The roles of cognitive biases, cravings, and inhibitory control in unhealthy beverage and food consumption

By

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CONTENTS

ABSTRACT

Excessive consumption of sugar-based soft drinks and unhealthy foods high in sugar, fat, and salt, has been recognized as a major public health concern and a significant factor contributing to the increasing prevalence of obesity globally. Current strategies to reduce soft drink consumption include soft drink taxation and promoting sugar-free alternatives. For unhealthy foods, public health initiatives have focused on their removal from environments such as schools, universities, and hospitals, as well as curbing the marketing of unhealthy foods, especially to children. However, these strategies have not been altogether successful. Notably, none of these strategies address the underlying mechanisms driving soft drink and unhealthy food consumption. Therefore, there is a need to explore alternative interventions that target such mechanisms, which may be more effective methods for reducing such consumption. Thus, the overarching aim of this thesis was to investigate the underlying mechanisms associated with soft drink and unhealthy food consumption and to assess the effectiveness of interventions targeting these mechanisms in reducing such consumption. Craving, the strong desire to consume a specific substance like drugs, alcohol, or food, was explored as one such mechanism. Furthermore, as dual-process models propose that behaviours are impacted by a combination of automatic (fast and unconscious) and controlled (slow and conscious) processes, cognitive biases and inhibitory (or self-regulatory) control were examined as potential predictors of appetitive consumption. Cognitive biases (automatic processing) refer to automatic inclinations that lead individuals to deviate from rational or objective thinking, whereas inhibitory control (controlled processing) refers to the ability to regulate behaviour or restrain impulsive actions. These mechanisms were the focus of investigation across a series of five studies.

Study 1 (Chapter 2), a cross-sectional study, investigated the roles of cognitive biases (evaluative, attentional, and approach biases) and inhibitory control in soft drink consumption. The results showed that evaluative bias, the automatic positive judgement of soft drinks, was the only cognitive bias associated with soft drink consumption. Lower inhibitory control was also associated with greater consumption, but only for men. Overall, Study 1 demonstrated that both automatic (evaluative bias) and controlled processes (inhibitory control) independently predict soft drink consumption.

Study 2 (Chapter 3), a second cross-sectional study, aimed to provide a thorough investigation of cravings for non-alcoholic beverages and their link to consumption. Participants reported cravings for a variety of non-alcoholic beverages, with coffee, soft drink, and water by far the most frequently craved. Unlike water cravings, which were primarily driven by thirst, coffee cravings were most often triggered by tiredness, while soft drink cravings were predominantly driven by external environmental cues. Across all beverages, as well as individually for soft drinks, stronger cravings were associated with a higher likelihood of drinking and consuming more of the

craved beverage. In addition, the number of cravings for coffee and soft drink each uniquely predicted how much of these beverages was drunk over the course of a week.

Study 3 (Chapter 4), a meta-analysis, sought to determine whether inhibitory control, as measured by the Go/No-Go and Stop-Signal tasks, is associated with food consumption. Overall, there was a small association between inhibitory control and food choice or consumption. This association remained significant when inhibitory control was measured using the Stop-Signal Task. However, when measured with the Go/No-Go Task, this association was only significant in children and when food choice or consumption was measured objectively.

Study 4 (Chapter 5), a second meta-analysis, investigated how parameter differences in Go/No-Go and Stop-Signal inhibitory control interventions impact the effectiveness of such tasks in reducing food consumption. Overall, inhibitory control training was found to reduce food choices or consumption, but this effect was separately significant only for training protocols using the Go/No-Go Task. Among Go/No-Go protocols, a single training session led to greater reductions in food choices or consumption compared to multiple sessions. Furthermore, the effectiveness of Go/No-Go protocols in reducing food choices or consumption was found to be robust across various demographic groups.

Study 5 (Chapter 6), an experimental study, investigated the individual and combined effects of evaluative conditioning and Go/No-Go inhibitory control interventions in reducing soft drink choices and consumption. Neither intervention successfully altered its respective targeted mechanism (evaluative bias and motor responses to soft drink cues, respectively). Additionally, neither intervention, whether used alone or together, reduced soft drink choices or consumption. However, there was a trend (although not statistically significant) indicating that inhibitory control training may reduce soft drink choices among men. Thus, it was concluded that Go/No-Go inhibitory control training may be particularly effective for men in reducing soft drink choices or consumption.

Overall, the present thesis provides evidence for the relationships between underlying mechanisms and the consumption of soft drinks and unhealthy foods. Specifically, it identifies key targets for potentially reducing such consumption, namely evaluative bias towards soft drink cues, inhibitory control, and cravings for soft drinks. Thus, this thesis offers a valuable and unique contribution to understanding and potentially addressing a significant public health concern, namely soft drink and unhealthy food consumption.

DECLARATION

I certify that this thesis:

1. does not incorporate without acknowledgment any material previously submitted for a degree or diploma in any university

2. and the research within will not be submitted for any other future degree or diploma without the permission of Flinders University; and

3. to the best of my knowledge and belief, does not contain any material previously published or written by another person except where due reference is made in the text.

Signed.....Joshua McGreen.....

Date.....27/11/2024.....

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CHAPTER ONE: GENERAL INTRODUCTION

Chapter Overview

This opening chapter of the thesis aims to provide a comprehensive background to the overconsumption of soft drinks and unhealthy foods, along with associated health implications. It outlines general strategies that have been employed to tackle this overconsumption and discusses the existing literature on the underlying mechanisms that drive such consumption. Specifically, the chapter introduces craving, cognitive biases, and inhibitory control, as underlying mechanisms of appetitive consumption, and potential avenues for reducing consumption of soft drinks and unhealthy foods. It further introduces dual-process models, which propose that behaviour results from a combination of controlled and automatic processes. In addition, it summarizes the current literature on interventions targeting cognitive biases and inhibitory control within the appetitive consumption domain. Finally, the chapter concludes with the presentation of the overarching aim of the thesis and an overview of the subsequent chapters.

Soft Drink and Unhealthy Food Consumption, and Health Implications

Excessive consumption of sugar-based soft drinks, such as carbonated beverages like Coca-Cola, and unhealthy foods, particularly those rich in sugar, fat, and salt, has been identified as a significant contributor to the rising prevalence of obesity worldwide (Cecchini et al., 2010; Machado et al., 2020; Pan & Hu, 2011; World Health Organization, 2017). In the case of sugar-based soft drinks, which are high in added sugars, excess consumption is particularly problematic because these drinks provide no nutritional value (World Health Organization, 2017). This pattern of overconsumption of both unhealthy foods and sugar-based soft drinks has been linked to various adverse health outcomes, including diabetes (Bray & Popkin, 2013; Sami et al., 2017), hypertension (Margerison et al., 2020), cardiovascular diseases such as heart disease and stroke (Anand et al., 2015), dental problems like tooth decay (Mobley et al., 2009; Vartanian et al., 2007), and mental health issues like depression (Ljungberg et al., 2020).

The World Health Organization (2017) recommends restricting the consumption of sugar-based soft drinks and unhealthy foods, emphasizing that even a single can of Coca-Cola can exceed daily sugar intake recommendations. Despite these warnings, the global consumption of both soft drinks and unhealthy foods remains high. Statistics indicate that a considerable proportion of adults in countries like Australia and the United States regularly

consume soft drinks, with estimates ranging from 40 to 50 percent in Australia (Miller et al., 2019; Roy Morgan Research, 2015) and approximately half of adults in the United States drinking at least one glass daily (Gallup Poll, 2012). Additionally, it has been reported that in the United States, around half of adults' daily energy intake comes from unhealthy foods or beverages, among which soft drinks play a significant role (Dunford et al., 2022). Moreover, the consumption of sugar-sweetened beverages, including soft drinks, accounts for over 40% of the total sugar intake derived from unhealthy food or beverage sources (Dunford et al., 2022). Globally, sales of unhealthy foods are on the rise, including in countries like Australia (Machado et al., 2020). Consequently, exploring potential interventions aimed at reducing the consumption of unhealthy foods and soft drinks is a crucial area of research.

Strategies for Reducing Soft Drink and Unhealthy Food Consumption

Current strategies aimed at reducing the consumption of sugar-based soft drinks include implementing soft drink taxation and, more recently, promoting sugar-free alternatives (Khan et al., 2023). For unhealthy foods, public health initiatives have focused on removing such foods from settings such as schools (Jacob et al., 2021), universities (Howse et al., 2017; Shi et al., 2018), and hospitals (Tinney et al., 2022), and reducing marketing of unhealthy foods to children (Dillman et al., 2023; World Health Organization, 2010).

None of these strategies, however, focus on the underlying mechanism that drives such intake. For example, while soft drink taxation has been implemented to curb such consumption, it may not effectively reduce overall sugar consumption because it does not directly address the underlying mechanisms that drive soft drink intake. Studies have indicated that reductions in soft drink consumption following taxation may be counteracted by increased consumption of other high-calorie beverages (Fletcher et al., 2010; Sacks et al., 2021). Moreover, recent advice from the World Health Organization (2023) cautions against replacing sugar with non-sugar sweeteners, commonly found in sugar-free soft drinks. This guidance is based on concerns that non-sugar sweeteners may not provide long-term benefits in reducing body fat and could potentially elevate the risk of developing type 2 diabetes, cardiovascular diseases, and mortality (World Health Organization, 2023). Hence, there is a need to explore alternative interventions that target the underlying mechanisms of soft drink and unhealthy food consumption to develop more effective strategies for reducing such intake.

Craving, defined as a strong desire to consume a specific substance like drugs, alcohol, or food (World Health Organization, 1993), has been investigated as one such mechanism underlying soft drink and unhealthy food consumption (Boswell & Kober, 2016; Falbe et al., 2019; Martin et al., 2008; May et al., 2004; Richard et al., 2017). Researchers have also investigated automatic (fast and unconscious) and controlled (slow and involving conscious decision-making) cognitive processes as potential predictors of both soft drink and unhealthy food consumption because dual-process models (Strack & Deutsch, 2004) posit that behaviours are influenced by a combination of automatic and controlled processes. In particular, investigation of automatic and controlled processes in the appetitive consumption domain has focused on cognitive biases and inhibitory (or self-regulatory) control as potential predictors of consumption (Ames et al., 2014; Appelhans et al., 2011; Carbine et al., 2017; de Bruijn et al., 2012; Larsen et al., 2012; Richetin et al., 2007; Shaw et al., 2016; Werthmann et al., 2011, 2014). A cognitive bias, a type of automatic processing, refers to an automatic tendency or inclination in human decision-making that can lead to inaccurate or suboptimal outcomes (MacLeod & Matthews, 2012; Tversky & Kahneman, 1974), whereas inhibitory control, a type of controlled processing, refers to the capacity to regulate behaviour or suppress behavioural impulses (Bari & Robbins, 2013; Houben et al., 2012).

Craving

Craving is a complex concept encompassing both physiological and psychological components (Meule, 2020). Physiologically, cravings may stem from factors such as nutritional deficiencies, dehydration, hormonal changes, or activation of reward-related brain areas (Alonso-Alonso et al., 2015; Chao et al., 2017; Morris et al., 2008; Popkin et al., 2010). Psychologically, they can be triggered by emotional states or environmental cues (May et al., 2012; Yau & Potenza, 2013). Theoretical models of craving, including the incentive-sensitization theory of addiction (Berridge & Robinson, 1995), the elaborated intrusion theory of desire (Kavanagh et al., 2005), and the cognitive processing model of craving (Tiffany, 1990; Tiffany & Conklin, 2000), all propose that cravings motivate consumption. This motivation has been supported by studies showing that cravings for food (Boswell & Kober, 2016; Martin et al., 2008; Richard et al., 2017), alcohol (Anton et al., 1995; Bottlender & Soyka, 2004; Fazzino et al., 2013; Flannery et al., 2003), and drugs (Galloway & Singleton, 2008; Hartz et al., 2001; Rohsenow et al., 2007) predict subsequent consumption or weight gain.

