intakes and anthropometric variables over longer time periods is warranted.
5.2 INTRODUCTION

In 2017, the Government of Canada reported that 30% of children between the ages of 5 and 17 years were overweight or obese (GC, 2018). Childhood obesity rates have tripled in the last 30 years (GC, 2018). Being overweight or obese can increase the risk of chronic disease development, increase healthcare costs and decrease quality of life (Rao, Kropac et al., 2016). Thus, a multipronged approach for a complex issue such as childhood obesity is needed to establish effective interventions for prevention. The World Health Organization (WHO) recommends limiting free sugar intake, as excessive consumption remains a public health concern in several countries (WHO, 2015). Dietary sugar intake above the WHO guidelines in school-aged children may increase risk of obesity and dental caries (Keller & Bucher Della Torre, 2015; WHO, 2015). Excessive sugar intake can also impact diet quality and lead to nutritional inadequacies (WHO, 2015). Early life interventions such as limiting free and added sugar intakes in preschool-aged children can contribute to reducing the risk of obesity and chronic disease as well as dental caries later in life (Keller & Bucher Della Torre, 2015).

Dietary sugar intake in children can be influenced by many factors including genetics, maternal and cultural factors as well as by food supply availability and globalization (Fidler Mis et al., 2017; Malik, Willett et al., 2013). Examining sugar intake patterns of young children is critical as dietary patterns become established at a young age and can extend into adulthood (Ricciuto et al., 2022). Furthermore, overconsumption of sugar intake in early childhood can lead to the intake of “empty” calories leading to weight gain and displacement of nutrient-dense foods associated with high sugar intake (DC, 2016). Excessive free and added sugar intakes may also predispose children to the development of non-alcoholic fatty liver disease and cardiometabolic risk markers such as increases in triglycerides, systolic blood pressure, insulin, cholesterol, waist
circumference and C-reactive protein (Herrick et al., 2020; Leermakers et al., 2015; Skinner et al., 2015). Moreover, added sugars (processed) are present in large quantities in packaged foods in the Canadian food supply (Acton, Vanderlee et al., 2017).

Several gaps and limitations exist in the literature on sugar intake, including limited research studies in young children in the Canadian context along with differing study methodologies, definitions of sugar, and underreporting of food intake (Davis & Lee, 2014; Khan & Sievenpiper, 2016). Many studies have found positive associations between sugar intake and body weight while others have found no significant association (Davis & Lee, 2014; Khan & Sievenpiper, 2016) [13,14]. The gaps could be attributed to the limitations cross-sectional studies and compounded by the fact that most studies have focused on sugar-sweetened beverages (SSB) (Mahajan et al., 2021; Vos et al., 2017) which have consistently been demonstrated to cause weight gain in children and adolescents (aged 2 to 16 y) (Malik et al., 2013). Contrary to above, a systematic review has indicated that randomized controlled trials (in children) aimed to limit sugar intake, have not led a significant change in body weight (Te Morenga, Mallard et al., 2012). These contradictory results from different studies make it important to investigate longitudinal associations between dietary sugar intake and anthropometric measures.

A cross-sectional study from the Guelph Family Health Study (GFHS) has previously identified that 80% of the 109 enrolled preschool-aged children exceeded the 5% free sugar intake recommendation set by the WHO and 32% exceeded the 10% recommendation (Mahajan et al., 2021). Further analysis demonstrated a weak inverse but statistically significant cross-sectional association between energy-adjusted free sugar intake and waist circumference (Mahajan et al., 2021). The primary objective of the current study was to extend these findings by examining longitudinal associations between baseline intakes of total, free and added sugars and
anthropometric measures (body weight, BMI Z-scores, percent fat mass and waist circumference) at 18 months among young children (aged 1.5 to <8 y) in the GFHS pilot studies.

5.3 METHODS

5.3.1 Study Design, Participants and Recruitment

The current study is a secondary data analysis of longitudinal data of sugar intake at baseline and anthropometric measurements at baseline and 18-month time points of the Guelph Family Health Study (GFHS) pilots. The GFHS is a family-based cohort and health promotion study initiated in 2014 at the University of Guelph, Ontario, Canada (Haines et al., 2018)[18]. The GFHS includes families with at least one child aged 1.5 to 5 years, who were not relocating within the next year, and who have English as their primary language (Haines et al., 2018) [18]. Families were recruited from September 2014 to December 2016 for the baseline study. Follow-up study measures, including health assessments, were completed from March 2016 to March 2019. Families were enrolled if they were living in the Guelph-Wellington areas through Family Health Teams, Community Health Centres and Ontario Early Years Centres (Haines et al., 2018). Participants were recruited using social media channels such as the University of Guelph and GFHS websites (Haines et al., 2018). Participants were initially enrolled into the GFHS pilot studies before the full GFHS began (Haines et al., 2018). Sample characteristics at study baseline have been reported elsewhere (Mahajan et al., 2021). Families in the GFHS were randomized to either an intervention (behaviour change goals along with either 2 or 4 home visits with a health educator, emails and mailed incentives) or a control group (general health advice through emails) (Haines et al., 2018). The current study included intervention or control as a covariate, particularly since one of the behaviour change goals was to limit SSB intake, although SSB intake did not significantly differ between the intervention and control groups (Haines et al., 2018). The study
was approved by the University of Guelph Research Ethics Board (REB #14AP009). Participants’ parents or guardians provided consent for their child(ren)’s participation.

5.3.2 Study Measures

5.3.2.1 Predictor Variables

5.3.2.1.1 Dietary Assessment

Dietary assessment was completed at baseline by parents for their child(ren) using 3-day food records. The food records were paper based on which parents were instructed to record their child(ren)’s food and drink intake for 3 non-consecutive days, including amount, description including product brand names, and recipes for mixed foods. Food record data were entered into the ESHA Food Processor software (Version 11.6.441, Salem, OR, 2015) for analysis of 3-day average energy and nutrient intakes.

5.3.2.1.2 Total, Free and Added Sugar Intake Calculations

Added and free sugar intakes were determined through manual calculations and review of product and SMART LABEL websites for data extracted from ESHA and 3-day averages of the total, free and added sugar intake. This study adapted the algorithm of Louie and colleagues (Louie et al., 2015) that included a stepwise approach to calculate added sugar (including honey and syrups) and free sugar (including foods with added sugar and 100% fruit juice and concentrates) content. While this definition of added sugar differs from that of the WHO, this calculation has been used in other studies that investigated free sugar intake in preschool-aged children (Devenish et al., 2019; Mahajan et al., 2021). These calculations were performed manually as this information is limited in food composition databases and were independently reviewed by two research analysts to ensure data quality.

5.3.2.2 Outcome Variables
Outcome variables included anthropometric measures completed at baseline and 18 months follow-up by trained research staff. Participants were measured standing unless otherwise noted, and without footwear and outer garments.

5.3.2.2.1 Waist circumference (WC)

WC was measured in cm during mid-respiration at the top of the iliac crest of participants’ bare abdomen, using a non-elastic tape measure (Gulick II™, Country Technology Inc., Gay Mills, Wisconsin). WC was measured in duplicate; if the values were within 0.5 cm, a mean value was calculated. Otherwise, a third measurement was taken and the mean of the two closest values was calculated.

5.3.2.2.2 Height, body weight and BMI Z-scores

Height was measured in cm in duplicate, using a child stadiometer. If the two values were within 0.5 cm, a mean value was calculated. Otherwise, a third measurement was taken and the mean of the two closest values was calculated. Body weight (kg) was measured using a BOD POD™ electronic weighing scale, to 3 decimal places. BMI Z-scores were calculated using WHO Anthro™ or WHO AnthroPlus™ using the R package zscorer (Myatt & Guevarra, 2019).

5.3.2.2.3 Percent fat mass

Body composition was measured using bioelectrical impedance analysis (BIA, Quantum IV BIA Analyzer System, RJL Systems, Clinton Township, MI, USA). Participants were measured supine, with electrodes in tetrapolar configuration, and arms and legs abducted 30 degrees from midline. Participants were instructed to avoid food, drink and vigorous physical activity for 30 minutes prior to the measurement. Resistance was measured in duplicate; if measures differed by more than 5%, a third measure was taken, and the average of the two closest measures were used. Inter-rater and intra-rater reliability were 0.79 and 0.99, respectively. BIA-derived resistance
values were used to calculate total body water, using the equation of Kushner et al (Kushner et al., 1992). Total body water was then divided by an age- and gender-specific hydration constant to determine fat-free mass (Fomon et al., 1982). Percent fat mass was then calculated as [(body weight – fat-free mass)/body weight] *100%.

5.3.2.3 Covariates

Parents reported child age, sex and family’s household income. For the outcome variables including percent fat mass and BMI Z-scores, which already account for age and sex, models were controlled for only household income. Study group (intervention or control) was also included as a covariate.

5.3.3 Missing Data

Participants were included in the analytic sample if they had a complete 3-day food record and if breastfeeding did not replace a meal. Thus, of the 117 participants (from 83 families), 109 participants (from 77 families) were included in the analysis. At 18 months follow-up, there was missing data for body weight measures and BMI Z-scores for 24 participants (22%), waist circumference for 23 participants (21%) and percent fat mass there for 25 participants (23%), for a final analytic sample of 84 to 86 participants (depending on the variable). Participants with missing data were not significantly different from those with complete data with respect to age, sex and household income.

5.3.4 Statistical Analysis

Total, free and added sugar intakes, predictor variables, were normalized to grams (g) per 1000 kcal/day. For the data analysis, linear regression models used generalized estimating equations (GEE) to estimate associations between total, free and added sugar and anthropometric measures and adjusted for age, sex, household income and intervention for the outcomes of body
weight and waist circumference variables. For the outcome variables including percent fat mass and BMI Z-scores, which already account for age and gender, models were controlled for only household income and study group. The GEE approach is used to account for any dependence between sibling participants (Liang & Zeger, 1986). For this study data analysis, R (RCoreTeam, 2022) was used within RStudio 2021.09.0 Build 351 Version 3, Posit Software, PBC Boston, MA.

5.4 RESULTS

The final analytic sample for baseline and at 18 months was 109 (55 females, 54 males) from 77 families as seen in Figure 5.1. The average age at baseline was 3.7 ± 1.2 (SD) years and 5.59 ± 1.3 years at 18 months. The majority (84%) of participants identified as white; 48% of the families had an annual household income greater than $90,000 and 42% of the one of the parents had a postgraduate education. This has also been described in Table 1 of this study and elsewhere in detail 5.4.2. Among these children, 69% (n=73) were classified as normal or underweight (BMI Z-scores <1) and 31% (n=33) as overweight (BMI Z-scores >1).

5.4.1 Sugar intake and anthropometric measures

As reported in a previous study, sugar intakes at baseline (mean (g) ± SD/day) were 86 ± 26 (21.5 teaspoons) for total sugars, 31 ± 15 (7.75 teaspoons) for free sugars and 26 ± 13 (6.5 teaspoons) for added sugars (Mahajan et al., 2021). Anthropometric values are presented in Table 5.1.