While cravings for non-alcoholic beverages, including sugar-based soft drinks, are less explored, preliminary evidence suggests that such cravings do occur (Falbe et al., 2019; May et al., 2004; Kemps & Tiggemann, 2009; Knäuper et al., 2011; Mills et al., 2016; May et

al., 2004). In the case of soft drinks, this finding aligns with the suggestion that sugar, a primary ingredient in such beverages, may be addictive (Avena et al., 2008; Wiss et al., 2018). Importantly, craving is considered a modifiable predictor of consumption (Berridge & Robinson, 1995; Kavanagh et al., 2005; Tiffany, 1990; Tiffany & Conklin, 2000), suggesting that it could be a target for interventions aimed at reducing excessive intake of these beverages. However, the link between cravings for non-alcoholic beverages, including sugar-based soft drinks, and subsequent intake has yet to be systematically investigated. Thus, given the gap in the literature, the present thesis aimed to provide a comprehensive understanding of cravings for non-alcoholic beverages, including sugar-based soft drinks, and to investigate their association with subsequent consumption.

Cognitive Biases and Inhibitory Control

One probable factor contributing to the rise in soft drink and unhealthy food consumption is the frequent exposure to such cues in the environment, as both soft drinks and unhealthy foods are heavily marketed (NCES, 2020; O'Dowd, 2017; UConn Rudd Center for Food Policy & Health, 2021) and are available 24/7. For example, research indicates that exposure to television advertising correlates with increased consumption of unhealthy foods (Kelly et al., 2016). Individual differences in responsiveness to these cues may be understood through dual-process models (Strack & Deutsch, 2004), and the proposition that behaviour is governed by automatic (e.g., cognitive biases) and controlled (e.g., inhibitory control) processes. In the case of cognitive biases, three major sources have been identified: evaluative bias, attentional bias, and approach bias. Evaluative bias refers to the automatic inclination to positively judge stimuli or cues (Field et al., 2005). Attentional bias involves the automatic focus of attention on one cue over others (MacLeod & Mathews, 2012). Approach bias refers to the automatic tendency to move toward a specific cue (Wiers et al., 2013). As such, following dual-process models (Strack & Deutsch, 2004), consumption is influenced by automatic processes (e.g., cognitive biases toward soft drink cues) and moderated by controlled processes (e.g., inhibitory control). Consequently, individuals exhibiting strong cognitive biases and/or low inhibitory control may be particularly susceptible to the effects of exposure to soft drink or unhealthy food cues.

The association between cognitive biases and appetitive consumption has been observed across various domains, including alcohol consumption (Cousijn et al., 2011) and drug use (Zhang et al., 2018). In the domain of unhealthy eating, evaluative, attentional, and approach biases towards food cues have each been linked to increased food consumption or choice (Brignell et al., 2009; de Bruijn et al., 2012; Richetin et al., 2007; Kemps & Tiggemann, 2015; Werthmann et al., 2011, 2014). Regarding soft drink consumption,

findings are limited to one study. In the sole study investigating the role of any cognitive bias in soft drink consumption, Shaw et al. (2016) reported that a more negative evaluative bias towards soft drink cues was associated with lower self-reported soft drink intake.

Likewise, the relationship between poorer inhibitory control and increased appetitive consumption has been observed in various domains, including unhealthy eating (Ames et al., 2014; Appelhans et al., 2011; Carbine et al., 2017; Guerrieri et al., 2007; He et al., 2014; Lavagnino et al., 2016; Lyu et al., 2017) and alcohol consumption (Jones et al., 2018; Weafer & Fillmore, 2008). However, while some studies have shown that individuals with poorer inhibitory control eat more unhealthy food, findings overall have been inconsistent, with other studies showing no such relationship (Aiello et al., 2018; Bennett & Blissett, 2019; Fonseca et al., 2020; Goldstein et al., 2014). Therefore, it is important to ascertain whether inhibitory control is indeed associated with food consumption. In this vein, the present thesis aimed to consolidate and analyse data from multiple studies to determine whether, and under which conditions, inhibitory control is associated with unhealthy food consumption.

In the case of soft drink consumption and inhibitory control, research that has focused specifically on soft drinks is again limited. In the only study investigating inhibitory control and soft drink consumption, Ames et al. (2014) found a relationship between lower inhibitory control and greater soft drink intake. Specifically, they observed that poorer inhibitory control was associated with increased self-reported consumption of sugar-sweetened beverages, among men.

Overall, dual-process models suggest that behaviour is best predicted by a combination of automatic and controlled processes (Strack & Deutsch, 2004). In support, research has shown that a strong approach bias (an automatic process) combined with poor inhibitory control (a controlled process) predicts increased consumption of snack foods (Kakoschke et al., 2015) and future alcohol intake (Peeters et al., 2013). Additionally, strong attentional bias for food cues combined with poor inhibitory control has been shown to predict loss of control over eating (Van Malderen et al., 2020) and unhealthy food choices (Zhang et al., 2017). Therefore, heightened soft drink intake or choice may also occur when automatic processes are activated (potentially in response to environmental cues) and inhibitory control is diminished.

Given the limited research that has focused specifically on soft drinks, the present thesis aimed to provide a comprehensive investigation of the roles of evaluative bias, attentional bias, approach bias, and inhibitory control in soft drink consumption.

Cognitive Bias and Inhibitory Control Interventions

Importantly, cognitive biases have been identified as potentially modifiable (Jones & Sharpe, 2017; Martinelli et al., 2022; Masterton et al., 2021; Mehl et al., 2019), with Cognitive Bias Modification techniques aimed at directly altering cognitive processes such as evaluative, attentional, and approach biases. For example, evaluative conditioning, a type of Cognitive Bias Modification, targets evaluative bias and involves changing unconscious attitudes through repeated pairing of an object with positively or negatively valanced stimuli (Hofmann et al., 2010; Houben et al., 2010). In the case of inhibitory control, protocols are frequently termed motor response training, as they focus primarily on altering motor responses rather than directly modifying inhibitory control (Masterton et al., 2021). Inhibitory control training protocols involve repeatedly pairing stimuli with stop cues, and aim to establish automatic inhibition associations and diminish explicit evaluations of the paired stimuli (Veling et al., 2017). Based on dual-process models (Strack & Deutsch, 2004), a change in unconscious attitude or inhibition will reduce consumption, as automatic processes, like evaluative bias, and controlled process, like inhibitory control, are posited to influence behaviour.

Recent studies have demonstrated that evaluative conditioning can effectively alter unconscious attitudes (Hofmann et al., 2010; Lebens et al., 2011; Wang et al., 2017). However, its effectiveness in reducing food consumption is not consistently supported (Bui & Fazio, 2016; Haynes et al., 2015; Hensels & Baines, 2016; Hofmann et al., 2010; Hollands et al., 2011; Lebens et al., 2011; Wang et al., 2017). Nonetheless, the sole study examining the impact of evaluative conditioning on soft drink intake found that this intervention led to a greater reduction in reported soft drink consumption compared to a control condition (Shaw et al., 2016). Moreover, Cognitive Bias Modification interventions targeting attentional bias and/or approach bias have been shown to strengthen avoidance tendencies away from unhealthy foods or cues (Kakoschke et al., 2018; Mehl et al., 2019; Navas et al., 2021; Yang et al., 2019) and reduce consumption or choice of unhealthy foods (Kakoschke et al., 2018; Navas et al., 2021; Yang et al., 2019). Nevertheless, it is worth noting that such findings are not consistent across studies (Masterton et al., 2021; Yang et al., 2019).

In addition, inhibitory control training protocols have demonstrated effectiveness in curbing unhealthy food consumption (Allom et al., 2016; Jones et al., 2016) and alcohol intake (Allom et al., 2016; Jones et al., 2016; Veling et al., 2017). Despite its efficacy in other domains, only one study has explored the effectiveness of inhibitory control training in reducing soft drink consumption, with no significant effect observed (Ames et al., 2016). However, participants who underwent inhibitory control training and also engaged in a sugar-

sweetened beverage implementation intention exercise structured as “If I see X, then I will resist it”, made fewer unhealthy drink choices compared to those in other conditions (Ames et al., 2016).

Given the limited research that has focused specifically on soft drinks, the present thesis aimed to investigate the efficacy of Cognitive Bias Modification interventions targeting evaluative bias, attentional bias, approach bias, and/or inhibitory control in reducing soft drink consumption.

Aims and Overview of the Present Thesis

The overarching aim of the present thesis was to investigate the underlying mechanisms associated with soft drink and unhealthy food consumption, and to determine the effectiveness of interventions that target these mechanisms for reducing consumption. Each chapter in the thesis had its own specific aims, which were informed by the findings of previous chapters. In particular, Chapter 2 presents a cross-sectional study (Study 1) which investigated the roles of cognitive biases (evaluative, attentional, and approach biases) and inhibitory control in soft drink consumption. Chapter 3 presents a cross-sectional study (Study 2) which provides a comprehensive account of naturalistic cravings for non-alcoholic beverages and their link to naturalistic consumption. Chapter 4 presents the results of a meta-analysis (Study 3) which aimed to determine whether, and under which conditions, inhibitory control, as measured by the Go/No-Go and Stop-Signal tasks, is associated with food consumption. Chapter 5 presents the results of a second meta-analysis (Study 4) which aimed to determine the effectiveness of Go/No-Go and Stop-Signal training in reducing food consumption. Chapter 6 presents an experimental study (Study 5) which investigated the individual and combined impact of evaluative conditioning and inhibitory control training in reducing soft drink consumption. Finally, Chapter 7 provides a general discussion, bringing together all the findings from the conducted research. The chapter also identifies theoretical and practical implications, and limitations of the thesis findings, and offers recommendations for future research. Excluding Chapters 1 and 7, all chapters have been formatted as manuscripts for publication. Chapter 2 (Study 1), Chapter 4 (Study 3), and Chapter 5 (Study 4) have each been published in the journal *Appetite*, and Chapter 3 (Study 2) has been published in the journal *Eating Behaviors*. Consequently, there is some overlap in the Introduction and Method sections of some of the chapters.

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CHAPTER TWO: THE PREDICTIVE VALUE OF EVALUATIVE BIAS, ATTENTIONAL BIAS, APPROACH BIAS, AND SELF-REGULATORY CONTROL IN SOFT DRINK CONSUMPTION

For the published version of this chapter, see:

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Abstract

Global consumption of soft drinks has increased rapidly over the past 50 years, making this a major public health problem. Guided by dual-process models, the present study aimed to provide a comprehensive investigation of the roles of cognitive biases (evaluative, attentional, and approach biases) and self-regulatory control in soft drink consumption and choice. Participants were 128 undergraduate students (17–25 years). They completed computer-based measures of the three biases (Implicit Association Task, Dot Probe Task, and Approach Avoidance Task) and self-regulatory control (Go/No-Go Task). Soft drink consumption and choice were measured using a taste test and a take home beverage choice task, respectively. Evaluative bias for soft drink cues was positively associated with the amount of soft drink consumed. Self-regulatory control was negatively correlated with amount of soft drink consumed, but only for men. There was no interaction between cognitive biases and self-regulatory control in predicting soft drink consumption or choice. Nonetheless, the results support the application of dual-process models to soft drink consumption in that automatic (evaluative bias) and controlled processes (self-regulatory control) each predicted amount of soft drink consumed, albeit independently and only for certain individuals. Future research should extend these findings to habitual soft drink consumers and to individuals who actively wish to limit their soft drink intake.

Keywords: evaluative bias, self-regulatory control, dual-process models, soft drink consumption, soft drink choice.

Introduction

Global consumption of soft drinks (carbonated non-alcoholic drinks containing sugar e.g., Coca-Cola, Fanta) has increased rapidly over the past 50 years (Basu et al., 2013; GBD 2016 Risk Factors Collaborators, 2017; Tahmassebi & BaniHani, 2020). Approximately

40–50 percent of adults in Australia consume at least one soft drink per week (Miller et al., 2019; Roy Morgan Research, 2015), while approximately 50 percent of adults in the United States drink at least one glass of soft drink per day (Gallup Poll, 2012). Young adults aged 17–25 years are the core consumers of soft drinks (Miller et al., 2019; Roy Morgan Research, 2015). The increased consumption of sugar in the form of soft drinks has become a major public health problem, contributing to excess weight gain (Pan & Hu, 2011), increased risk of dental caries (Vartanian et al., 2007), increased risk of diabetes (Bray & Popkin, 2013), and poor academic performance (Ickovics et al., 2014).

One strategy to curb the increase in soft drink consumption is a tax on soft drinks, which has been considered and/or introduced in several countries (Capacci et al., 2019). However, taxing soft drinks does not address the underlying mechanisms that drive soft drink consumption; nor does it empower individuals to regulate their own consumption behaviour. Moreover, a tax on soft drinks may not have the intended impact of reducing sugar consumption. Although soft drink taxation in some states in the US has led to moderate reductions in soft drink consumption, these have been shown to be offset by increased consumption of alternative high-calorie drinks (Fletcher et al., 2010). Therefore, investigating the mechanisms underlying soft drink consumption may point to other targets for more effective intervention.

One likely contributing factor to the increase in soft drink consumption is repeated exposure to soft drink cues. Soft drinks are now available/accessible 24/7 from supermarkets, petrol stations, convenience stores, and vending machines. Soft drinks are also heavily marketed. For example, in the United States alone, Coca-Cola Company spent more than 280 million dollars advertising Coca-Cola in 2019 (NCES, 2020).

There are likely to be individual differences in responsiveness to soft drink cues. These may be explained in terms of dual-process models (Strack & Deutsch, 2004), which propose that behaviour is controlled by two types of processes: automatic and controlled processes (Strack & Deutsch, 2004). Automatic processes (e.g., cognitive biases) are unconscious, automatic, and fast, whereas controlled processes (e.g., self-regulatory control) are slow and reflective, involving conscious decision-making. Cognitive biases (an example of automatic processing) are systematic biases in thinking that occur in response to cues or environmental stimuli (MacLeod & Mathews, 2012). Three major sources of cognitive bias have been identified: evaluative bias refers to automatic positive judgement of stimuli/cues (Field et al., 2005); attentional bias to the automatic focus of attention to one cue over others (MacLeod & Mathews, 2012); and approach bias to the automatic tendency to move towards a particular cue (Wiers et al., 2013). On the other hand, self-regulatory (or

inhibitory) control, a type of controlled processing, refers to the ability to regulate behaviour or inhibit behavioural impulses in accordance with higher order goals (Houben et al., 2012). Consumption, then, is guided by automatic processes (e.g., cognitive biases for environmental cues) and regulated by controlled processes (e.g., self-regulatory control). Accordingly, individuals with strong cognitive biases and/or low self-regulatory control may be especially vulnerable to exposure to soft drink cues.

Relationships between cognitive biases and appetitive consumption have been demonstrated in domains such as unhealthy eating, alcohol consumption, and cannabis usage. For example, evaluative and attentional biases to food cues have each been shown to be associated with increased consumption and choice of food (de Bruijn et al., 2012; Richetin et al., 2007; Werthmann et al., 2011, 2014); and heavy cannabis users with strong approach biases are more likely to engage in increased cannabis usage (Cousijn et al., 2011). However, not all studies have consistently shown a relationship between cognitive biases for cues and appetitive consumption (Christiansen et al., 2015; Larsen et al., 2012). In the only study to investigate the role of any bias in soft drink consumption, Shaw et al. (2016) found that a more negative evaluative bias for soft drink cues was associated with less self-reported soft drink consumption.

Relationships between low self-regulatory control and increased appetitive consumption have also been demonstrated in a number of domains, such as unhealthy eating and alcohol consumption (Ames et al., 2014; Appelhans et al., 2011; Carbine et al., 2017; Jones et al., 2018; Weafer & Fillmore, 2008). In the only study to investigate the role of self-regulatory control in soft drink consumption, Ames et al. (2014) showed that low scores on a measure of general self-regulatory control were associated with greater self-reported consumption of sugar-sweetened beverages (including soft drinks and fruit juice) in men, but not in women.

Bringing these factors together, dual-process models further suggest that behaviour may be best predicted by a combination of automatic and controlled processes. In support, it has been shown that a strong approach bias coupled with low self-regulatory control predicts increased snack food consumption (Kakoschke et al., 2015) and future alcohol consumption (Peeters et al., 2013). Furthermore, the combination of a strong attentional bias for food cues and weaker self-regulatory control has been shown to predict loss of control over eating (Van Malderen et al., 2020) and food choice (Zhang et al., 2017). Therefore, increased soft drink intake or choice may occur when automatic processes (e.g., cognitive biases) are sensitized (in response to environmental cues) and self-regulatory control is low.

The Current Study

Thus, given the limited research on soft drinks, the present study aimed to provide a comprehensive investigation of the roles of evaluative, attentional, and approach biases for soft drink cues, as well as self-regulatory control, in the amount of soft drink consumed and soft drink choice using objective measures. Our main prediction was that:

1. The three cognitive biases would each be positively correlated with the amount of soft drink consumed in a taste test and the likelihood of choosing a soft drink to take home, and that self-regulatory control would be negatively correlated.
2. On the basis of dual-process models, we further predicted that each of the biases would interact with self-regulatory control such that individuals with strong cognitive biases coupled with low self-regulatory control would consume and choose the most soft drink.

Method

Participants

Participants were 128 undergraduate students at Flinders University, including volunteer first-year Psychology students (81 women and 38 men) who received course credit, and undergraduate students who were reimbursed $20 for their participation (7 women and 2 men). Sample size was adequate to detect at least a moderate-sized effect with an alpha level of 0.05 and 90% power for all analyses (Faul et al., 2009). For correlational analyses, the minimum detectable effect was r = 0.18. For hierarchical linear regression with 5 control variables and 3 test variables, the minimum detectable effect for single variables was Cohen's f^2 = 0.03. The sample consisted of young adults ranging in age from 17 to 25 years (M = 19.77, SD = 1.99) because young adults are the core consumers of soft drinks (Miller et al., 2019; Roy Morgan Research, 2015). In addition, only participants who did not have any food or drink allergies or intolerances were included, as the study involved a taste test. Mean BMI of the sample was 24.28 kg/m^2 (SD = 5.97), indicating normal weight (Centers for Disease Control and Prevention, 2020). Most participants reported consuming a soft drink every month (25.0%), followed by every fortnight (23.4%) and every week (18.8%). Mean liking of soft drinks was around the midpoint of the scale, as rated on a 100 mm visual analogue scale ranging from “not at all” to “very much” (M = 41.15, SD = 22.45). Current level of thirst, rated on a similar scale ranging from “not at all thirsty” to “extremely thirsty”, was also around the midpoint of the scale (M = 48.08, SD = 19.45).

Materials

Cognitive Biases and Self-Regulatory Control Task Stimuli

The stimuli for the cognitive bias and self-regulatory control tasks were taken from a common set of 68 pictures of soft drinks and water (control). The soft drink pictures consisted of two broad categories of sugar-based soft drinks: Cola (e.g., Coca Cola, Pepsi) and lemon-based drinks (e.g., Solo, Schweppes Lemonade, Mountain Dew). These were used as they are the most popular sugar-based soft drinks in Australia (Roy Morgan Research, 2015). The water pictures comprised plain water (e.g., Mount Franklin, Evian, Aqua Pura), and sparkling water (e.g., Schweppes Soda Water, Mount Franklin Sparkling Water). Pictures of water were used for the comparison control condition because water is a healthy, sugar-free alternative to soft drinks. The soft drink and water pictures comprised bottled, canned, and in-glass variants of the drinks to reflect common real-world variations of each drink. The soft drink and water pictures were sourced from Google Images. All pictures were standardized to ensure they were visually similar, i.e., the same size (whilst maintaining the pictures' original aspect ratio) against a white background.

Evaluative Bias

Evaluative bias for soft drink cues was measured using a personalized, recoding free version of the Implicit Association Test (IAT-RF, Rothermund et al., 2009). The test used 10 soft drink pictures, 10 water pictures, 10 pictures with positive associations (e.g., a cute animal), and 10 pictures with negative associations (e.g., a dirty toilet). The positive and negative pictures were taken from the International Affective Picture System (IAPS) database (Lang et al., 2008).[1] Participants completed three blocks: (i) associated attribute discrimination (Block 1); (ii) target-concept discrimination (Block 2); and (iii) combined task (Block 3).

Blocks 1 and 2 each consisted of 40 trials, and Block 3 consisted of 80 trials. In each block, participants were instructed to categorize each picture as quickly as possible, according to the category labels displayed in the top left and top right hand corners of the computer screen. The location of the category labels was counterbalanced across participants. Each picture was presented in the centre of the computer screen and remained there until the participant responded. Participants responded using the "Z" key for left and the "/" key for right, labelled "L" and "R", respectively. Participants were instructed to focus on the centre of the screen. The inter-trial interval was 400 ms.

In Block 1, the category labels "I like" and "I dislike" were displayed in the top left and top right hand corners of the screen. Participants were instructed to categorize each of the pictures with positive or negative associations according to the categories labelled "I like" and "I dislike". Each picture was presented twice in a new random order for each participant,

with constraints such that: (i) the same picture was not repeated on consecutive trials; and (ii) the same response (left or right) occurred on no more than three consecutive trials.

In Block 2, the category labels “soft drink” and “water” were displayed in the top left and top right hand corners of the screen. However, the location of the category labels switched randomly between trials. Participants were instructed to categorize each of the beverage pictures according to whether it was a “soft drink” or “water”. Category labels were displayed for 1500 ms before the picture was displayed and removed following the participant's response. Each picture was presented twice in a new random order for each participant, with the same constraints as for Block 1, but with the additional constraint that each picture had to be responded to once with the left (“L”) key and once with the right (“R”) key.

In Block 3, the category labels “I like”, “I dislike”, “soft drink”, and “water” were displayed in the top left and top right hand corners of the screen. The location of the category labels “soft drink” and “water” switched randomly between trials, but the category labels “I like” and “I dislike” remained in a constant position. Therefore, for each trial, two category labels were displayed in each corner of the screen, with the “soft drink” and “water” category labels displayed underneath the “I like” and “I dislike” category labels. Half of the trials were congruent (i.e., “I like” and “soft drink” versus “I dislike” and “water”), and the other half were incongruent (i.e., “I like” and “water” versus “I dislike” and “soft drink”). Participants were instructed to categorize each picture according to the category labels “I like” and “I dislike”, and the category labels “soft drink” and “water”. Category labels were displayed for 1500 ms before the picture was displayed and removed following the participant's response. Each picture was presented twice in a new random order for each participant, with the same constraints as for Block 2, but with the additional constraint that the congruent and incongruent trials were randomly intermixed throughout the block.

Evaluative bias was calculated using the D600 algorithm (Greenwald et al., 2003). The D600 score excludes response times greater than 10,000 ms as these are deemed delayed, as well as participants with more than 10% of trials faster than 300 ms as these responses are deemed anticipatory. The D600 score then adds an error penalty, such that response time for each error trial is computed as the mean response time in Block 3 plus an additional 600 ms (Greenwald et al., 2003). The difference in mean response time between the congruent and incongruent trials in Block 3 is then divided by the standard deviation for all trials. A positive score indicates a positive evaluative bias for soft drink cues. Split-half reliability for the IAT in the present study was acceptable, $r_{SB} = 0.67$.