5.4.2 Longitudinal associations between sugar intakes and anthropometric measures

There were no significant associations between sugar intake at baseline and at 18 months for total, free and added sugar intakes and body weight, waist circumference, BMI Z-scores and percent fat mass, except for the association between total sugar and body weight (interaction P=0.01). For every kcal increase in total sugar at baseline there was a decrease in body weight at 18
months of 0.017 kg (P=0.04; 95% CI= -0.03 to -0.001). Overall associations are reported in Table 5.2 in addition to the time-dependent (baseline and 18 months) associations for total sugar and weight. The data were further stratified by sex and baseline weight status to examine the potential role of subgroups; however, results did not differ from the initial analyses (data not shown).

5.5 DISCUSSION

This study examined longitudinal associations between dietary intakes of total, free and added sugar at baseline with anthropometric measures (percent fat mass, weight, waist circumference and BMI Z-scores) at baseline and 18 months for children between the ages of 1.5 and <8 y. Except for a small but statistically significant inverse association between total sugar intake at baseline and body weight at 18 months, we did not find any significant associations between total, free and added sugar intakes and anthropometric measures at either baseline or 18 months in young children.

There may be varied reasons for the absence of associations between total, free and added sugars and anthropometric measures including body weight, waist circumference, percent fat mass and BMI Z-scores. At this young age and period of rapid growth, dietary patterns differing in macronutrient composition may have varied influence on growth. Thus, these findings highlight the challenge of discerning the specific contribution of sugar on anthropometric outcomes in tandem with this rapid growth phase. Similar to our study, other research has found no significant associations between dietary sugar intake and anthropometric measures in children. For instance, a cross-sectional data analysis of the National Health and Nutrition Examination Survey (NHANES) (1971 to 1975; 1988 to 1994) enrolled children (n=20,000) aged 1 to 18 y and found no significant associations between total and added sugar intakes and BMI (Song et al., 2012). This study determined that total energy intake had the greatest impact on children’s BMI (Song et
al., 2012). Also, the NHANES data from 1999 to 2002 for children aged 2 to 5 years (n=1160) did not find any association between BMI and SSB intake (O'Connor et al., 2006). Another study in n=1345 children in the North Dakota Special Supplemental Nutrition Program for Women, Infants, and Children group found no significant association between SSB consumption and changes in weight and BMI at 6 months and 12 months follow-up (Newby et al., 2004). The lack of significant associations in these studies could be due to differing anthropometry methodology and/or use of self-reported dietary data. As well, it may be that parents of children who are overweight and obese may restrict their children’s intake of sugar as reported in other research studies (Drouin-Chartier, Zheng et al., 2019; Yin, Zhu et al., 2021). Thus, there is the potential for reverse causation. Further long-term studies which address these methodological shortcomings are needed.

In contrast to the results in the aforementioned studies, there is a concern that consumption of sugar above the WHO guidelines can contribute to increased body weight and BMI in young children. A cross-sectional study investigated the association between SSB (specifically packaged juices, including fruit drinks and fruit juices, and soft drinks) intake and weight in obese children (n=1823) aged 4 to 5 years (Gonzalez-Palacios et al., 2019). This study found a high prevalence of obesity ranging from 5.9% to 9.3% within the study cohort that was mostly mediated by the intake of packaged juices (P=0.03) (Gonzalez-Palacios et al., 2019). Children who consumed >1 serving (1 serving=175mL/6fl oz) of SSB (both packaged juices and soft drinks) per day had a significantly higher prevalence of obesity (OR=3.23; 95% CI 1.48-6.98) (Gonzalez-Palacios et al., 2019).

Most of the longitudinal research on dietary sugar intake has focused on SSB as the main source of free and added sugar for young children. A longitudinal study conducted in Québec, Canada found that children between the ages of 2.5 and 3.5 years (n=2,103) consuming more SSB
were at higher risk of being overweight at 4.5 years (Dubois et al., 2007). Another longitudinal study from the United States, examined intake of SSB of children (n=1189) from infancy to 6 years in relation to the prevalence of obesity in these children with advancing age (Pan et al., 2014). This study found that infants exposed to SSB were twice as likely to be obese at 6 y of age when compared with infants who were not exposed to SSB (Pan et al., 2014). It was also noted that the likelihood of consuming SSB at age 6 years was 71% higher for those children with any consumption of SSBs and 92% higher for SSB intake before 6 months of age (Pan et al., 2014). Added sugars from baked goods, sweets and spreads, sweetened dairy products, consumed in excess in the first two years of life were associated with an increased BMI at age 7 y in a subset of the longitudinal Dortmund Nutritional and Anthropometric Longitudinally Designed study (n=216; 111 boys and 105 girls) (Herbst et al., 2011). Similar results were seen in the Early Childhood Longitudinal Birth-Cohort study, where SSB intake in children aged 2 to 5 y were examined (DeBoer et al., 2013). This study showed that children with a higher BMI Z-score at age 4 or 5 years, but not at 2 years, had increased SSB intake (DeBoer et al., 2013). Another study by Lim and colleagues, of low-income Black preschool aged children (n=365) between the ages of 3 to 5 years, suggested that increased SSB intake was linked to higher odds of being overweight over 2 years (Lim, Zoellner et al., 2009). Thus, these studies suggest that there is a link between added sugars and SSB intake in early childhood with an increase in weight and BMI in later childhood.

Considered together, these cross-sectional and longitudinal studies demonstrate inconsistent findings in this research area, likely due to the young age of children who are still growing. Nevertheless, longitudinal studies suggest an association between sugar intake and anthropometric outcomes, thus highlighting the need for longer multiyear follow-up.
5.5.1 Study Strengths and Limitations

Although this study is novel and adds to the limited longitudinal research studies on dietary sugar intake in young children, certain strengths and limitations should be considered. Sugar intake and weight status of the children in the present study are comparable to other Canadian studies (Birken, Tu et al., 2017; Biro, Barber et al., 2016; Mahajan et al., 2021). However, the study results may not be generalizable to diverse and low socioeconomic populations. Parent-reported food records may have underreporting errors along with social desirability bias. This was also a small study; thus, further replication is needed in a larger cohort. We did not adjust for physical activity; this may be a limitation as physical activity may counteract the sugar impact on body weight. Sugar intake in this study was manually inspected and calculated using the algorithm of Louie and colleagues (Louie et al., 2015) due to limitations of nutritional databases. This adds confidence in our measures of sugar intake.

5.6 Relevance to practice

There are many negative consequences with excessive sugar consumption and so this remains a concern for young children in Canada. While this study did not find clinically significant associations between sugar intake at baseline and anthropometric measures after 18 months of follow-up, there are many established consequences associated with excessive sugar intake. Dietitians working in pediatrics should continue to recommend limiting children’s intake of free sugar from all food sources and should support families to identify ways to replace foods high in free sugar, including highly processed snack foods, with nutrient-dense foods low in free sugar.
5.7 ACKNOWLEDGEMENTS:

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Short title: Dietary sugar and anthropometrics among young children.

Key word(s): dietary sugar, free sugar, total sugar, added sugar, preschool-aged children, BMI Z-scores, body weight, waist circumference, percent fat mass.

Financial Support(s): Funding for this project provided by Canadian Foundation for Dietetic Practice and Research, Canadian Institutes of Health Research and Health for Life Initiative at the University of Guelph; however, none of the organizations had any role in the project design, data collection, analyses, interpretation of data, or writing of the manuscript.

Acknowledgements: All the authors would like to extend their thanks and gratitude to the participating families, the research team of the Guelph Family Health Study, and to Angela Annis, Madeline Nixon, Jessica Yu, Alex Carriero, Jaimie L. Hogan, Adam Sadowski and Sabrina Douglas for their support in facilitating this research. The authors acknowledge Wellington-Dufferin-Guelph Public Health and the Guelph Family Health Team for their collaborative support of this work.

Conflict of interest statement: The authors declare that there are no competing interests.

Author contributions: AM was the co-Principal Investigator and conceptualized the sub-study, reviewed the data, completed the analysis and wrote the manuscript. ACB was the co-Principal Investigator for this sub-study and supervised the anthropometric data collection for the study. DWLM and JH are the Co-Directors of the GFHS, and conceptualized and supervised this
project. GD was the statistical advisor. AMD supervised the dietary data collection and analysis. All authors reviewed and revised this manuscript.

**Institutional Review Board Statement:** The study was approved by the Institutional Review Board (or Ethics Committee) of University of Guelph Research Ethics Board (REB#14AP009).

**Informed Consent Statement:** Informed consent was obtained from all subjects involved in the study.

**Data availability:** The GFHS welcomes external collaborators. Interested investigators can contact GFHS investigators to explore this option, which preserves participant confidentiality and meets the requirements of our Research Ethics Board, to protect human subjects. Due to Research Ethics Board restrictions, we do not make participant data publicly available.
Figure 1: Participant flow chart

Eligibility criteria reviewed:
Pilot 1
- Families ineligible
  - Did not have children in target: 1
  - Planning to move: 1
- Active Decline (declined to schedule Home Visit)
- Passive Decline (Families did not schedule Health Assessment Visit)
- Family discontinued due to family illness
Pilot 2
1 - Passive Decline (invited but did not schedule a Home Visit)
1 - Passive Decline (invited but did not schedule a Health Assessment Visit)

Participants excluded (from both pilots):
4 - Incomplete food records
4 - Breast fed participants

Table 5.1: Anthropometric measures and demographics at baseline and at 18 months (n=109, mean ± standard deviation)

<table>
<thead>
<tr>
<th>Anthropometric measure</th>
<th>Baseline</th>
<th>18 months</th>
</tr>
</thead>
<tbody>
<tr>
<td>Body weight (kg)</td>
<td>16.2 ± 3.6</td>
<td>20.3 ± 5.1</td>
</tr>
<tr>
<td>Waist circumference (cm)</td>
<td>50.8 ± 4.6</td>
<td>53.5 ± 5.0</td>
</tr>
<tr>
<td>Percent fat mass (%)</td>
<td>29.8 ± 5.2</td>
<td>27.5 ± 6.2</td>
</tr>
<tr>
<td>BMI Z-scores</td>
<td>0.6 ± 1.0</td>
<td>0.1 ± 0.8</td>
</tr>
<tr>
<td>Demographics</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Age (years)</td>
<td>3.7 ± 1.2</td>
<td>5.6 ± 1.3</td>
</tr>
<tr>
<td>Child sex (No./%)</td>
<td>Male = 54 (50)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Female =55 (50)</td>
<td></td>
</tr>
<tr>
<td>Child ethnicity (No./%)</td>
<td>White = 92 (84)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Other = 17 (16)</td>
<td></td>
</tr>
</tbody>
</table>
### Household Income (Canadian) (No./%)