Attentional Bias

Following Kakoschke et al. (2014), a soft drink specific version of the visual dot probe task was created to measure attentional bias for soft drink cues. The task used 20 soft drink pictures and 40 water pictures, such that there were 20 soft drink-water picture pairings (experimental) and 20 water-water picture pairings (neutral). The picture pairs were displayed on the computer screen such that one picture was presented on the left side of the screen and the other on the right side of the screen. The pictures were displayed 80 mm apart, such that each picture was 40 mm from the centre of the screen.

The task involved 12 practice trials and 160 test trials. The practice trials used "non-drink" picture pairs (e.g., duck-umbrella) derived from Kemps et al. (2014). The test trials consisted of 80 experimental trials (i.e., soft drink-water picture pairs) and 80 neutral trials (i.e., water-water picture pairs). All experimental and neutral pairs were presented 4 times, so all combinations of picture location and probe location were presented. Each trial consisted of the following sequential procedure: (i) a fixation cross was displayed in the centre of the computer screen for 500 ms; (ii) the picture pair was then displayed for 500 ms; (iii) a probe stimulus (i.e., a small black dot) appeared in the location of one of the pictures until the participant responded. Participants indicated, as quickly and accurately as possible, whether the probe stimulus replaced the left or right picture by pressing the associated key (i.e., "L" (Z) or "R" (/) on the computer keyboard). The inter-trial interval was 500 ms. Response time was measured in milliseconds. Attentional bias was measured as the difference in mean response time between the soft drink probe location trials and the water probe location trials, where a positive score indicates an attentional bias for soft drink cues. Split-half reliability for the visual dot probe task in the present study was low, $r_{SB} = 0.29$.

Approach Bias

The Approach Avoidance Task (AAT; Rinck & Becker, 2007) was used to measure approach bias for soft drink cues. The task used 20 soft drink pictures and 20 water pictures. Two versions of each picture were created: a landscape orientation and a portrait orientation version.

The task involved 12 practice trials and 80 test trials. The practice trials used neutral, "non-drink" pictures. All practice pictures were shown once, with half presented in portrait orientation and half in landscape orientation. Following the practice trials, there were 40 trials with soft drink pictures and 40 trials with water pictures. Participants responded to each picture using a computer joystick, by either pulling the joystick towards themselves or pushing the joystick away from themselves. Pulling the joystick caused the picture to become larger and appear "closer" (i.e., approach), whereas pushing the joystick caused the

picture to become smaller and appear “further away” (i.e., avoidance). Half of the participants responded to pictures in portrait orientation by pulling the joystick and to pictures in landscape orientation by pushing the joystick, and vice versa for the other half. Trials were presented in random order, with the constraints that: (i) the same picture was not repeated on consecutive trials; (ii) the same picture category (soft drink or water) occurred on no more than 3 consecutive trials; and (iii) the same response (push or pull) occurred on no more than 3 consecutive trials. Each picture was presented twice, such that every combination of picture and orientation was presented. Final response time for the pull and push responses was measured in milliseconds. Approach bias was measured as the difference in mean response time between trials that paired soft drink pictures with push responses and soft drink pictures with pull responses, where a positive score indicates an approach bias for soft drink cues. Split-half reliability for the AAT in the present study was low, $r_{SB} = 0.44$.

Self-Regulatory Control

A soft drink specific version of the Go/No-Go task (Houben & Jansen, 2011) was created to measure self-regulatory control. The task consisted of 8 practice trials and 168 test trials. The practice trials used 8 neutral, non-drink pictures. The test trials used 7 soft drink pictures and 7 water pictures. Participants were instructed to either press “the space bar” if they saw the “go” cue (the letter “p”), or do nothing if they saw the “no-go” cue (the letter “f”). The letters used to designate cues were counterbalanced across participants. The “go” and “no-go” cues were displayed randomly in one of four locations over the picture (i.e., top right, top left, bottom right, or bottom left). For each trial, the picture appeared in the centre of the screen (together with the “go” or “no-go” cue) for 1500 ms.

The practice trials presented each neutral picture once, with half presenting the letter “p” (once in each of the four locations) and half the letter “f” (once in each of the four locations). The test trials consisted of 112 “go” trials and 56 “no-go” trials, presented in random order. There were more “go” trials than “no-go” trials to increase the task difficulty and to ensure that the “no-go” trials tested self-regulatory control (Young et al., 2017). Each picture was presented 4 times in the “no-go” trials and 8 times in the “go” trials, such that every combination of cue, picture, and cue location was presented. Soft drink specific self-regulatory control was assessed by the number of commission errors for soft drink picture trials (i.e., participant pressed the space bar in response to a “no-go” cue). For ease of interpretation, commission errors were reverse scored, such that a higher number indicates a higher level of self-regulatory control. Split-half reliability for the Go/No-Go task in the present study was low, $r_{SB} = 0.37$.

Soft Drink Consumption

The amount of soft drink consumed was measured using a taste test, an established and validated measure of intake (Robinson et al., 2017). Participants were presented with four matching cups filled equally (each cup weighing 265 g) containing Coca Cola, Schweppes Lemonade, water, or sparkling water. The cups were presented to participants on a tray. The presentation of the drinks was counterbalanced across participants using a 4 × 4 Latin square. Participants were instructed to taste each of the drinks and rate them on several dimensions (e.g., sweetness). Participants were given 10 minutes to complete the task and told: (i) to taste and think about the drinks carefully; (ii) to drink as much of the drinks as needed to make their ratings as accurate as possible; (iii) that once their ratings were completed, they were free to go back and sample more of the drinks if they wanted, as any left-overs would be thrown away; and (iv) to not change their initial ratings. Following the taste test, each cup was weighed to the nearest gram, to determine the amount of each drink consumed relative to the baseline weight.

Soft Drink Choice

To assess soft drink choice, participants were given the opportunity to choose a bottled/canned drink to take home, as a token of appreciation for their participation, from a selection of 4 drinks: Coca Cola (can), Schweppes Lemonade (can), plain water (bottle), or sparkling water (can). Each of the drink options contained 250 mL. The drinks were presented on a tray. The choice of water or sparkling water was coded “0” (water), and Coca Cola or Schweppes Lemonade was coded “1” (soft drink).

Procedure

Participants were tested individually in a quiet room in the Food Laboratory at Flinders University. After providing written informed consent, participants provided background information and rated their current level of thirst. They then completed the Implicit Association Test, the Visual Dot Probe Task, the Approach Avoidance Task and the Go/No-Go Task, in counterbalanced order. Next, participants completed the taste test. The researcher then measured participants’ height and weight to calculate body mass index (kg/m^2). Lastly, participants chose a drink to take home with them.

Results

Data Preparation

As is standard practice for calculating attentional and approach bias scores, incorrect trials as well as response times 2.5 standard deviations above or below the mean were excluded. The percentage of attentional and approach bias trials excluded was 3.07% and 4.03%, respectively. Following the protocol for calculating the D600 algorithm (Greenwald et

al., 2003), evaluative bias data from one participant was excluded, as more than 10% of trials were faster than 300 ms.

Relationships between Cognitive Biases and Amount of Soft Drink Consumed and Soft Drink Choice

One-sample *t*-tests were used to investigate whether the sample as a whole showed evaluative, attentional, and approach biases for soft drink cues. Means are presented in Table 1. Approach bias for soft drink cues was significantly different from zero, $t(127) = 2.58$, $p = .011$, $d = 0.23$, whereas evaluative bias, $t(126) = 1.98$, $p = .050$, $d = 0.18$, and attentional bias, $t(127) = 1.89$, $p = .061$, $d = 0.17$, were in the positive direction but fell just short of statistical significance.

Correlational analyses were conducted to investigate the relationships between evaluative, attentional, and approach biases for soft drink cues, and the amount of soft drink consumed and soft drink choice. Correlation coefficients are shown in Table 2. Evaluative bias was positively correlated with the amount of soft drink consumed, $r = 0.18$, $p = .044$ (scatterplot in Figure 1), but not with soft drink choice. Attentional and approach biases were not significantly associated with either outcome variable.

Differences between men and women were also investigated post hoc because men consumed significantly more soft drink than women in the taste test, $t(126) = 3.75$, $p < .001$, $d = 0.71$ (see Table 1). Independent samples *t* tests showed that there were no significant differences between men and women on any of the biases (all $t's < 1.26$, $p's > 0.211$). Correlational analyses showed that attentional bias was negatively correlated with soft drink choice for men, $r = -0.32$, $p = .045$; all other correlations were not significant.

Relationships between Self-Regulatory Control and Amount of Soft Drink Consumed and Soft Drink Choice

The results of correlational analyses between self-regulatory control, as measured by number of commission errors, and the amount of soft drink consumed and soft drink choice are also presented in Table 2. It can be seen that for the sample as a whole, self-regulatory control was not significantly correlated with either outcome.

Self-regulatory control did not differ significantly between men and women, $t(126) = 0.11$, $p = .913$. However, self-regulatory control was negatively correlated with the amount of soft drink consumed in the taste test for men, $r = -0.33$, $p = .036$ (scatterplot in Figure 2), but clearly not for women, $r = -0.04$, $p = .728$. Self-regulatory control did not correlate with soft drink choice for either gender.

Interactions between Cognitive Biases and Self-Regulatory Control

A hierarchical linear regression was conducted to investigate the interactions between evaluative, attentional, and approach biases for soft drink cues and self-regulatory control, in predicting the amount of soft drink consumed. A parallel logistic regression was used to investigate the interactions in predicting soft drink choice. For both analyses, the predictor variables were mean centred, and interaction product terms were computed using mean centred variables to reduce the risk of multicollinearity. Three product terms were calculated, for each combination of evaluative, attentional, or approach bias, with self-regulatory control. For both analyses, evaluative bias, attentional bias, approach bias, self-regulatory control, and gender were entered in Step 1. The interaction product variables were then entered in Step 2.

The regression analyses showed that the product terms did not explain any significant additional variance over the main effects in either the amount of soft drink consumed, $R^2_{CHANGE} = 0.014$, $F_{CHANGE}(3, 118) = 0.65$, $p = .583$, or in soft drink choice, Nagelkerke $R^2_{CHANGE} = 0.024$, $\chi^2(3) = 2.36$, $p = .501$. Thus, there were no significant interactions between cognitive biases and self-regulatory control in predicting either outcome variable.

These analyses were repeated for men and women separately. For both men and women, there were no significant interactions between cognitive biases and self-regulatory control in the prediction of amount of soft drink consumed (men, $R^2_{CHANGE} = 0.078$, $F_{CHANGE}(3, 32) = 1.10$, $p = .363$; women, $R^2_{CHANGE} = 0.020$, $F_{CHANGE}(3, 79) = 0.56$, $p = .644$) or soft drink choice (men, Nagelkerke $R^2_{CHANGE} = 0.115$, $\chi^2(3) = 4.31$, $p = .230$; women, Nagelkerke $R^2_{CHANGE} = 0.025$, $\chi^2(3) = 1.74$, $p = .629$).

Discussion

The present study aimed to provide a comprehensive investigation of the roles of evaluative, attentional, and approach biases for soft drink cues, as well as self-regulatory control, in the amount of soft drink consumed and soft drink choice. For the sample as a whole, evaluative bias was associated with a greater amount of soft drink consumed in the taste test, but not with the likelihood of choosing a soft drink to take home. Neither attentional bias nor approach bias was associated with amount of soft drink consumed or the likelihood of choosing a soft drink. While self-regulatory control was not associated with the amount of soft drink consumed nor with the likelihood of choosing a soft drink for the total sample, for men, lower self-regulatory control was associated with greater consumption of soft drink in the taste test. There was no evidence to support any interaction between strong

biases for soft drink cues and low-self-regulatory control in predicting the amount of soft drink consumed or the likelihood of choosing a soft drink.

The sample as a whole showed an approach bias for soft drink cues, and trends towards significance for evaluative and attentional biases for such cues. Although the present study used a general sample with a wide range of soft drink consumers, participants were collectively susceptible to environmental exposure to soft drink cues. The results suggest that heavy soft drink marketing and repeated exposure to soft drinks and images of soft drinks in the environment may manifest in cognitive biases for young adults in general. Of course, it is likely that such biases would be stronger in habitual or heavy consumers of soft drink.

The finding that evaluative bias for soft drink cues was associated with the amount of soft drink consumed suggests that automatic positive evaluations of soft drink cues may be an important factor in soft drink consumption. This is consistent with findings in other domains, such as food and alcohol consumption (de Bruijn et al., 2012; Ostafin & Palfai, 2006). More importantly, it extends Shaw et al.'s (2016) finding that a more negative evaluative bias for soft drink cues was associated with less self-reported soft drink consumption by demonstrating a relationship between evaluative bias and an objective measure of amount of soft drink consumed (taste test). Evaluative bias for soft drink cues may be related to soft drink consumption because soft drink cues, through learned association, become associated with the intrinsically rewarding aspect of soft drink consumption, i.e., sugar (Avena et al., 2008; Volkow et al., 2008; Volkow & Wise, 2005). Therefore, for individuals with automatic positive evaluations of soft drinks, exposure to soft drink cues may sensitize these evaluations, activate brain reward regions, and accordingly, increase the automatic desire for soft drink and ultimately, the amount of soft drink consumed.

In contrast, attentional and approach biases for soft drink cues did not predict the amount of soft drink consumed. These findings are not consistent with some previous studies on food consumption (de Bruijn et al., 2012; Richetin et al., 2007; Werthmann et al., 2011, 2014), but in line with Christiansen et al. (2015) who found that attentional bias was not associated with substance use. The difference in results between evaluative bias and attentional/approach biases for soft drink cues here may be explained by the nature of the different cognitive biases. Evaluative bias is an affective bias (involving automatic appraisal), whereas attentional bias and approach bias are cognitive and physical biases, respectively (Field et al., 2005; MacLeod & Mathews, 2012; Wiers et al., 2013). It may be that automatic affective responses such as evaluative bias play a relatively larger role in soft drink

consumption, compared to automatic cognitive (attentional bias) or physical (approach bias) responses because soft drinks are so heavily marketed. Soft drink marketing often associates soft drinks with positive emotions such as ‘having fun with friends’, ‘being cool’, or ‘happiness’ (Brownbill et al., 2018). More generally, according to cognitive models (Cisler & Koster, 2010), automatic evaluations occur before attentional or approach tendencies.

Although there was no association between self-regulatory control and the amount of soft drink consumed for the sample as a whole, low self-regulatory control was associated with consuming a greater amount of soft drink for men, but not for women. This gender difference parallels exactly that reported by Ames et al. (2014) for self-reported sugar-sweetened beverage consumption. The present study refines this to soft drinks in particular and extends the finding using an objective measure of consumption (taste test). Thus, preliminary evidence from two different studies with different samples and methodologies has shown that low self-regulatory control is related to men's, but not women's, consumption of soft drinks. Ames et al. (2014) explained their result by suggesting that gender differences in self-regulatory control and eating behaviour may translate to greater habitual responding to sugary foods/beverages in men, and hence more difficulty resisting such foods during no-go trials.

For the sample as a whole, none of the biases for soft drink cues or self-regulatory control were associated with the likelihood of choosing a soft drink to take home. It is possible that this results from the taste test occurring before the take home beverage choice task. Thus, any potential behavioural impulse or automatic desire for soft drink consumption elicited through exposure to the soft drink cues may have been satisfied when participants were given the opportunity to consume soft drink in the taste test. Future research might investigate the relationships between cognitive biases, self-regulatory control, and beverage choice in the absence of a preceding taste test.

One unexpected finding was that for men (but not women) attentional bias for soft drink cues was associated with an increased likelihood of choosing water to take home. There is no obvious explanation for this finding, given that men and women both chose water to take home at similar rates. It is possible that the men's choice was a reaction to them drinking considerably more soft drink than women in the taste test.

In contrast to prediction, there was no evidence to support the proposed interactions between strong biases for soft drink cues and low self-regulatory control in predicting soft drink consumption and choice. These findings do not support the aspect of dual-process models that proposes consumption is regulated by a combination of automatic and

controlled processes (Strack & Deutsch, 2004). Instead, the results suggest that evaluative bias for soft drink cues (an automatic process) and self-regulatory control (a controlled process), albeit for men only, may each be independently associated with amount of soft drink consumed. This is not consistent with some recent food and alcohol studies which showed that the combination of strong biases and low self-regulatory control predicted consumption or choice of food (Kakoschke et al., 2015; Peeters et al., 2013; Van Malderen et al., 2020; Zhang et al., 2017).

The present findings for soft drinks are both similar and different from those generally obtained for food. Soft drinks may differ from food because soft drink consumption is much more discretionary (Vartanian et al., 2007). People need to eat, and even unhealthy food serves to satisfy hunger and supply some nutrients, whereas people do not need to ever drink soft drink. Accordingly, soft drink consumption may be driven less by homeostatic states such as thirst or hunger, but instead, more by individual differences in affective associations (evaluative bias). In addition, soft drinks and food are marketed differently. While soft drinks are often associated with positive emotions (Brownbill et al., 2018), food advertising tends to highlight aspects such as ‘taste’, ‘convenience’, or ‘health’ (Kim et al., 2009; Manganello et al., 2013; Tan et al., 2018). Furthermore, in contrast to many foods, the major component of soft drink is sugar which has been argued to be addictive (Avena et al., 2008; Wiss et al., 2018).

Overall, the present results have some practical implications. The results support the application of dual-process models to soft drink consumption in that automatic processes (evaluative bias) and controlled processes (self-regulatory control) each predicted the amount of soft drink consumed, albeit independently and only for certain individuals. Furthermore, the results suggest that cognitive biases for soft drink cues may be present within the general population and that exposure to soft drink cues in the environment may sensitize evaluative, attentional, and approach biases for soft drink cues. Future research should extend these findings obtained in a general sample to habitual soft drink consumers and those who are actively trying to limit their soft drink intake. If confirmed, the findings may point to evaluative bias for soft drink cues and self-regulatory control as potential targets for reducing soft drink consumption. Future research could then investigate the impact of reducing evaluative bias and/or strengthening self-regulatory control on problematic soft drink consumption.

As with all research, there are a number of limitations that need to be acknowledged. First, the study was powered to detect a moderate-sized effect for all analyses but not a small-sized effect (a sample size of 758 participants would have been needed). Relatedly,

the significant correlations were not sufficiently large to survive corrections for multiple testing. Second, the sample consisted of young adults who are the core consumers of soft drinks. However, children and older adults also drink soft drinks and so future research should investigate the roles of cognitive biases and self-regulatory control in the soft drink consumption of other demographic groups. Third, although the present study tested specific hypotheses, it was not pre-registered. Fourth, as is often found for cognitive bias and inhibitory control measures (e.g., Brown et al., 2014; Czapla et al., 2016; Kahveci et al., 2020; Rodebaugh et al., 2016), split-half reliability of the dot probe, approach avoidance and go/no-go tasks was low. Finally, we used the original dot probe task, which has been criticized for allowing participants to ignore the two stimuli and focus on the centre of the screen. Future research might employ the probe classification version of the task instead (Mogg & Bradley, 1999).

In conclusion, the present study found that evaluative bias for soft drink cues, but not attentional or approach bias, was associated with a greater amount of soft drink consumed in a taste test. For men, low self-regulatory control was also associated with a greater amount of soft drink consumed. However, in contrast to the predictions of dual-process models, there was no evidence of any interaction between strong biases for soft drink cues and low-self-regulatory control. Future research should investigate these processes in a sample of habitual soft drink consumers.

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Contributors

All authors contributed to the design of the study and writing the manuscript. Joshua McGreen was responsible for data collection, under supervision of Eva Kemps. Joshua McGreen conducted the statistical analyses and wrote the first draft of the manuscript. All other authors edited subsequent drafts of the manuscript, and have approved the final manuscript.

Data and code availability

All data used in the study are available from the corresponding author who has full access to the data reported in the manuscript.

Ethical statement

The study protocol was approved by the Flinders University Social and Behavioural Research Ethics Committee. Participants gave informed consent before taking part.

Declaration of competing interest

None.

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Table 1

Means (standard deviations) for evaluative, attentional, and approach biases, self-regulatory control, amount of soft drink consumed, and soft drink choice

		***Mean* (*SD*)**		
		All (*N* = 128)	**Men (*N* = 40)**	**Women (*N* = 88)**
Cognitive biases				
	Evaluative bias (D600 score)	0.07 (0.39)	0.09 (0.35)	0.06 (0.40)
	Attentional bias (milliseconds)	2.23 (13.98)	4.63 (12.41)	1.29 (14.58)
	Approach bias (milliseconds)	20.52 (92.78)	11.66 (90.72)	25.44 (93.74)
Self-regulatory control				
	Reversed commission errors	-0.72 (1.09)	-0.75 (1.15)	-0.73 (1.07)
Soft drink outcomes				
	Amount of soft drink consumed (grams)	189.67 (96.77)	234.65 (96.65)	168.95 (89.55)
	Soft drink choice	0.43 (0.50)	0.45 (0.50)	0.42 (0.50)

Note. Soft drink choice (0 = water, 1 = soft drink).

Table 2

Correlation matrix for the relationships between evaluative, attentional, and approach biases, self-regulatory control, amount of soft drink consumed, and soft drink choice

	All (*N* = 128)		**Men (*N* = 40)**		**Women (*N* = 88)**	
	r	***p***	***r***	***p***	***r***	***p***
	Amount of soft drink consumed (grams)					
Evaluative bias (D600 score)	.18	.044	.24	.141	.16	.151
Attentional bias (milliseconds)	-.00	.929	-.22	.170	.03	.811
Approach bias (milliseconds)	.00	.986	.03	.839	.02	.882
Self-regulatory control (reversed commission errors)	-.14	.130	-.33	.036	-.04	.728
	Soft drink choice					
Evaluative bias (D600 score)	.14	.112	.09	.578	.16	.136
Attentional bias (milliseconds)	-.03	.716	-.32	.045	-.01	.912
Approach bias (milliseconds)	.03	.773	.04	.822	.02	.826
Self-regulatory control (reversed commission errors)	.09	.297	.07	.684	.11	.324

Note. Soft drink choice (0 = water choice, 1 = soft drink choice). None of the significant correlations survived a Bonferroni correction for multiple testing.