<table>
<thead>
<tr>
<th>Category</th>
<th>No.</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Did not answer</td>
<td>3</td>
<td>(4)</td>
</tr>
<tr>
<td>&lt;$39,000</td>
<td>5</td>
<td>(6)</td>
</tr>
<tr>
<td>$40,000-$49,999</td>
<td>6</td>
<td>(8)</td>
</tr>
<tr>
<td>$50,000-$59,999</td>
<td>5</td>
<td>(6)</td>
</tr>
<tr>
<td>$60,000-$69,999</td>
<td>5</td>
<td>(6)</td>
</tr>
<tr>
<td>$70,000-$79,999</td>
<td>6</td>
<td>(8)</td>
</tr>
<tr>
<td>$80,000-$89,999</td>
<td>10</td>
<td>(13)</td>
</tr>
<tr>
<td>&gt;$90,000</td>
<td>37</td>
<td>(48)</td>
</tr>
</tbody>
</table>

### Parent Education (No./%)

<table>
<thead>
<tr>
<th>Category</th>
<th>No.</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Postgraduate training or degree</td>
<td>32</td>
<td>(42)</td>
</tr>
<tr>
<td>University graduate</td>
<td>30</td>
<td>(39)</td>
</tr>
<tr>
<td>College graduate</td>
<td>7</td>
<td>(9)</td>
</tr>
<tr>
<td>Some university, some college or technical school</td>
<td>8</td>
<td>(10)</td>
</tr>
</tbody>
</table>

---

**Table 5.2: Associations between sugar intakes and anthropometric measures at baseline and 18 months (n=109)**

<table>
<thead>
<tr>
<th>Type of sugar*</th>
<th>β</th>
<th>SE</th>
<th>P-value</th>
<th>95% CI low</th>
<th>95% CI high</th>
</tr>
</thead>
<tbody>
<tr>
<td>Free sugar and fat percent</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Adjusted FS (kcal)</td>
<td>-0.022</td>
<td>0.014</td>
<td>0.120</td>
<td>-0.050</td>
<td>0.006</td>
</tr>
<tr>
<td>Free sugar and body weight**</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Adjusted FS (kcal)</td>
<td>-0.019</td>
<td>0.010</td>
<td>0.045</td>
<td>-0.038</td>
<td>0.000</td>
</tr>
<tr>
<td>Free sugar and waist circumference**</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Adjusted FS (kcal)</td>
<td>-0.024</td>
<td>0.014</td>
<td>0.076</td>
<td>-0.051</td>
<td>0.003</td>
</tr>
<tr>
<td>Free sugar and BMI Z-scores</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Adjusted FS (kcal)</td>
<td>-0.003</td>
<td>0.002</td>
<td>0.177</td>
<td>-0.007</td>
<td>0.001</td>
</tr>
<tr>
<td>Added sugar and fat percent</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Adjusted AS (kcal)</td>
<td>-0.036</td>
<td>0.019</td>
<td>0.056</td>
<td>-0.073</td>
<td>0.001</td>
</tr>
<tr>
<td>Added sugar and body weight**</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Adjusted AS (kcal)</td>
<td>-0.017</td>
<td>0.012</td>
<td>0.162</td>
<td>-0.041</td>
<td>0.007</td>
</tr>
<tr>
<td>Added sugar and waist circumference**</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Adjusted AS (kcal)</td>
<td>-0.023</td>
<td>0.017</td>
<td>0.178</td>
<td>-0.057</td>
<td>0.011</td>
</tr>
<tr>
<td>Added sugar and BMI Z-scores</td>
<td></td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Adjusted AS (kcal)</td>
<td>-0.004</td>
<td>0.002</td>
<td>0.109</td>
<td>-0.009</td>
<td>0.001</td>
</tr>
</tbody>
</table>

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93
<table>
<thead>
<tr>
<th></th>
<th>Adjusted TS (kcal)</th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Total sugar and body weight</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Baseline Adjusted TS (kcal)</td>
<td>-0.004 0.005 0.381 -0.013 0.005</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>18 month Adjusted TS (kcal)</td>
<td>-0.017 0.009 0.042 -0.034 -0.001</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Total sugar and waist circumference</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Adjusted TS (kcal)</td>
<td>-0.016 0.009 0.078 -0.033 0.002</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Total sugar and BMI Z-scores</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Adjusted TS (kcal)</td>
<td>-0.002 0.002 0.226 -0.005 0.001</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

BMI= body mass index, CI= Confidence Interval
FS= Free sugar, AS=Added sugar, TS = Total sugar
*Units for total, free and added sugar were normalized to kcal/1000 kcal.
**Data are presented controlling for age, sex, household income and intervention variable for body weight and waist circumference.
CHAPTER 6: RATIONALE

So far, this thesis has presented a unique examination on total, free and added sugar intake in young children in Canada in 3 studies (Chapters 3-5). In the last study of this thesis, the focus shifts to investigating alternatives to sugar intake in young children, particularly NNS, within the GFHS pilot cohort. This study was prompted by concerns related to sugar intake by parents that may lead to consumption of NNS as a perceived healthier alternative.

This study was undertaken to gain an in-depth understanding of current consumption patterns and types of NNS intake in young children including the types of NNS consumed and the food sources from which they are derived. Currently, there is limited research available on NNS intake and its potential health impacts in young children. Moreover, the food supply has seen an increase in the availability of NNS containing products often with reduced NNS information on food packages. Also, parents have received limited education on NNS intake in young children.

Considering these factors, it is crucial to investigate NNS consumption patterns and monitor them for young children in the Canadian context. By gaining insights into the usage and sources of NNS in this population, researchers can contribute to filling the existing knowledge gaps surrounding NNS intake and its potential for health of young children.
CHAPTER 6

Study 4: Non-nutritive sweetener intake is low in preschool-aged children in the Guelph Family Health Pilot Study

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Alex Carriero¹
Jaimie L. Hogan¹
Jessica Yu¹
Andrea C. Buchholz²
Alison M. Duncan¹
Gerarda Darlington³
David W.L. Ma ¹,*
and on behalf of the Guelph Family Health Study

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This chapter has been published in the Nutrients journal, presented here with permission and references and table/figure numbers are formatted for this dissertation for consistency.

6.1 Abstract:

There is limited research on the intake of non-nutritive sweeteners (NNS) among preschool-aged children. Canada’s Food Guide suggests limiting intake of NNS for all population groups and Health Canada recommends that young children (<2 y) avoid consuming beverages containing NNS. Our study aimed to investigate intake patterns through frequency and type of NNS intake from different food sources in preschool-aged children participating in the Guelph Family Health Study (GFHS) pilots. Parents (n=78 families) completed 3-day food records describing their children’s food and beverage intake (n=112 children; n=55 females, n=57 males; 3.6 y ± 1.3). Food records were reviewed by trained staff to examine NNS intake and types. Results showed limited consumption of NNS with 17% of the children (n=19) reported consumption of foods or beverages containing NNS (range: 1 to 3 food or beverage items per food record). Food sources with NNS included: freezies, beverages (such as oral nutritional supplements, flavored water and carbonated drinks), sugar free jam and protein powder. The majority of NNS contained in these foods were identified as stevia leaf extract, acesulfame K, sucralose, monk fruit extract and aspartame. Canadian preschool-aged children are consuming foods that contain NNS starting at a young age, although intakes are low. This study helps to elucidate NNS intake among preschool-aged children in Canada. Future research should continue to study NNS intake patterns longitudinally in children and examine the association of NNS intake with diet quality and health outcomes.

Keywords:

preschool, children, non-nutritive sweeteners

Novelty bullet:

• This is the first study to investigate intake frequency and types of non-nutritive sweeteners in Canadian preschool-aged children.
6.2 Introduction:

Non-nutritive sweeteners (NNS), defined as alternatives to sucrose or high fructose corn syrup, are extracted from natural sources and provide low to no calories (GC, 2010; Gil-Campos et al., 2015). These are known by different names such as “low-calorie sweeteners”, “sugar substitutes”, “artificial sweeteners” or “non-nutritive sweeteners” (AHS, 2020; GC, 2010). Canada’s Food Guide recommends limiting intake of NNS for all population groups (GC, 2019). In addition, Health Canada recommends avoiding the consumption of food or beverages containing NNS to children between birth and 24 months (GC, 2015a). This is because NNS intake can displace nutrient-dense foods needed for growth and development (AHS, 2020). Currently, NNS intake is being researched in relation to several different health outcomes including gut microbiome, weight management, cardiometabolic health, appetite control, kidney function and dental decay (AHS, 2020). A systematic review conducted to inform World Health Organization’s policy and guideline on NNS use for both adults (≥ 18 years) and children (< 18 years) (Rios-Leyvraz & Montez, 2022). This review found that there can be reductions in body weight, BMI Z-score, waist circumference and percent fat mass when NNS were consumed instead of sugar sweetened beverages (Rios-Leyvraz & Montez, 2022) [6]. This can likely be attributed to a decrease in energy intake with NNS consumption (Rios-Leyvraz & Montez, 2022). However, limited research has examined NNS intake in young children (< 5 y) (Andrade et al., 2021; Venegas Hargous et al., 2020). A meta-analysis of available randomized controlled trials and cohort studies suggests inconclusive effects of NNS intake and long-term metabolic health outcomes including weight gain and development of type 2 diabetes in infants and children (< 12 y) (Reid, Chauhan et al., 2016).

Understanding intake of NNS in young children is important as there is an increase of NNS in the food supply in North America (Sylvetsky et al., 2011). This can include foods consumed by
children such as candy, yogurts, breakfast cereals, bakery products and jams (GC, 2019). In Canada, several NNS are approved for consumption (under acceptable levels) and use by food companies (Archibald et al., 2018; GC, 2010). Furthermore, since excessive dietary sugar intake is associated with weight gain, NNS are often promoted as a substitute or “healthier” alternative to sugar intake (Archibald et al., 2018; GC, 2021; Swithers, 2015). Given that NNS are available in our food supply, but are not recommended for young children, it is important to assess and monitor dietary intakes of NNS among young children. Thus, the aim of this study was to examine NNS intake among a sample of children aged 1.5 to 5 y.

6.3 Methods:

6.2.1. Participants:

Cross-sectional data from the Guelph Family Health Study (GFHS) were used for these analyses. The GFHS is a family-based health promotion and obesity prevention study, that began in 2014 at the University of Guelph, Ontario, Canada (Haines et al., 2018). Families with at least one child aged 1.5 to 5 y, who were not planning to move within the next year, were recruited from the Guelph-Wellington area through the local Family Health team, Community Health Centre and Ontario Early Years Centres (Haines et al., 2018). This analysis used baseline data collected from pilot families in 2014 and 2015 and was approved by the University of Guelph Research Ethics Board (REB#14AP009).