Figure 1

The relationship between evaluative bias and amount of soft drink consumed

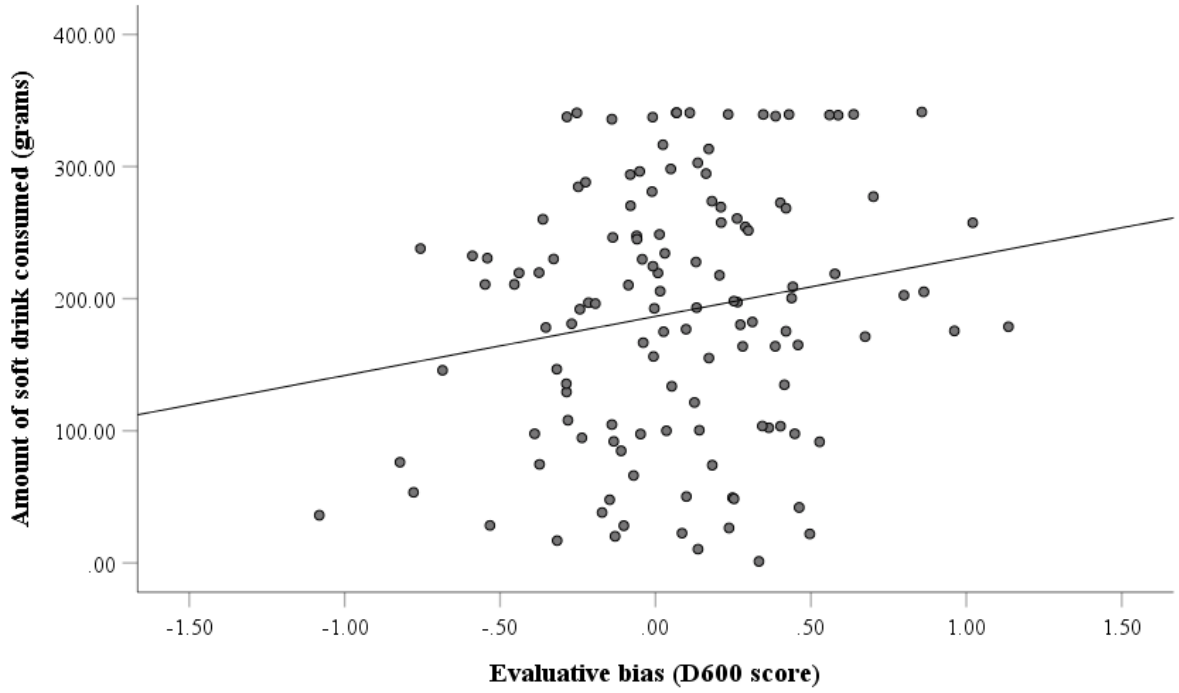
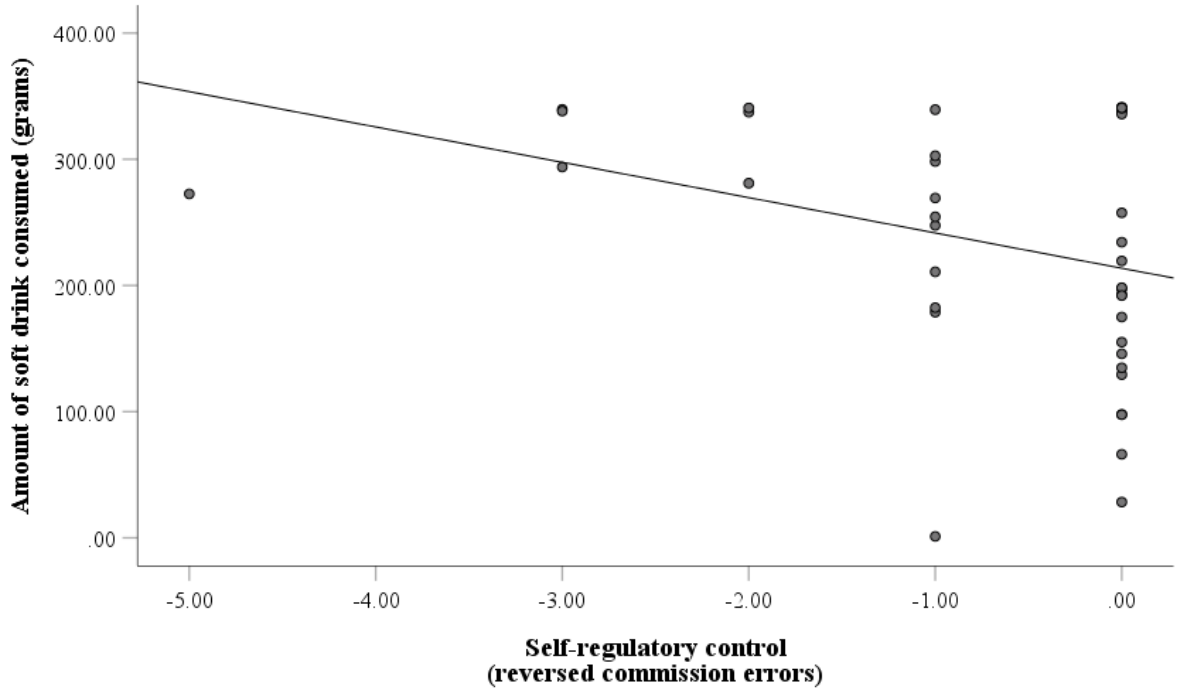


Figure 2

The relationship between self-regulatory control and amount of soft drink consumed in men



LINKING CHAPTER: CHAPTER THREE

Study 1 (Chapter 2) examined the roles of cognitive biases (evaluative, attentional, and approach biases) and inhibitory (self-regulatory) control in soft drink consumption and choice. The results showed that both evaluative bias and inhibitory control are linked to soft drink consumption. Nonetheless, there are other factors, not yet explored, that likely contribute to soft drink consumption, and thus warrant investigation. One such factor is cravings, which have been shown to impact appetitive behaviours such as food, alcohol, and drug consumption (Anton et al., 1995; Boswell & Kober, 2016; Bottlender & Soyka, 2004; Fazzino et al., 2013; Flannery et al., 2003; Galloway & Singleton, 2008; Hartz et al., 2001; Martin et al., 2008; Richard et al., 2017; Rohsenow et al., 2007), and have preliminarily been shown to also occur for non-alcoholic beverages, such as sugar-sweetened and caffeinated drinks (Falbe et al., 2019; Kemps & Tiggemann, 2009; Knäuper et al., 2011; May et al., 2004; Mills et al., 2016). However, beyond this preliminary evidence, the link between these cravings and actual consumption has not yet been systematically explored. Therefore, Study 2 (Chapter 3) aimed to comprehensively investigate the link between cravings and consumption for non-alcoholic beverages, including soft drink.

Data for Study 1 (Chapter 2) and Study 2 (Chapter 3) were collected successively, using the same participants, but with different methods. Specifically, Study 2 (Chapter 3) used a 7-day self-report diary that tracked participants' cravings and consumption.

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CHAPTER THREE: BEYOND THIRST: CRAVINGS FOR NON-ALCOHOLIC BEVERAGES INCLUDING SOFT DRINK

For the published version of this chapter, see:

McGreen, J., Kemps, E., & Tiggemann, M. (2022). Beyond thirst: Cravings for non-alcoholic beverages including soft drink. *Eating Behaviors*, *46*, 101662. https://doi.org/10.1016/j.eatbeh.2022.101662

Abstract

Cravings for a range of substances including drugs, alcohol, and food have been shown to predict subsequent consumption or use. However, this link has not yet been systematically examined for beverages other than alcohol. The present study aimed to provide a comprehensive investigation of cravings for non-alcoholic beverages and their link to consumption. Participants were 128 undergraduate students (17–25 years) who completed a craving diary and daily consumption measure over a period of a week. Cravings were reported for a range of beverages, including tea, juice, and flavoured milk, but by far the most craved beverages were water, coffee, and soft drink. Stronger cravings were associated with a greater likelihood of drinking and drinking more of the craved beverage. This was particularly the case for soft drink. Unlike water, cravings for coffee and soft drink were triggered by factors other than thirst, and the number of cravings predicted the total amount drunk over the week. The findings demonstrate the existence of cravings for non-alcoholic beverages such as soft drink, and point to these cravings as a potential target for reducing consumption.

Keywords: craving, beverage, soft drink, coffee, consumption.

Introduction

Craving refers to the intense desire to consume a specific substance, such as a drug, alcohol, or food (World Health Organization, 1993). Craving is a multidimensional construct, which includes physiological and psychological components (Meule, 2020). Physiologically, cravings may be caused by nutritional deficiencies (Morris et al., 2008), dehydration (Popkin et al., 2010), hormonal changes (Chao et al., 2017) or the activation of reward-related brain areas (Alonso-Alonso et al., 2015). Psychologically, they may be elicited by emotional states (Yau & Potenza, 2013) or environmental cues (May et al., 2012).

There are several theoretical models of craving, including the incentive-sensitization theory of addiction (Berridge & Robinson, 1995), the elaborated intrusion theory of desire (Kavanagh et al., 2005), and the cognitive processing model of craving (Tiffany, 1990; Tiffany & Conklin, 2000). Common to all models is the proposition that cravings serve to motivate consumption. In support, cravings for alcohol and drugs have been shown to predict subsequent alcohol consumption (Anton et al., 1995; Bottlender & Soyka, 2004; Fazzino et al., 2013; Flannery et al., 2003) and drug use (Galloway & Singleton, 2008; Hartz et al., 2001; Rohsenow et al., 2007). In addition, cravings for food have been shown to account for variance in eating behaviour and weight gain (Boswell & Kober, 2016), and stronger cravings for snack foods have been associated with increased consumption of those snack foods (Martin et al., 2008; Richard et al., 2017).

There is also a small amount of preliminary evidence to support the occurrence of cravings for some non-alcoholic beverages. In particular, cravings for sugar-sweetened beverages have been shown (Falbe et al., 2019; May et al., 2004), with sugar, the major component of such beverages, suggested to be addictive (Avena et al., 2008; Wiss et al., 2018). In addition, cravings for coffee have been demonstrated in habitual coffee drinkers (Kemps & Tiggemann, 2009; Knäuper et al., 2011; Mills et al., 2016). However, the link between cravings for non-alcoholic beverages, including sugar-sweetened and caffeinated beverages, and subsequent consumption has yet to be systematically examined.

Systematic examination of cravings for non-alcoholic beverages is important as global consumption of sugar-sweetened (World Health Organization, 2016, World Health Organization, 2017) and caffeinated (Alsunni, 2015; Geleijnse, 2008; Nadeem et al., 2021; Temple et al., 2017) beverages has become a major public health problem. In particular, consumption of free sugars, i.e., sugar added to food or drink, such as soft drinks, fruit drinks, sports drinks, and energy drinks, or naturally present in fruit juices, has been shown to be associated with type 2 diabetes (DiNicolantonio et al., 2015; Malik et al., 2010), increased risk of dental caries (Sheiham & James, 2015) and excess weight gain (Malik et al., 2010; Mussa et al., 2021; Sundborn et al., 2019). Although some caffeine-containing beverages (e.g., plain coffee) have been shown to have some health benefits (Poole et al., 2017; Saimaiti et al., 2022), others such as energy drinks are less healthy, having been linked to headaches, insomnia, and depressive mood (Alsunni, 2015; Nadeem et al., 2021). In addition, excess caffeine intake (e.g., more than four cups of coffee a day; Higdon & Frei, 2006; Nawrot et al., 2003) has been associated with negative health outcomes, such as elevated blood pressure (Geleijnse, 2008) and a greater risk of cardiovascular disease (Temple et al., 2017; Zhou & Hyppönen, 2019). Importantly, craving is a potentially

modifiable predictor of consumption (Berridge & Robinson, 1995; Kavanagh et al., 2005; Tiffany, 1990; Tiffany & Conklin, 2000), and thus may be a potential target for reducing excess intake of such beverages.

Thus, the present study aimed to offer the first comprehensive account of cravings for non-alcoholic beverages, including sugar-sweetened and caffeinated beverages, and to investigate their link to subsequent consumption. Specifically, diary methodology was used to investigate craving intensity, triggers, and consumption for non-alcoholic beverages drunk over seven days.

Method

Participants

Participants were 128 undergraduate students (88 women and 40 men) at Flinders University. The sample consisted of young adults ranging in age from 17 to 25 years (*M* = 19.77, *SD* = 1.99). Mean BMI of the sample was 24.28 kg/m2 (*SD* = 5.97), indicating normal weight (Centers for Disease Control and Prevention, 2020).

Measures

Craving Diary

Cravings for non-alcoholic beverages were measured using a 7-day self-report diary, in the form of a mobile phone application. A beverage craving was defined for participants as a “strong desire to consume a *specific* beverage”. Whenever participants experienced such a craving, they were instructed to record it immediately. A message reminding them of this was sent each morning at 9:00 am. For each craving, participants then recorded the time of the craving, the beverage craved, what triggered the craving, and rated the intensity of the craving on a visual analogue scale (ranging from “not at all intense” to “extremely intense”). Visual analogue scales have been shown to be a valid measure of subjective experiences (Aitken, 1969; Gift, 1989), including craving intensity (Lee et al., 2002; Wewers et al., 1990). Participants also reported whether or not they had drunk in response to the craving (“yes”/“no”) and, if yes, indicated the specific beverage and amount drunk (in mL).