6.2.2 Food records:

Parents completed 3-day paper food records for their children and were given detailed instructions from trained staff to record all food and beverages consumed over 2 weekdays and 1 weekend day, including brand names of products. The paper food records were entered into the ESHA Food Processor Software after which trained staff reviewed every packaged food or
beverage to determine if they contained NNS. NNS content and type were determined using product websites and product ingredients lists. Since in Canada, NNS amounts are not required to be included in the list of ingredients on the food product packages, our study was unable to quantify these amounts. Thus, food records were reviewed for the type of food and beverage items containing NNS, the frequency of intake, and type of NNS contained in these products.

6.4 Results:

6.4.1 Demographic characteristics:

The GFHS pilot sample consisted of a total of n=117 preschool-aged children from 83 families. Five children were excluded due to missing or incomplete food records. Among the final analytic sample of n=112 children (n=78 families; n=55 females, n=57 males), the mean age ± SD was 3.6 ± 1.3 y and 82.1% (n=92) of the participants identified as white. Approximately 47% (n=37) of families reported their annual household income as >$90,000 and 41% (n=32) of families had at least one parent who had completed a university degree (Table 1).

6.4.2 NNS intake, frequency and types:

Nineteen (17%) children reported intake of NNS-containing foods or beverages over the 3-day period. Among these children, the intake frequency of foods or beverages containing NNS ranged from 1 to 3 times over the 3-day period. NNS-containing food or beverage items consumed included: freezies, beverages (such as pediatric oral nutritional supplements, flavored water and carbonated drinks), sugar free jam and protein powder. The main NNS types in these foods were stevia leaf extract, acesulfame K, sucralose, monk fruit extract and aspartame.

6.5 Discussion:

Although NNS exposure was limited to a small proportion of children in this study, insights into NNS-containing foods that young children consume were identified. Out of the 112
participants, 19 participants (17%) reported consuming NNS containing foods. This is higher than NNS intakes from a 2016 Irish study of preschool-aged children (n=500; aged 1 to 4 y), which found that 5% of children consumed NNS (Martyn et al., 2016). An American study (2009-2012) reported that approximately 25% of the children and adolescents (2 to ≤18 y) were consuming NNS from foods, beverages and packets of NNS (Sylvetsky, Jin et al., 2017). This same study also showed a 200% increase in NNS consumption among children and adolescents from 1999-2000 to 2009-2012 (Sylvetsky et al., 2017). A 2020 Chilean study found that 65% of children aged 4 to 6 y consumed at least one source of NNS per day (Venegas Hargous et al., 2020). These differing results suggest that the availability of NNS in the food supply could be a key determinant in children’s NNS intake and that NNS intake may be increasing over time. Furthermore, since young children are consuming different kinds of NNS worldwide (Gil-Campos et al., 2015; Sylvetsky et al., 2017; Venegas Hargous et al., 2020), further investigation on the impact of NNS intake on diet quality and health outcomes is warranted.

6.5.1 Limitations:

Although our study addresses an important knowledge gap in current NNS intake patterns among Canadian preschool-aged children, study limitations should be considered when interpreting our results. Specific amounts of NNS in the list of ingredients on food packages were not available, thus, our study was only able to document frequency, and not quantity of NNS intake. Food records are self-reported data and the data for NNS intake, types and frequency were extracted manually by trained staff, which may be subject to error. Dietary intake was assessed using a 3-day food record at a single time point, which may not have sufficiently captured children’s NNS intake. Assessing dietary intake across more days and at multiple time points could provide more accurate assessments of NNS intake. Moreover, from the time the data were collected
to the time we conducted our final review, certain food product formulations may have changed. Study participant families were primarily white with relatively highly educated parents; thus, our findings may not be generalizable to ethnically diverse or lower socio-economic populations.

6.6 Conclusions:

This is the first study to examine NNS intake in Canadian preschool-aged children. Results indicate that a small percentage of preschool-aged children already consume NNS. Future research is warranted to monitor NNS intake in young children. Additional research should also explore the potential effects of NNS intake on diet quality and health outcomes among young children.
6.8 ACKNOWLEDGEMENTS:

Data availability:

The GFHS welcomes external collaborators. Interested investigators can contact GFHS investigators to explore this option, which preserves participant confidentiality and meets the requirements of our Research Ethics Board, to protect human subjects. Due to Research Ethics Board restrictions, we do not make participant data publicly available.

Acknowledgements:

All the authors would like to extend their thanks and gratitude to the participating families, the research team of the Guelph Family Health Study, and to Angela Annis, Adam Sadowski, Madeline Nixon, Erin Smith and Sabrina Douglas for their support in facilitating this research.

Conflict of interest statement:

The authors declare that there are no competing interests.

Author contributions:

AM reviewed the data, completed the analysis and wrote the manuscript. DWLM and JH are the Co-Directors of the GFHS and supervised this project. GD was the statistical advisor. AMD supervised the dietary data collection and analysis. ACB and AMD were co-advisors for this project. These authors critically reviewed the results of this project. AC, JY and JLH, assisted with data cleaning and data review. All authors reviewed and revised this manuscript.
Table 6.1: Characteristics of families and children participating in Guelph Family Health Study pilot studies at baseline.

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>N (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Household Income (Canadian)</strong></td>
<td></td>
</tr>
<tr>
<td>(family data)</td>
<td></td>
</tr>
<tr>
<td>Did not answer</td>
<td>3 (3.8%)</td>
</tr>
<tr>
<td>&lt;$39,000</td>
<td>5 (6.4%)</td>
</tr>
<tr>
<td>$40,000-49,999</td>
<td>6 (7.6%)</td>
</tr>
<tr>
<td>$50,000-59,999</td>
<td>5 (6.4%)</td>
</tr>
<tr>
<td>$60,000-69,999</td>
<td>5 (6.4%)</td>
</tr>
<tr>
<td>$70,000-79,999</td>
<td>7 (9.0%)</td>
</tr>
<tr>
<td>$80,000-89,999</td>
<td>10 (13%)</td>
</tr>
<tr>
<td>&gt;$90,000</td>
<td>37 (47.4%)</td>
</tr>
<tr>
<td><strong>Parent Education (family data)</strong></td>
<td></td>
</tr>
<tr>
<td>Postgraduate training or degree</td>
<td>32 (41%)</td>
</tr>
<tr>
<td>University graduate</td>
<td>32 (41%)</td>
</tr>
<tr>
<td>College graduate</td>
<td>6 (7.7%)</td>
</tr>
<tr>
<td>Some university, some college or technical school</td>
<td>8 (10.3%)</td>
</tr>
<tr>
<td><strong>Child Ethnicity</strong></td>
<td></td>
</tr>
<tr>
<td>White</td>
<td>92 (82.1%)</td>
</tr>
<tr>
<td>Other</td>
<td>20 (17.6%)</td>
</tr>
<tr>
<td><strong>Child Age in years, Mean ± SD</strong></td>
<td>3.6±1.3 y</td>
</tr>
<tr>
<td><strong>Child Sex</strong></td>
<td></td>
</tr>
<tr>
<td>Male</td>
<td>57 (51%)</td>
</tr>
<tr>
<td>Female</td>
<td>55 (49.1%)</td>
</tr>
</tbody>
</table>

Children participants (n=112) and families (n=78)
Chapter 7: Integrative Discussion
7.1 Summary of major thesis findings

The findings of this thesis substantially contribute to current research on sugar intake in young children (<8 y) and uses a multi-dimensional approach (Figure 7.1) to better understand the factors contributing to sugar intake and potential relationships with anthropometrics such as body composition as an indicator of health. The aim of the first study was to investigate the association between sociodemographic characteristics of the parent and child and total, free and added sugar intake in young children (Study 1). The aim of the second and third study was to examine the relationship between of sugar intake in young children (1.5 y and <8 y) and their anthropometric measures including body weight, BMI Z-scores, waist circumference and percent fat mass cross-sectionally (Study 2) and longitudinally (Study 3). Finally, this thesis examined the current consumption patterns of NNS types, and foods sources of NNS in young children (1.5 to <6 y) in the Canadian context (Study 4).

Study 1 investigated the associations between total, free, and added sugar intake and sociodemographic characteristics in young children (<6 y). The results of Study 1 demonstrated that child age is associated with free and added sugar intake for preschool-aged children; child ethnicity is associated with total sugar intake and household income can be associated with free sugar intake. This led to a series of questions in Study 2 and Study 3 to further examine the downstream consequences of high sugar intake.

Study 2 shifted focus to examine current intakes of sugar in preschool-aged children, food sources of sugar and associations with anthropometric measures. This study found that 80% of the children had free sugar intake exceeding the 5% of daily energy recommendation set by the World Health Organization and 32% exceeded the 10% recommendation. The most frequently consumed food sources of free and added sugar were bakery products and sugars and sweets. There were no
statistically significant associations between total, free, and added sugar intakes found with anthropometric measures of body weight, BMI Z-scores, waist circumference and percent fat mass.

Building on the cross-sectional analyses of Study 2; Study 3 investigated the longitudinal associations between preschool-aged children’s (aged 1.5 to <8 y) sugars intake at baseline with anthropometric measures at 18 months follow up. No significant effect of time on any associations was found, which may be confounded by the rapid growth of children during this same time period.

The use of sugar alternatives for weight management may also explain the lack of associations between sugar intake and anthropometrics measures. Thus, Study 4 set out to gain an understanding of food sources of NNS and their frequency of consumption in foods and beverages in preschool aged children. NNS intake in preschool-aged children was 1 to 3 times per food record. The types of NNS consumed by the children included stevia leaf extract, acesulfame K, sucralose, monk fruit extract, and aspartame. Foods and beverages that contained NNS included: freezies, beverages, sugar free jam and protein powder.

Collectively *(Figure 7.1)*, these studies provide a multifaceted viewpoint on sugar intake and significantly contribute to the research gaps in the Canadian context in young children. This is important given that the food supply in every country is different. The next section further delves into a comprehensive discussion of these findings.
Figure 7.1 Graphical representation of the dissertation studies

Study 1: Sociodemographic characteristics

- Variables:
  - Child age, sex, ethnicity
  - Parent years of living in Canada
  - Household income
  - Parent marital status
  - Parent education

Study 2: Anthropometric measures (cross-sectionally)

Study 3: Anthropometric measures (longitudinal at 18 mo follow up)

Study 4: Sugar alternatives such as non-nutritive sweeteners

Total, free and added sugar intake in young children in GFHS

association

solution (?)
7.2 Discussion of Major Findings

7.2.1 Study 1: Implications for children’s health with sugar intake: Sociodemographic characteristics

Understanding the potential influence of sociodemographic characteristics on dietary patterns is crucial as these relationships may have an impact on health disparities and inequities in low SES communities (Alkerwi, Vernier et al., 2015; Manyanga, Tremblay et al., 2017). Thus, Study 1 investigated the association between the total, free, and added sugar intake in young children and sociodemographic characteristics of the parent and child. Child age, child sex, child ethnicity, parent years of living in Canada, annual household income, parent marital status, and parent education were found to be important factors contributing to the intake of specific types of sugars.