Daily Consumption Measure

At the end of each day participants were asked to estimate their total non-alcoholic beverage intake for the day. A reminder message to this effect was sent each evening at 8:00 pm. Participants were specifically instructed not to report any intake combined with an alcoholic beverage. Participants were provided with a list of 11 beverage categories (e.g., coffee, cordial (a concentrated syrup, usually fruit-flavoured to which water is added), energy

drink, flavoured water, juice, milk), as well as an “other” option, and asked to indicate which they had drunk during that day. Participants then specified the beverage/s (e.g., “flat white”, “Coke”) and estimated the total amount drunk for the day (in mL). Such 24-hour dietary recall measures have been shown to provide a valid, low-cost, and low-burden method for collecting consumption information (Foster et al., 2019; Koch et al., 2021; Timon et al., 2016).

All participants completed the daily consumption measure. No participants were excluded and there were no missing data.

Procedure

After providing written informed consent, participants reported demographics, and rated how much they liked a selection of drinks (including water, coffee, and soft drink) on 100 mm visual analogue scales (ranging from “not at all” to “very much”). The following day, participants started completing the craving diary and daily consumption measure for a 7-day period.

Results

Sample Characteristics

Overall, 101 of the 128 participants reported at least one craving for a beverage. Across all participants, the number of cravings ranged from 0 to 28 (M = 4.03, SD = 4.76). The total amount they reported drinking over the 7 days ranged from 3.60 to 36.25 L (M = 11.82, SD = 5.28).

Most participants craved soft drink, 53 participants reporting at least one soft drink craving, followed by water (N = 47) and then coffee (N = 43). For these three main beverages, Figure 1 shows a moderate degree of overlap, with 11 participants reporting at least one craving for all three beverages, and 16 participants reporting cravings for soft drink only, followed by water (14), and then coffee (10). Of the participants who drank soft drink over the 7 days, 60.9% (N = 87) experienced at least one soft drink craving, while 38.2% of water drinkers (N = 127) experienced at least one water craving, and 50.0% of coffee drinkers (N = 86) experienced at least one coffee craving.

Craving Characteristics

A total of 516 cravings were reported. Mean craving intensity across all cravings was 57.87 (SD = 22.66), and 71.9% of cravings were followed by consumption. Mean amount drunk following a craving was 352.11 mL (SD = 176.15). Table 1 provides the number of

cravings experienced, the number of participants who experienced that craving, as well as aggregated means across participants for craving intensity, the likelihood of drinking immediately following the craving, and amount drunk immediately following the craving, for each beverage. It can be seen that although a wide range of different beverages were craved, by far the most frequent cravings were for water (*N* = 148). This was closely followed by coffee (*N* = 112), and soft drink (*N* = 102). Tea (*N* = 31), juice (*N* = 27), and flavoured milk (*N* = 23) were craved less often. As the most commonly craved beverages, subsequent analyses focus on water, coffee, and soft drink, with water, a healthy beverage, also providing an interesting point of comparison to coffee and soft drink.

Comparison Between Main Beverages

A series of multilevel models was performed to test for differences in craving intensity, the likelihood of drinking and amount drunk immediately following a craving, between cravings for the three main beverages (water, coffee, and soft drink), controlling for multiple within-subject reports across the 7-day period. There were statistically significant differences between the beverages on all three outcomes: craving intensity, $F(2, 358.76) = 13.94$, $p < .001$, likelihood to drink, $F(2, 318.52) = 26.56$, $p < .001$, and amount drunk, $F(2, 315.12) = 21.04$, $p < .001$. Pairwise comparisons showed that cravings were stronger for water than for soft drink ($p = .001$), and that participants drank more water following a craving than either coffee ($p < .001$) or soft drink ($p < .001$). A different pattern emerged for likelihood of drinking, such that participants were much less likely to drink soft drink following a craving than was the case for water ($p < .001$) or coffee ($p < .001$), and less likely to drink coffee than water ($p = .028$). All significant results survived a Bonferroni correction for multiple comparisons, except for the finding that participants were less likely to drink coffee than water.

We also investigated how much craving-related consumption contributed to the total amount drunk over the 7 days. Table 2 provides the amount drunk immediately following cravings as a percentage of the total amount of water, coffee, and soft drink drunk over the 7 days. It can be seen that for coffee and soft drink, craving related consumption accounted for over a fifth (20.2% and 22.2%, respectively) of the total amount drunk. In contrast, for water, craving-related consumption accounted for only 4.7% of the total amount of water drunk.

Craving Triggers

The reported triggers for craving were sorted into thirteen categories, the most common of which were thirst, tired, beverage cue, and food. A complete list of the craving

triggers, including descriptions and examples, is shown in Table 3. Triggers that included more than one idea were counted once in each of the relevant categories. A reliability check of category assignment by an independent reviewer showed good reliability, $\kappa = 0.86$. Disagreements were resolved by discussion between the reviewers.

As can be seen in Table 3, there was considerable difference in the triggers for the different beverages. Perhaps not surprisingly, by far the most common trigger for craving water was “thirst” ($N = 109$; 73.7% of cravings), whereas for coffee it was “tired” ($N = 76$; 67.9%). For soft drink, there was more variation in triggers, with “beverage cue” the most common ($N = 29$; 28.4%), followed by “food” ($N = 27$; 26.5%), “thirst” ($N = 26$; 25.5%), and “setting” ($N = 14$; 13.7%).

Relationship Between Craving Intensity and Beverage Consumption Outcomes

A series of multilevel models was conducted to investigate the relationship between craving intensity and the likelihood of drinking and amount drunk immediately following a craving, controlling for multiple within-subject reports across the 7-day period. For all beverages together, craving intensity was positively correlated with both the likelihood of drinking, $b = 0.00$, $SE = 0.00$, $t = 4.59$, $p < .001$, and the amount drunk immediately following a craving, $b = 2.93$, $SE = 0.43$, $t = 6.87$, $p < .001$.

When multilevel models were run separately for water, coffee, and soft drink (multilevel estimates are shown in Table 4), it was found that craving intensity for water was positively correlated with the amount of water drunk immediately following a craving. For coffee, craving intensity was not related to either outcome. For soft drink, however, craving intensity was positively correlated with both the likelihood of drinking and the amount of soft drink drunk immediately following a craving.

Number of Cravings as a Predictor of Total Beverage Consumption

A multiple linear regression was conducted to investigate the roles of BMI, gender, and the number of cravings experienced in predicting the total amount of all beverages drunk by participants over the 7 days. All participants were included in this and subsequent regression analyses. The regression analysis showed that the predictors together explained significant variance in the amount drunk, $R^2 = 0.124$, $F(3, 124) = 5.84$, $p = .001$. However, the only significant unique predictor was gender, $\beta = -0.35$, $p < .001$, such that men drank more.

A series of multiple linear regressions was conducted to determine whether the number of specific cravings predicted the total amount of water, coffee, and soft drink drunk.

Predictors entered were BMI, gender, and how much the beverage was liked, in addition to the number of cravings experienced. The predictors together explained significant variance in the amount drunk for water, $R^2 = 0.158$, $F(4, 123) = 5.75$, $p < .001$, coffee, $R^2 = 0.477$, $F(4, 123) = 28.07$, $p < .001$, and soft drink, $R^2 = 0.177$, $F(4, 123) = 6.62$, $p < .001$. The regression results are shown in Table 5. It can be seen that for water, male gender and liking water predicted drinking more water. For coffee, liking and the number of cravings predicted amount drunk. For soft drink, greater BMI and number of cravings predicted drinking more soft drink. Thus, for both coffee and soft drink, unlike water, the number of cravings independently predicted consumption over and above liking of the beverage.

Discussion

The present study aimed to provide the first comprehensive investigation of cravings for beverages other than alcohol and their link to consumption. Overall, participants reported cravings for a range of non-alcoholic beverages. By far the most craved beverages were coffee, soft drink, and water. Although water may not be considered a substance that is typically craved, the present sample clearly experienced a strong desire to consume this particular beverage, in accord with the formal definition of craving (World Health Organization, 1993). Across all beverages the results showed that stronger cravings were associated with a greater likelihood of drinking and drinking more of the craved beverage following the craving. However, among the most commonly drunk beverages (water, coffee, and soft drink), this was individually the case only for soft drink. In addition, the number of cravings for coffee and soft drink over the week independently predicted the total amount drunk of these beverages.

Overall, just as is the case for alcohol (Bottlender & Soyka, 2004; Fazzino et al., 2013), cravings were reported for a range of non-alcoholic beverages, including water, coffee, soft drink, tea, juice, and flavoured milk. This finding confirms previous reports of cravings for coffee (Kemps & Tiggemann, 2009; Knäuper et al., 2011; Mills et al., 2016) and soft drink (Falbe et al., 2019; May et al., 2004), and extends these to other non-alcoholic beverages. In addition, for the beverages as a whole, stronger cravings were associated with a greater likelihood of drinking and drinking more of the craved beverage immediately following the craving episode. This finding provides support for theoretical models of craving (Berridge & Robinson, 1995; Kavanagh et al., 2005; Tiffany, 1990) in their proposition that cravings serve to motivate consumption, but extends this to a new domain, namely, non-alcoholic beverages.

Nevertheless, there were differences between the three most craved beverages (water, coffee, and soft drink) in the link between craving and subsequent consumption. First, although water was the most craved beverage, it was also by far the most consumed beverage. Indeed, only a minority of water drinkers experienced craving for water and craving-related consumption accounted for only a small amount (<5%) of the total amount of water drunk. In addition, the number of cravings for water during the week did not predict the amount drunk over the week. Instead, the amount of water drunk was predicted by how much participants liked water and being of male gender. Thus, cravings for water appear to play little role in water consumption, which itself is a healthy rather than problematic practice (Popkin et al., 2010).

In contrast, the results showed that cravings for coffee and soft drink did play a role in their consumption. Specifically, for each of these beverages, the number of cravings experienced predicted the amount of coffee and soft drink drunk over the week. Furthermore, craving-related consumption accounted for over a fifth of this consumption over the week. This greater impact on consumption of cravings for soft drink and coffee, compared to water, may be a function of the sugar in soft drink (Avena et al., 2008; Wiss et al., 2018) and caffeine in coffee (Meredith et al., 2013), both of which have been shown to be addictive substances, in contrast to water which has no addictive properties.

However, there were some clear differences between soft drink and coffee. Stronger cravings for soft drink were associated with a greater likelihood of drinking and drinking more soft drink immediately following the craving, in a way that was not the case for coffee. In addition, while approximately 80% of cravings for coffee were followed by consumption, only half of the cravings for soft drink (50%) were followed by consumption. It is possible that individuals attempt to resist their cravings for soft drink more so than cravings for coffee, which may account for the importance of craving intensity in subsequent consumption of soft drink. Alternatively, it may be that cravings for coffee were resisted less because of the functional benefits of coffee in terms of alertness, one of the leading motives for coffee intake (Samoggia & Riedel, 2018), or to manage any accompanying withdrawal symptoms (Addicott, 2014). Future research could investigate whether other factors not measured here (e.g., exercise, sleep) could account for the differential findings for soft drink and coffee.