This study adds to the limited body of literature evaluating associations between sociodemographic factors and types of sugar defined as total, added, and free sugars. In contrast, the literature to-date on sociodemographic factors and sugar have been divided between studies investigating associations with diet quality, specific types of sugars (added or free, but not both) and SSB.

In brief, sociodemographic variables including parent marital status and parent education level have been associated with increased intake of sweets, sugar sweetened beverages, chocolates, cookies, and gummy bears (Brekke et al., 2007). The sociodemographic factors including age and ethnicity have been associated with increased intake of added sugars (Kranz & Siega-Riz, 2002). Lastly, low SES has been positively associated with SSB intake in another study set in the Indigenous population in Australia (Thurber et al., 2020). Taken together, there is high heterogeneity of results in this area of research highlighted by differing sociodemographic factors that were found to predict sugar intake. Differences in types of sugars or dietary food sources (foods vs SSB) explored may help explain the
heterogeneity in the results. Nevertheless, the totality of evidence to-date including findings from Study 1 highlights the need for further research on the impact of sociodemographic factors on dietary consumption of sugar. Future research could focus on understanding the associations between key sociodemographic variables such as child age, sex, ethnicity, annual household income, and parent education on sugar intake in young children. This could enable policy measures, increase knowledge and awareness of practitioners, and provide education to parents of young children for early life dietary interventions and healthy lifestyle habits.

7.2.2 Study 2: Sugar intake and food sources in preschool aged children

In addition to the lack of knowledge regarding the contribution of sociodemographic factors, there is also a general lack of information on sugar intake and dietary sources of sugars in preschool-aged children in Canada. Study 2 addressed this gap and found that children in the GFHS exceeded sugar intake recommendations and top dietary sources included many common foods such as bakery products, sugars and sweets, cereals and grains, and beverages. These findings were further reinforced in a collaborative project showing that free sugar intake from GFHS preschool-aged children’s snacks and beverages contributed significantly to total energy intake (Yu et al., 2023). Although there are limited other studies, excessive intake of sugar and dietary sources are consistent with other US and Canadian studies of similar age (Bailey et al., 2018; Chiavaroli, Wang et al., 2022; Rana, Mallet et al., 2021). Examining studies from across the globe, similar increases in consumption trends of free and added sugars are observed (Crowe et al., 2020; Devenish et al., 2019; Essman, Popkin et al., 2018).

The totality of research studies including Study 2 suggest that free and added sugar intake levels starting at a young age are significant and an important public health concern to address. The contribution of excessive calories from a young age has limited nutritional value whether from sweets or SSB, leads to increased weight gain in children (Malik & Hu, 2022). Collectively, this research
highlights the need for researchers and policy makers to advocate efforts to reduce free and added sugar consumption in children worldwide. Dedicated measures for continuously monitoring these trends and ongoing public health measures such as nutrition education to parents and children need to be sought to reduce any harmful health effects of excessive sugar intake in children (Malik & Hu, 2015; Ruperez, Mesana et al., 2019). Also, there is a need for early life intervention programs to provide knowledge and education to families and communities.

Reducing the prevalence of high sugar intake identified in Study 2 may seem to be a simple and straightforward solution. However, the development of interventions and education programs to address high sugar intake must also consider potential complexities when accounting for sociodemographic factors, as identified in Study 1. For example, it is likely that children from low SES or marginalized communities need different support while addressing food insecurity to access and purchase healthy foods in addition to support regarding awareness and education about sugar intake. Thus, these studies in this dissertation highlight the need to develop policies for sugar intake in Canada bearing in mind the sociodemographic characteristics of the Canadian population.

7.2.3 Study 2 and Study 3: Implications for children’s health with sugar intake: Anthropometric measures

The implied consequence of excessive sugar is higher caloric intake leading to excess weight gain and increased obesity risk (Malik et al., 2013). The initial work of Study 2 confirmed high intake of sugar in preschool aged children was similarly observed in older children. Thus, the secondary part of Study 2 and Study 3 of this dissertation investigated cross-sectional and longitudinal associations between total, free, and added sugar intake in young children with body weight, BMI Z-scores, waist circumference, and percent fat mass respectively. Neither the cross-sectional nor longitudinal analyses after 18 months of follow up showed a strong relationship with any anthropometric measure. These findings are in contrast to the larger body of evidence and dietary guidance by the WHO that sugar
and SSB be limited to prevent overweight and obesity (WHO, 2015). The likely reason for the lack of association in Studies 2 and 3 is the narrow age range of preschool children from 18 months to 5 years.

A systematic review and meta-analysis, suggested that there is a strong positive association between SSB intake in children and adolescents aged 2 to 16 y (n=25,745) with an increase in BMI aside from the trials in children from random-effects model (Malik et al., 2013). This review concluded that for children and adolescents, with every 1 serving (12 oz) intake of SSB daily, a 0.06 unit increase in BMI over a 1 y time period was noted simultaneously (Malik et al., 2013). Thus, biologically meaningful changes in weight status may only manifest over a prolonged period arising from small incremental changes. Taken together, these findings highlight the need for longitudinal follow-up to elucidate the role and associations between total, free, and added sugar and anthropometrics outcomes. This work also highlights the need to identify sensitive biological biomarkers (e.g., HOMA-IR and insulin) or alternate outcome measures than anthropometric measures in preschool-aged children. Nevertheless, based on the available evidence from older children sugar intake should be monitored from as young as preschool-aged children. This recommendation is supported by research demonstrating that healthy eating habits begin early in life (Mikkila et al., 2005) and determinants of adult-onset chronic diseases begin early in life (Mikkila et al., 2005).

7.2.4 Study 4: Implications for children’s health with NNS intake

Awareness of the potential negative health consequences associated with excess sugar intake may prompt the use of sugar substitutes, known as non-nutritive sweeteners (NNS). The intake of NNS and also potential negative effects is widely debated amongst researchers in the absence of quantitative evidence (Sylvetsky et al., 2017). Therefore, the purpose of Study 4 was to quantify and identify sources of NNS currently consumed by young children in the Canadian context. In the GFHS
preschool-aged children a low percentage of children were found to be consuming NNS (17%). These findings were similar to an Irish cohort of preschool aged children between the ages of 1 to 4 y (n=500) (Martyn et al., 2016). However, intake of NNS can also be as high as ~40-50% in as found in preschool-aged children in Buenos Aires (Garavaglia et al., 2018). Although consumption of NNS was low, Study 4 identified a wide range of food sources of NNS in children’s diet including freezies, oral nutritional supplements, flavored water, carbonated drinks, sugar free jam and protein powder. Similar to Study 4, beverages, candies and dairy products are the primary contributors of NNS intake in children’s diets (Martinez et al., 2020). At present time, there is a lack of data on the understanding of short- and long-term biological effects in children. NNS intake in adults have been linked to cancer, diabetes, atherosclerosis, heart disease and altered gut microbiome (Rios-Leyvraz & Montez, 2022). Considered together, longitudinal monitoring of NNS consumption, food sources, and changes in health measures are needed for a longer period of time (Rios-Leyvraz & Montez, 2022).

Health practitioners and health professionals should recommend the use of NNS as a weight maintenance option for young children with caution (AHS, 2020; Shum & Georgia, 2021). Furthermore, nutrition education should be provided to parents of young children to review food packages with ingredients containing NNS (Harris & Pomeranz, 2021). Health authorities need to consider providing consistent messaging with the consumption of NNS in children as current messages appear ambiguous and confusing (Baker-Smith et al., 2019). There is less concern about the toxicological safety concerns as per national health authorities. The Academy of Nutrition and Dietetics is encouraging the use of NNS intake as a sweetener (within safe ADI limits) (Fitch et al., 2012), whilst the recent Canada’s Food Guide suggests limiting consumption of NNS for all age groups (GC, 2019). Also, for children <2 y, NNS can displace key nutrients needed for growth and development of young children including carbohydrates and vitamins and as such should be limited.
for infants (AHS, 2020). Thus, considering the current state of knowledge available through evidence, practice and limited available of information on food packages (i.e., amounts of NNS), it is prudent to limit usage of NNS intake in young children (<8 y).

7.3 Strengths and Limitations

7.3.1 Strengths

There are several strengths that are noteworthy of the studies in this dissertation. Firstly, this research fills a substantial gap in the Canadian context regarding the impact of sociodemographic characteristics with sugar intake in young children. Furthermore, there is limited research evidence on sugar intake and the associations with anthropometric measures in young children, both cross-sectionally and longitudinally. Additionally, to the best of our knowledge, there are few research studies that have monitored NNS intake in young Canadian children. Most of the current research describes trends or statistical analyses in relation to sugar intake grouped together for children and adolescents (birth to 18 y), making it challenging to specifically understand trends for children under the age of 6 y. Moreover, previous research studies have explored sociodemographic characteristics and their association with overall diet quality, however as Study 1 has highlighted, results could vary on how sociodemographic characteristics have an impact on consumption of different types of sugar intakes in young children. Thus, these findings can inform policy decisions, allocate resources, and guide counselling efforts for parents with young children.

Study 2 (and many other research studies) demonstrates that young children are exceeding the WHO and Health Canada recommendations suggesting that SSB are not the only source of processed sugar for children. A few research studies have also found no associations between sugar intake in young children and BMI or weight gain (Newby et al., 2004; O’Connor et al., 2006; Song et al., 2012). This raises the question of whether factors such as growth velocity, parental involvement, adequate
household income and physical activity play a role in mitigating the effects of sugar intake on anthropometric measures of young children. Moreover, there is limited longitudinal data available on the long-term effects of sugar intake and therefore, Study 3 contributes to this limited body of research.

Lastly, Study 4 is the first of its kind to report on monitoring types and sources of NNS intake in young Canadian children. The study found that a low percentage of preschool-aged children (17%) from the study sample (n=112) were consuming NNS in foods and beverages. The common food sources for the NNS included: freezies, oral nutritional supplements, flavored water, carbonated drinks, sugar free jam, and protein powder. The types of NNS in these foods were identified as stevia leaf extract, acesulfame K, sucralose, monk fruit extract and aspartame.

Study 2 and Study 3 included manual calculations of free and added sugar consumption as this information was not available in the nutritional database used (i.e., ESHA). However, our study team was able to overcome this challenge by considering available tools such as the algorithm for calculating added sugar intake by Louie and colleagues that was used in Study 2 and Study 3 (Louie et al., 2015). This algorithm has been used in multiple other studies and thus, there is consistency in research on these calculations. Furthermore, this added to the strength in the research completed in this dissertation.

7.3.2 Limitations

Despite the novelty of the studies in this dissertation, the results should be interpreted bearing some limitations. Firstly, the sample enrollment for this study includes participants recruited through community centres and social media posts, that may introduce selection bias by attracting participants that are highly motivated by health to enroll. Additionally, the analyses used parent-reported diet information, which is susceptible to social desirability bias. As stated in Studies 1-3, there is limited capacity of nutritional databases such as ESHA and ASA-24 to calculate free sugar and added sugar.
accurately. This made it necessary for the study team to have multiple data analysts to review the data to ensure there were minimal calculation errors to ensure data quality. Since the food records were manually inspected for these calculations, these could be prone to human error.

As this study used secondary data analyses, the sample size was predetermined based on initial enrollment. For Study 1, the final analysis included n=267 out of n=322 children after excluding implausible data, incomplete food records and outliers. Similarly, in Study 2 and Study 3, the final analysis included n=109 children out of n=117 children (aged 1.5 to 5 y) at baseline after removing incomplete data and breastfed participants. In Study 4, n=112 children were included out of n=117 based on the complete food records available. Since these studies are relatively small samples and lack diversity, there could be an increase in Type II errors and the generalizability of the findings could also be limited.

Furthermore, the definitions of added sugar in the dissertation studies were inconsistent with those provided by the WHO and Health Canada, as they did not include naturally added sugars such as honey or maple syrup into this definition which are included in free sugars (GC, 2019; WHO, 2015).

It is important to note that the study participants and families enrolled in the GFHS cohorts (in all the studies) are predominantly white; come from a household with high income and the parents were well-educated. Therefore, the research findings cannot be generalized to diverse populations or lower socioeconomic groups.

All studies are observational in nature and thus are subject to confounding. Therefore, causation cannot be inferred from these study designs (Wang & Cheng, 2020).

7.4 Implications and Recommendations for Public Health Programs and Policies

Excessive consumption of refined sugars and sugar sweetened beverages has been identified as a public health concern for consumption in young children (NAP, 2017). Additionally, the
Organization for Economic Cooperation and Development (OECD) report has recognized refined sugar in convenience and processed foods as a nutrient of concern (OECD, 2019). Despite our understanding that total calories may play a significant role in increase in body weight and chronic disease development, it is important to isolate the role of sugar intake and examine the impacts on health outcomes in young children. Thus, this dissertation focused on understanding total, free, and added sugar intake in young children from various viewpoints.

This research is crucial and as this information is relevant for informing public health intervention and policy as well as clinical care an support among families with young children (Vercammen, Frelier et al., 2018). Potential intervention and policy approaches could include streamlining recommendations from global and national health authorities; using multiple tools such as front of package labelling; utilizing mobiles (mHealth) in study interventions for outreach (Nezami, Ward et al., 2018); nutrition labelling on packaged foods; and, nutrition education by registered dietitians imparted to all segments of the communities along with early life nutrition interventions (Vercammen et al., 2018).

Since there are many challenges and limitations in sugar research globally, the following are recommendations for policy and practice on sugar intake in young children:

7.4.1 The definitions in sugar research and nutrition composition databases need to be streamlined.

As suggested in the articles by Erickson & Slavin, 2015, Mela and Woolner, 2018 and Fidler Mis et al., 2017, there is inconsistency in the definitions of the type of sugars within the research literature and the shift towards use of the definition of “free sugars”. While this is a holistic and an all-encompassing definition, this shift, in turn may need an infrastructural change. If the definition of free sugars were to be implemented, this would have an impact on measuring free sugars using nutritional databases that are limited in capacity at this time. Additionally, nutrition labels on packaged foods do
have free sugars currently and this change may also have an impact on consumer understanding of the definition of free sugars (Mela & Woolner, 2018). Furthermore, current recommendations for sugar intake for young children from multiple health authorities and organizations are not consistent across the globe and these should be reviewed and discussed (Table 1). Some health authorities recommend a limit on added sugars while others focus on free sugars. Thus, it is suggested to align the definitions and recommendations of sugar intake for children worldwide to improve clarity for the public and reduce ambiguity for researchers.

7.4.2 Nutrition policy to reduce refined sugar intake in young children needs to be strengthened.

Currently, many different policy interventions such as taxation of SSB, marketing sugary products to children in schools and nutrition labelling are under review (Malik & Hu, 2015). A wider range of policy interventions and options are needed to further limit sugar intake in young children (Davis & Lee, 2014; Malik & Hu, 2015). Also, the effectiveness of these policy interventions needs to be continuously assessed and strengthened in Canada to make everlasting changes to limit sugar intake in Canadians to promote health.

7.4.3 Knowledge translation strategies for reducing sugar intake in children should be amplified.

Early intervention programs should focus on using plain language resources to bring evidence-based information to parents of young children within the community similar to GFHS. Thus, further work is needed to develop effective knowledge uptake tools for healthcare professionals to use during counselling.

7.4.4 Balance the sugar and calorie recommendations with body image messaging

Since there can be a heavy focus on calorie restrictions, it is prudent that the interventions and policies for reducing sugar intake for weight management should be balanced with children’s mental
health. Messages of positive body image should be promoted, to dissuade concerns of disordered eating patterns in young children that are often visible in dietetic practice (Mahn & Lordly, 2015).

7.5 Future research within GFHS

The insights from this dissertation can be used as a foundation for future research topics including:

1) Investigating the impact of sociodemographic characteristics on free sugar intake: Along with sociodemographic characteristics of the children and parents, future studies can expand on the findings of Study 1 by exploring additional factors that may influence free sugar intake in young children. These can include behavioral factors such as child eating behaviour and environmental factors such as screen time that may influence free sugar intake in study participants.

2) Covariates: Future studies should consider adjusting for other confounding factors such as physical activity and total caloric intake of study participants when investigating associations between sugar intake and anthropometric measures.

3) Longer time for follow-up: Longitudinal studies with larger sample sizes and longer follow-up periods are needed to investigate long-term effects of sugar intake in young children. By following children from preschool-age to school-age and even into adolescence, researchers can assess the impact of sugar intake on anthropometric measures, biomarkers (e.g., insulin) to assess health outcomes in children over an extended period of time.

4) Total caloric intake: Future studies can aim to understand associations between total caloric intake (instead of solely focusing on calories from free sugar) and anthropometric measures. This broader perspective can help evaluate the overall energy balance and the relationship with anthropometric measures such as fat mass and waist circumference to understand the role of dietary intake in children’s health.
5) Monitoring of NNS intake: Research from the GFHS can continue to monitor NNS intake in young children with a larger sample size. This will enable a further understanding of NNS consumption patterns at differing time points.

6) Qualitative research on NNS intake among parents: At present, there is limited research on parent perception of NNS intake. Researchers can consider conducting qualitative research with parents enrolled in the GFHS for this.

7) Knowledge uptake: Future research can also focus on understanding the different strategies that can be used to enhance knowledge uptake among parents and public.

7.6 Conclusions

Collectively, this dissertation presents a multidimensional view of research on total, free and added sugar and NNS intake in young children (1.5 y to <8 y). Sugar intake in preschool-aged children is determined by sociodemographic factors and sugar intake by a large proportion of children exceeding recommended limits is of concern. Overall, this research has the potential to inform nutrition policy regarding sugar intake in children and highlight the need for both more research and early life intervention programs to reduce sugar intake.
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Te Morenga, L., Mallard, S., & Mann, J. (2012). Dietary sugars and body weight: systematic review and meta-analyses of randomised controlled trials and cohort studies. *BMJ*, 346, e7492. [https://doi.org/10.1136/bmj.e7492](https://doi.org/10.1136/bmj.e7492)


APPENDICES
APPENDIX: SUGAR CALCULATIONS AND SOURCES

A.1: SOP - Estimating Added Sugars and Free Sugars: Guelph Family Health Study – Pilot 1 and 2 Data (Added in part)

**NOTE: This SOP was created by the Guelph Family Health Study Team to calculate sugars**

This SOP details how to calculate added sugars and free sugars from a three-day food record using pilot 1 and 2 data from the Guelph Family Health Study.

**Overall Steps (scoring added and free sugars for a single 3-day food record):**

1. Open participant food record on GFHS OneDrive ex. (Pilot Phase 1 or 2; BL or 6 months)
   
   a. In open food record, enter your initials and the date of data entry

<table>
<thead>
<tr>
<th>SUGARS</th>
<th>DE#1</th>
<th>Initials ex. JD</th>
<th>Date</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>30-May-19</td>
</tr>
</tbody>
</table>

2. Open the sugar summary spreadsheet appropriate to the food record
   
   a. If participant is from Pilot 1 --> Open Pilot 1 Added and Free Sugar Summary Data
   
   b. If participant is from Pilot 2 --> Open Pilot 2 Added and Free Sugar Summary Data

3. Open relevant sheet (baseline, 6 months or 18 months)
   
   a. Enter Initials and date under DE and DE Date for appropriate food record.

<table>
<thead>
<tr>
<th>PID</th>
<th>Added Sugar (kcal)</th>
<th>Excess Free Sugar (kcal)</th>
<th>Total Free Sugars (g)</th>
<th>Total Free Sugars (DE1)</th>
<th>DE1 Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>XXXXX</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>JY</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1-May-19</td>
</tr>
</tbody>
</table>

4. Complete Score for Added Sugars
5. Complete Score for Excess Free Sugars
6. Complete Score for Free Sugars

**Score for Added Sugar:** Sugars added to foods and beverages during processing

**Product information** sources:
1) Smart Label website (http://www.smartlabel.org/)

2) Canadian Nutrient File (https://food-nutrition.canada.ca/cnf-fce/index-eng.jsp)

3) Official Product website

1) Determine if the first item in the participant’s food record contains added sugars through the following steps (Steps 1-4) and using the **Product Information** sources. Calculate grams AND kcal of added sugar consumed for each item according to the **Quantity** and **Measure** of the food item.

<table>
<thead>
<tr>
<th>Item Name</th>
<th>Quantity</th>
<th>Measure</th>
<th>HEI Serving</th>
</tr>
</thead>
<tbody>
<tr>
<td>Day 1 (4/28/2016)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Breakfast</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>milk, 1%, with vitamins A &amp; D</td>
<td>1.5</td>
<td>Cup</td>
<td>1.5</td>
</tr>
</tbody>
</table>

**Step 1:** Assign 0g added sugar to foods with 0g total sugar

**Step 2:** Assign 0g added sugar for foods in **Group A**

**Group A: Foods with sugars but without added sugars**

(a) 100% Fruit/vegetable juice and juice/cordial base sweetened with Non-nutritive sweeteners only. (**** These will be assigned as free sugars*****)

(b) All spices and herbs.

(c) All fats and oils.

(d) All plain cereal grains, pastas, rice and flours.

(e) Eggs and egg products (except egg-based desserts).

(f) Fresh fruit, fresh vegetables (including salads with no dressing), fresh meat, fresh seafood and tofu.

(g) Fruits canned in 100% fruit juice or liquid sweetened with artificial sweeteners only.

(h) Intensely sweetened jam and beverage base (without added sugar).

(i) Legumes (fresh, dried and/or processed, except sweetened varieties).

(j) Mixed meat dishes with no added sugar (decided on the basis of ingredient information; e.g., recipe).

(k) Non-sweetened alcoholic beverages.

(l) Non-sweetened coffees and tea.
(m) Non-sugar-sweetened milk and buttermilk; breast milk.
(n) Non-sugar-sweetened dairy products (including yoghurts sweetened with artificial sweeteners only).
(o) Nuts (except sweetened varieties and nut bars), coconut (and products except sweetened varieties) and seeds.
(p) Oats (and porridge) with no added sugar (decided based on ingredient information; e.g., ingredient list).
(q) Unsweetened dried fruits.

Step 3: Assign 100% of total sugars as added sugar for foods in **Group B**

**Group B: Foods where all total sugars are added sugars**

(a) All confectionery except those containing dairy products such as fudge and chocolate.
(b) Breakfast cereals and cereal bars without fruits, chocolate, dairy or milk solids.
(c) Coffee and beverage base with no milk solids, dry or made up with water.
(d) Crumbed/battered meat and seafood.
(e) Processed meats.
(f) Regular soft drinks, sport drinks, flavoured water and non-fruit-based energy drink.
(g) Savoury biscuits, sweet biscuits, cakes and buns, donuts and batterbased products that do not contain fruit, chocolate or dairy products.
(h) Soy beverages and soy yoghurt without added fruits.
(i) Stock powder.
(j) Sugar and syrups.
(k) Plain pastries without filling (such as chocolate, dried fruit and/or nuts).
(l) Plain breads (except gluten-free), English muffin, bagels, pizza bases and naan.
Step 4: Try to determine/estimate added sugars for foods in Group C

Group C: Foods containing added sugar + sugars from other sources ex. Free sugars, naturally occurring sugars (lactose), etc.

4. A) On many product labels (specifically products from the US), added sugar content is listed on the nutrition label in addition to total sugar. Look up food item from the Product Information sources to check for listed added sugar content.

4. B) If added sugar content is not available from the Product Information sources, check to see if there is an unsweetened variety of the food item (ex: chocolate milk vs. white dairy milk, sweetened dried cranberries vs. unsweetened dried cranberries). Added sugar will be assigned as total sugar (sweetened variety) – total sugar (unsweetened variety).

Example I. Neilson Chocolate 1% milk (1 cup) = 14 grams of added sugar

i. Identify total sugars in Neilson 1% white milk (1 cup = 12 g)
ii. Identify total sugars in Neilson 1% Chocolate milk (1 cup = 26 g)
iii. Added sugars/ cup Neilson Chocolate 1% milk = 26 g - 12 g = 14 g

2) If item contains added sugars, input the value of added sugars in kcal consumed into the first open cell to the right of the food item and “kcal” into the next cell to the right. Highlight both cells in yellow.

<table>
<thead>
<tr>
<th>Product Information Sources</th>
<th>36 kcal</th>
</tr>
</thead>
<tbody>
<tr>
<td>Afternoon Snack</td>
<td></td>
</tr>
<tr>
<td>cookie, sandwich, chocolate, Oreo</td>
<td>2 Each</td>
</tr>
<tr>
<td>crackers, cheese, cheddar, Goldfish</td>
<td>43 Gram</td>
</tr>
<tr>
<td>pears, boxc, fresh</td>
<td>0.5 Medium</td>
</tr>
</tbody>
</table>

3) Repeat Part 1 - 2 for each item on the food record.

4) Sum all added sugar kcal for the participant’s food record and divide by three (to get average added sugar intake per day). Input result into “Average Added Sugar (kcal)” column in Pilot 1 Added and Free Sugar Summary Data or Pilot 2 Added and Free Sugar Summary Data.

Score for Excess Free Sugars: Sugars from juices or concentrates

To score for total free sugars, excess free sugars from juices and concentrates ONLY will be calculated first. Total free sugars include all sugars from fruit/vegetable juice and concentrates in addition to added sugars and will be calculated in PART C). This excess free sugar value will then be added to the added sugar value to calculate total free sugar consumption for the participant.

Product Information sources
1. “Common Free Sugar Juice List” document (Location: GFHS Team Onedrive -> Students -> Jaimie and Jessica Summer 2019 -> Common Free Sugar Juice List)

<table>
<thead>
<tr>
<th>Juice</th>
<th>Free Sugar g/100 mL</th>
<th>Free Sugar kcal/100 mL</th>
<th>Free sugar Kcal/240 ml</th>
<th>Free Sugar g/240mL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Apple Juice</td>
<td>10</td>
<td>40</td>
<td>96</td>
<td>24</td>
</tr>
<tr>
<td>Orange Juice</td>
<td>9.17</td>
<td>36.7</td>
<td>88</td>
<td>22</td>
</tr>
<tr>
<td>Infant Juice, Mixed Fruit (Gerber)</td>
<td>11.01</td>
<td>44.05</td>
<td>105.72</td>
<td></td>
</tr>
<tr>
<td>V8 Splash (Orange Pineapple)</td>
<td>7.5</td>
<td>30</td>
<td>72</td>
<td>18</td>
</tr>
</tbody>
</table>

(Note: apple juice and orange juice are the most common juices seen in the food records and are negligibly variable in sugar content between different brands. The values on the Common Free Sugar Juice List can be applied to all brands of apple and orange juice).

If the food item is not present in the Common Free Sugar Juice List, look up sugar content on one of Product Information Sources 2 – 4.

2. Smart Label website (http://www.smartlabel.org/)
4. Product website

Determine if the first item in the food record contains juices or juice concentrates (items fitting into Categories 1-4) using Product Information sources.

Categories

1) 100% fruit or vegetables juices

2) Fruit or vegetable juices from concentrates

3) Smoothies/ Mixed Juices

4) Other/Foods containing juice concentrates and/or juice ex. Fruit leathers
If the food item is included in **Categories 1-4**, calculate grams/kcal of excess free sugar consumed for each item according to its **Category** using the **Quantity** and **Measure** column from the food record and nutrition data from one of the above **Product Information** sources.

<table>
<thead>
<tr>
<th>Item Name</th>
<th>Quantity</th>
<th>Measure</th>
<th>HEI Serving</th>
</tr>
</thead>
<tbody>
<tr>
<td>Day 1 (4/28/2016)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Breakfast</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>milk, 1%, with vitamins A &amp; D</td>
<td>1.5 Cup</td>
<td>1.5 D</td>
<td></td>
</tr>
</tbody>
</table>

**Category 1: 100% Fruit or vegetable juices**

A) Assign 100% of total sugars as excess free sugars

**Category 2: Fruit or vegetable juice from concentrates**

A) Assign 100% of total sugars as excess free sugars

**Category 3: Smoothies/Mixed Juices**

A) If proportion of juice to puree/whole fruits is known or can be deduced, calculate excess free sugars from juice

B) If proportion of juice to puree/whole fruits is unknown, assign 50% of total sugars as excess free sugars

**Category 4: Other/Foods containing juice concentrates and/or juices ex. Fruit leathers**

A) If amount of juice concentrate or juice is known or can be deduced, calculate excess free sugars from juice

B) Use judgment as new Other Foods arise and contact **Pilot Data Sugar Experts**

Multiply grams of excess free sugars by 4 to get kcal of excess free sugar. Input the value of excess free sugars in kcal consumed into the first open cell to the right of the food item and “kcal” into the next cell to the right. Highlight both cells in blue.

Repeat Part B.1-3 for all blue highlighted items on a single food record

Sum all excess free sugar kcal for the food record and divide by three (to get average excess free sugar intake per day). Input result into “**Excess Free Sugar (kcal)**” column in **Pilot 1 Added and Free Sugar Summary Data** or **Pilot 2 Added and Free Sugar Summary Data**.

**Score for Total Average Free Sugars (Excel Automated Calculation)**

All data from each participant should be recorded in the Excel spreadsheets “**Pilot 1 Added and Free Sugar Summary Data**” or “**Pilot 2 Added and Free Sugar Summary Data**.”
Open relevant spreadsheet (Pilot 1 Added and Free Sugar Summary Data or Pilot 2 Added and Free Sugar Summary Data).

Record “Free Sugar (kcal)” column = “Added sugar (kcal)” column + “Excess free sugars (kcal)” column

“Free Sugars (g)” column = “Free Sugars (kcal)” column / 4 --> average grams of free sugars consumed per day
To provide reliable between-country comparisons of added sugar intake, a standardised objective methodology that allows for the differences in product formulation and cultural preparation of foods is required. The aim of this study was to develop a systematic methodology to estimate added sugar values on the basis of analytical data and ingredients in food products. This methodology was then applied to an Australian food composition table 10 to estimate added sugar values for all foods.

MATERIALS AND METHODS

Definition of added sugar

In this work, the term ‘added sugar’ was defined similarly to that used by the USDA—that is, refined sugars added during cooking or manufacturing. 11 By using this definition, the following sweeteners are considered added sugars: sugar (granulated (sucrose), brown, powdered and maple); monosaccharides and disaccharides (e.g., fructose, lactose, maltose, glucose (dextrose)); single-ingredient syrups (light corn, dark corn, high-fructose corn syrup, maple, sorghum); honey and molasses; and maltodextrin. Despite being used as sweetening agents in some foods, sugar alcohols were not included as added sugars in this definition, because although they are not monosaccharides or disaccharides, and thus they are not normally considered as ‘sugars’, such as in the Australian and New Zealand Food Standards Code, 16 in line with the approach of the USDA 11 and Somerset, 12 undiluted fruit juice concentrate was considered as added sugar in this definition, whereas diluted fruit juice concentrates were considered to have no added sugar. This is because diluted fruit juice contains similar composition to normal fruit juices, where the sugar content by weight is low, making them ineffective as sweeteners. Products sweetened only with low-energy sugar substitutes (intense sweeteners) were considered to have no added sugar.

Proposed methodology for estimating added sugar content of foods

The following process outlines the methodology that we propose for estimating the added sugar content of foods, in which steps 1–6 were considered to be objective and steps 7–10 were considered subjective. Derivation of formulas used in steps 4, 5 and 6 and worked example of steps 4–9 are provided in Online Supplementary File 1.

Step 1: Assign 0% added sugar to foods with 0 g total sugars.

Step 2: Assign 0% added sugar to foods in the following food groups:

(a) 100% Fruit/vegetable juice and juice/cordial base sweetened with artificial sweeteners only.
(b) All spaces and herbs.
(c) All fats and oils.
(d) All plain cereals, grains, pastas, rice and flours.
(e) Eggs and egg products (except egg-based desserts).
(f) Fresh fruit, fresh vegetables (including salads with no dressings), fresh meat, fresh seafood and tofu.
(g) Fruits canned in 100% fruit juice or liquid sweetened with artificial sweeteners only.
(h) Intensively sweetened jam and beverage base (without added sugar).
(i) Legumes (fresh, dried and/or processed) except sweetened varieties.
(j) Mixed meat dishes with no added sugar (decided on the basis of ingredient information; e.g., recipe).
(k) Non-sweetened alcoholic beverages.
(l) Non-sweetened coffee and tea.
(m) Non-sweetened milk and buttermilk; breast milk.
(n) Non-sweetened dairy products (including yoghurts; sweetened with artificial sweeteners only).
(o) Nuts (except sweetened varieties and nut bars), coconut and products except sweetened varieties) and seeds.
(p) Rice, rice products, and products with no added sugar (decided based on ingredient information; e.g., ingredient list).
(q) Plain pastries without filling (such as chocolate, dried fruit and/or nuts).
(r) Plain breads (except gluten-free). English muffins, bagels, pizza bases and naan.
(s) Unsweetened dried fruits.

These food groups were selected because they are either unprocessed or minimally processed with no added sugar. Gluten-free breads were excluded, as some of them may also be yeast-free, meaning that all sugars added to the recipe serve only as a sweetener and not as a processing aid. Pastries with dried fruits and/or nuts were excluded from this step, as dried fruits containing added sugar may be used, and some pastries with fillings tend to be sweetened with sugars, and hence the group is not homogeneous; another subsequent step that can correctly take these into consideration (e.g., step 4) should be used to estimate their added sugar content.

Step 3: Assign 100% of total sugars as added sugar for foods in the following food groups:

(a) All confectionery except those containing dairy products such as fudge and chocolate.
(b) Breakfast cereals and cereal bars without fruits, chocolate, dairy or milk solids.
(c) Coffee and beverage base with no milk solids, dry or made up with water.
(d) Crumb/battered meat and seafood.
(e) Processed meats.
(f) Regular soft drinks, sport drinks, flavoured water and non-fruit-based energy drink.
(g) Savoury biscuits, sweet biscuits, cakes and buns, donuts and batter-based products that do not contain fruit, chocolate or dairy products.
(h) Soy beverages and soy yoghurt without added fruits.
(i) Steak powder.
(j) Sugar and syrups.

These food groups were selected as they contain minimal amounts of naturally occurring sugars—for example, the sugar content of plain wheat flour (used in biscuits and so on) or soya beans is negligibly low (<0.3 g/100 g); therefore, most, if not all, of the sugars present are likely to be added.

Step 4: Calculation based on standard recipe used in the food composition database—proportioning method where added sugar contents of all ingredients were available from steps 1 to 3.

Added sugar per 100 g ($A_{{\text{100g}}})$ is given by the following formula:

$$A_{{\text{100g}}} = \frac{\sum W_i \times A_{S_i}}{\sum W_i} \times (100\% + \%W)$$

where $W_i$ is the weight of the $i$th ingredient in recipe, $A_{S_i}$ is the added sugar content per 100 g of the $i$th ingredient and $\%W$, is the percentage change in weight on cooking.

Step 5: Calculation based on comparison with values from the unsweetened variety.

Added sugar per 100 g ($A_{{\text{100g}}}$) is given by the following formula:

$$A_{{\text{100g}}} = \frac{100 \times (S_0 - \text{unsweeten})}{S_0} - 100$$

where $S_0$ is the total sugar content per 100 g of the unsweetened variety of the food and $S_{{\text{unsweeten}}}$ is the final listed sugar content.

Step 6: Decision based on analytical data.

If analytical data for lactose are available, and the ingredients do not include dried fruits or milled cereals, added sugar content is calculated as total sugars – lactose. If the food contains milled cereals and lactose and maltose data are available, added sugar content is calculated as total sugars – lactose – maltose.

Step 7: Use borrowed values from similar products from steps 1 to 6 or from overseas databases.

Values from similar product(s) within local food composition databases (e.g., AUSNUT2007) should preferably be chosen in this step. If no similar product is available in the local database, values from an alternative database are borrowed, and the proportion of total sugars as added sugar is calculated for the borrowed food. The added sugar content of the target food is then estimated as total sugars × proportion of sugars as added sugar (calculated from the borrowed food). The choice of the foreign database to borrow data from is dependent on the similarity of the food supply between the countries (e.g., type of foods available), and in the current example, data from the last updated version USDA added sugar database 13 were used given the similarity in the types of food available in Australia and the United States.
A.2: SOP- Estimating Added Sugars and Free Sugars: Guelph Family Health Study FULL Study

**NOTE: This SOP was created by the Guelph Family Health Study Team**

Additional File 1: Stepwise determination of free sugars from ASA24-Canada-2016 data (.pdf)

<table>
<thead>
<tr>
<th></th>
<th>Added Sugar (tsp. eq.) was converted to kcal</th>
</tr>
</thead>
</table>
| 1 | a. Added sugar (tsp. eq.) from foods and beverages was determined by ASA24.  
   b. Added sugar (tsp. eq.) was converted to kcal using the following equation: \( \text{Added Sugar (kcal)} = \text{Added Sugar (tsp. eq.)} \times (4.2 \text{ g/1 tsp. eq.}) \times (4 \text{ kcal/1 g}) \). |

<table>
<thead>
<tr>
<th></th>
<th>‘Sugar from Fruit Juice’ was calculated for foods and beverages</th>
</tr>
</thead>
</table>
| 2 | a. Food and beverage items containing 100% fruit juice were identified using the ASA-24 F_JUICE variable. Items were categorized as 100% fruit juice or Mixed Items.  
   b. For 100% fruit juice (with no added sugar), free sugar is equal to total sugar and so the ASA24 total sugar data were used.  
   c. For Mixed Items, the type of 100% fruit juice in the food or beverage item was identified. If it could not be reasonably identified, apple juice was used since it is the most common fruit juice.  
   a. Sugar from Fruit Juice was calculated for each food and beverage item using the following equation: \( \text{Sugar from Fruit Juice} = \text{Fruit juice (cups.eq.)} \times \text{Grams Sugar Per Cup Fruit Juice} \).  
   b. For each food and beverage item, sugar from fruit juice was converted from grams to kcal using the following equation: \( \text{Sugar from fruit juice (kcal)} = \text{Sugar from fruit juice (g)} \times 4 \text{ kcal / 1g} \). |

<table>
<thead>
<tr>
<th></th>
<th>Free Sugar (kcal) was calculated</th>
</tr>
</thead>
</table>

---

1 ASA24 calculates added sugar using the USDA’s Food Patterns Equivalents Database (FPED) definition of added sugars. This includes all sugars added during processing, honey, syrups, and sugars from undiluted fruit juice concentrates (Bowman et al., 2018). The World Health Organization defines free sugar as monosaccharides and disaccharides added to foods and beverages by the manufacturer, cook or consumer, and sugars naturally present in honey, syrups, fruit juices and fruit juice concentrates (WHO, 2015). ASA24 added sugars were calculated based on the FPED definition of added sugars where one teaspoon equivalent of added sugars was reported to be equivalent to 4.2 grams.

2 ASA24 items (Food_Description) from the full study baseline children cohort that contain fruit juice were categorized into 1) 100% Fruit Juice or 2) Mixed Items. 1) 100% Fruit Juice includes 100% fruit juice & Fruit juice concentrate diluted to single strength with no added sugar. Items in...
a. Free sugar was calculated for each food and beverage item by summing ‘Added Sugar’ (Step 1) and ‘Sugar from Fruit Juice’ (Step 2).

This category included “Fruit juice blend, 100% juice, with added Vitamin C”, “Orange juice, chilled, includes from concentrate”, “Pomegranate juice, ready-to-drink”, “Apple juice, canned or bottled, added vitamin C”, “Fruit juice, NFS (Mixed fruit juices)”, “Orange juice, frozen concentrate, with calcium and vit. D added, diluted”, “Grape juice, canned or bottled, unsweetened, with added vitamin C”, and “Orange juice, frozen concentrate, unsweetened, diluted”). Coconut water is not counted as juice by ASA24-Canada-2016 but was treated as 100% fruit juice for this analysis. 2) Mixed Items included items that contain non-100% fruit juice sources of free sugar or 100% fruit juice plus other sources of free sugar. Items in this category include “Fruit smoothie drink, made with fruit or fruit juice only (no dairy products)”, “Sauce, fruit (All fruits)”, “Juice drink, fruit, ready-to-drink”, “Fruit smoothie drink, NFS”, “Fruit cocktail (peach, pear, apricot, pineapple, cherry, grape), canned, juice pack, solids and liquid”, ”Drink, fruit punch, vitamin C added, ready-to-drink”, “Fruit flavored drink, low calorie, with high vitamin C”, “Peach, canned halves or slices, juice pack, solids and liquid”, “Lemon juice, raw”, “Hummus, homemade”, “Sauce, plum, ready-to-serve”, “Macaroni or pasta salad”, “Dessert, frozen, sherbet, orange”, “Pad Thai with meat”, “Macaroni or pasta salad with cheese”, “Sweet and sour chicken”, “Lemonade, frozen, diluted with water”, “Fruit syrup (Strawberry, Blueberry)”, “Light ice cream, creamscicle or dreamsicle (formerly ice milk)”, “Sweets, jellies”, “Macaroni or pasta salad W/ MAYONNAISE-TYPE SALAD DRESSING (INCLUDE MIRACLE WHIP)”, “Sweets, fruit butters, apple”.

3 An in-house ‘Grams Sugar Per Cup Fruit Juice’ database was populated using ASA24 total sugar data for each fruit juice, e.g., “Apple juice, canned or bottled, added vitamin C” contains 24.05g / cup eq.

Source: Free sugar intake from snacks and beverages in Canadian preschool- and toddler-aged children: a cross-sectional study | BMC Nutrition | Full Text (biomedcentral.com)
### A.3: Sugar sources and categories used for coding for GFHS Pilot 1 and Pilot 2 data

**NOTE: This SOP was created and adapted from Bernstein et al., 2016 by the Guelph Family Health Study Team to categorize sugars**

<table>
<thead>
<tr>
<th>Category</th>
<th>Code</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bakery Products</td>
<td>A</td>
</tr>
<tr>
<td>Beverages</td>
<td>B</td>
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<tr>
<td>Cereals and Grain Products</td>
<td>C</td>
</tr>
<tr>
<td>Dairy Products and Substitutes</td>
<td>D</td>
</tr>
<tr>
<td>Desserts</td>
<td>E</td>
</tr>
<tr>
<td>Fats, Oils and Vinegars</td>
<td>F</td>
</tr>
<tr>
<td>Fish/Seafood</td>
<td>G</td>
</tr>
<tr>
<td>Fruits</td>
<td>H</td>
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<tr>
<td>Meats, Eggs and Substitutes</td>
<td>I</td>
</tr>
<tr>
<td>Mixed Dishes, Sides and Entrees</td>
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</tr>
<tr>
<td>Nuts and Seeds</td>
<td>K</td>
</tr>
<tr>
<td>Other Foods and Beverages</td>
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<tr>
<td>Sauces, Dips and Condiments</td>
<td>M</td>
</tr>
<tr>
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<tr>
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<tr>
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Source: FLIP Database, University of Toronto. [Link](https://europepmc.org/backend/ptpmcrender.fcgi?accid=PMC5037566&blobtype=pdf)