One major difference between the three main beverages was in the reported triggers for craving. For water, the most commonly reported trigger was “thirst”, although it should be noted that this was not the only trigger as other reported triggers included food cues, environmental cues, and feeling tired. Nevertheless, cravings for water appear to occur predominantly in response to physiological factors, in particular, the sensation of thirst

resulting from dehydration (Popkin et al., 2010). In contrast, for coffee, the most commonly reported trigger was not thirst, but “tired” (e.g., “needed a pick me up”, “woke up feeling kinda sluggish”). Thus, cravings for coffee appear to occur in response to internal cues, such as emotional fatigue or lack of energy, which motivate the consumption of coffee for its stimulant qualities (i.e., caffeine). For soft drink, the reported triggers were much more diverse, suggesting that the triggers for soft drink craving may be multi-faceted. Although some soft drink cravings were triggered by thirst, the large majority were not. Soft drink cravings were predominantly triggered by external environmental cues such as “beverage cues”, “food”, and “setting”. The observation that a range of external cues, such as seeing food, soft drink advertisements, or being out with friends, may induce cravings for soft drink is in line with several theoretical models of craving that conceptualise craving as a conditioned response to repeated pairing of a cue with consumption, which in turn motivates consumption (Berridge & Robinson, 1995; Kavanagh et al., 2005; Tiffany, 1990). Soft drink may be a particularly craved beverage and difficult to resist because of the abundance of external cues such as soft drink advertising in the environment (NCES, 2020). Soft drinks themselves are available 24/7 from a range of locations including supermarkets, restaurants, petrol stations and vending machines, making them difficult to avoid and providing many triggering opportunities for susceptible individuals. In addition, craving triggers may be more problematic for coffee and soft drink than for other beverages because of their addictive components (Avena et al., 2008; Meredith et al., 2013; Wiss et al., 2018). Future research could investigate which particular craving triggers motivate intake of coffee and soft drink.

Overall, the present findings have some practical implications. In particular, they point to cravings for soft drink and to a lesser extent coffee as potential targets for reducing consumption. It needs to be noted that the results were obtained in a general unselected sample and are likely to be even stronger in habitual or heavy beverage consumers. This is particularly significant as global consumption of soft drinks has increased rapidly over the past 50 years to become a major public health problem (Basu et al., 2013; GBD 2016 Risk Factors Collaborators, 2017; Tahmassebi & BaniHani, 2020). Global coffee consumption has similarly been on the rise (Statista, 2022). Craving is a potentially modifiable predictor of intake (Berridge & Robinson, 1995; Kavanagh et al., 2005; Tiffany, 1990; Tiffany & Conklin, 2000). Indeed, some experimental studies have successfully used guided imagery or cognitive defusion techniques to reduce cravings for coffee (Kemps & Tiggemann, 2009) and food (Hamilton et al., 2013; Schumacher et al., 2017). Thus, future research could extend these protocols to cravings for soft drink and investigate their impact on subsequent consumption.

As with all research, there are some limitations that need to be acknowledged. First, the sample consisted of young adults. Although these are the core consumers of soft drinks (Miller et al., 2019; Roy Morgan Research, 2015), children and older adults also drink soft drinks and other non-alcoholic beverages, and so future research should investigate cravings for such beverages in other demographic groups. Second, overall beverage intake was reported only once for the whole day, and so recall may not have been complete. Future research might use finer-grained measurement of beverage consumption. Third, there are other factors not measured here, such as sport participation, habitual consumption patterns, and sleep quality and quantity, that may have influenced participants' beverage intake and reported craving, and which future studies might include.

In conclusion, the present study has offered the first comprehensive account of cravings for a range of beverages other than alcohol. Such cravings were shown to occur and appear to be triggered by a range of internal and external cues, rather than simply by thirst. In particular, cravings appear to play a large role in the consumption of soft drink. Thus, the present study contributes to the understanding and possible remediation of what has become a major contemporary public health concern, namely, soft drink consumption.

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Data and code availability

All data used in the study are available from the corresponding author who has full access to the data reported in the manuscript.

Ethical statement

The study protocol was approved by the Flinders University Social and Behavioural Research Ethics Committee (SBREC). Participants gave informed consent before taking part. Please note that 17-year old Australian University students may participate in research without parental consent providing the project is deemed to be low risk by the SBREC, as was the case with the present study.

CRediT authorship contribution statement

All authors contributed to the design of the study and writing the manuscript. Joshua McGreen was responsible for data collection, under supervision of Eva Kemps. Joshua McGreen conducted the statistical analyses and wrote the first draft of the manuscript. All other authors edited subsequent drafts of the manuscript, and have approved the final manuscript.

Declaration of conflicting interests

The authors declare no conflicts of interest.

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Table 1

Number of cravings and number of participants who experienced at least one craving, as well as aggregated means for craving intensity, likelihood of drinking following a craving (percentage), and amount drunk (ml) following a craving, for each beverage

	Number of cravings	**Number of participants**	**Mean (*SD*) craving intensity**	**Likelihood of drinking (%)**	**Mean (*SD*) amount drunk**
Water	148	47	68.16 (20.60)	88.72	351.72 (222.39)
Coffee	112	43	55.28 (17.93)	82.74	227.24 (110.27)
Soft drink	102	53	51.17 (18.42)	52.23	190.17 (190.86)
Tea	31	19	48.85 (26.52)	63.28	179.09 (143.94)
Juice	27	20	53.81 (16.22)	62.50	181.25 (149.09)
Flavoured milk	23	14	54.90 (15.27)	40.71	179.46 (220.45)
Energy drink	16	11	53.27 (24.37)	45.45	152.42 (181.75)
Cordial (mixed)	7	4	58.75 (2.50)	91.67	510.42 (382.45)
Milo/hot chocolate	7	7	53.43 (8.32)	57.14	160.71 (156.70)
Bubble tea	7	4	71.50 (23.65)	37.50	237.50 (309.23)

Smoothie	6	5	60.80 (18.10)	60.00	380.00 (349.29)
Ice tea	5	5	52.60 (21.15)	60.00	235.00 (291.33)
Milk	4	2	39.00 (31.11)	50.00	137.50 (194.45)
Sports drink	4	3	70.67 (23.63)	33.33	200.00 (346.41)
Lassi/kefir	4	2	46.75 (8.84)	25.00	125.00 (176.78)
Kombucha	4	4	57.50 (7.85)	75.00	363.75 (307.01)
Anything cold	3	2	32.75 (18.03)	100.00	312.50 (88.39)
Aloe vera drink	2	1	29.00	0.00	0.00
Sparkling water	1	1	16.00	100.00	300.00
Flavoured water	1	1	49.00	100.00	250.00
Anything with sugar	1	1	65.00	0.00	0.00
Coconut water	1	1	25.00	100.00	200.00

Table 2

Amount drunk (L) following cravings, total amount drunk (L) over 7 days, and amount drunk following cravings as a percentage of total amount drunk over 7 days, for water, coffee, and soft drink

	Amount following cravings	**Total amount 7 days**	**Percentage (%)**
Water	51.42	1085.65	4.74
Coffee	25.01	123.79	20.20
Soft drink	18.64	83.90	22.22

Table 3

Frequency of craving triggers for water, coffee, and soft drink

Craving trigger	Description	Water	Coffee	Soft drink
Thirst	Thirst/dehydration; or activities causing thirst/dehydration, such as exercise. E.g., “was feeling dehydrated”, “went for a run”.	109	1	26
Tired	Fatigue, tiredness, exhaustion, etc. E.g., “being tired”, “needed a pick-me-up”.	7	76	9
Beverage cue	Beverage cues, including information, advertising, stimuli, conversations. E.g., “seeing other people drink coffee”, “a soft drink advertisement on TV”.	10	9	29

Food	Specific mention of the consumption of food or specific food cues. E.g., “wanted something to drink with lunch”, “I ate a rich brownie”.	19	0	27
Setting	Setting or location, such as parties, work, studying, etc. Excluding settings/locations that are specifically related to food cues/consumption e.g., restaurants. E.g., “working”, “social gathering with friends”.	7	13	14
Temperature	Cold/hot temperature or any type of weather. E.g., “heat”, “cold weather”.	6	4	6

Routine	Routine or habitual consumption. E.g., “I drink it every day”, “out of habit”.	0	10	0
Taste	Taste that does not specifically mention sugar. E.g., “I miss the taste of it”, “just thought it would taste nice”.	0	2	7
Sugar	Specific mention of sugar as the craving trigger. E.g., “sugar”, “feeling like sugar”.	0	0	5
Emotion	Affect, such as mood, stress, boredom, etc. E.g., “feeling sad”, “drinking out of boredom”.	1	2	1

Hunger	Hunger, stomach being empty, etc. E.g., “breakfast hunger”, “feelings of needing something to feel fuller”.	0	2	1
Illness	Sickness or illness. E.g., “feeling sick”, “sore throat”.	2	0	1
No reason	E.g., “no reason”, “-“, “I don’t know”, etc.	2	7	6

Table 4

Multi-level estimates for models of the association between craving intensity, and likelihood of drinking following a craving and amount drunk following a craving, for water, coffee, and soft drink, controlling for multiple within-subject reports across the 7-day period

Model	**Null**			**1**		
Variables	***Estimate***	***SE***	***t***	***Estimate***	***SE***	***t***
Water [a]						
Likelihood of drinking	0.81	0.08	10.23**	0.00	0.00	1.24
Amount drunk	85.37	63.47	1.35	3.95	0.85	4.64**
Coffee [b]						
Likelihood of drinking	0.92	0.11	8.38**	-0.00	0.00	-1.23
Amount drunk	272.81	42.14	6.47**	-0.86	0.68	-1.26
Soft drink [c]						
Likelihood of drinking	0.26	0.12	2.18*	0.01	0.00	2.32*
Amount drunk	53.71	49.59	1.08	2.48	0.84	2.96*

Note. *$p < .05$; **$p < .001$.

[a] $N = 47$ participants, $N = 148$ observations.

[b] $N = 43$ participants, $N = 112$ observations.

[c] $N = 53$ participants, $N = 102$ observations.

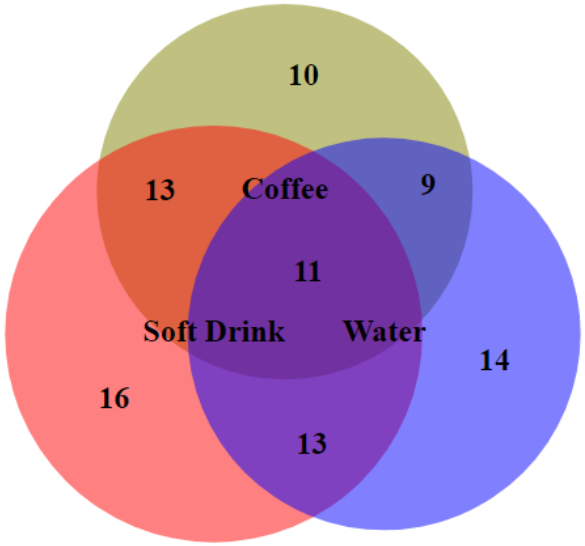
Table 5

Regression results for BMI, gender, beverage liking, and number of cravings experienced in predicting total amount of water, coffee, and soft drink drunk over 7 days, across all participants

	Water		**Coffee**		**Soft drink**	
	β	***p***	***β***	***p***	***β***	***p***
BMI	-0.04	.665	-0.07	.296	0.31	< .001
Gender	-0.30	< .001	-0.09	.173	-0.10	.250
Liking	0.27	.002	0.53	< .001	0.16	.070
Number of cravings	0.01	.873	0.27	< .001	0.20	.018

Figure 1

Venn diagram [a] *showing the number of participants who experienced at least one craving for water, coffee, and soft drink*



Note. [a] Constructed using BioVenn (Hulsen et al., 2008).

LINKING CHAPTER: CHAPTERS FOUR AND FIVE

Building on the results of Study 1 (Chapter 2), which found a link between inhibitory control and soft drink consumption, a systematic review and meta-analysis was planned to examine: (i) the relationship between inhibitory control, as measured by the Go/No-Go (Donders, 1969) and Stop-Signal (Logan & Cowan, 1984) tasks, and non-alcoholic beverage consumption, and (ii) the effectiveness of Go/No-Go and Stop-Signal training in reducing such consumption. This investigation was intended as a precursor to a future study (Study 5; Chapter 6) designed to test an intervention aimed at targeting inhibitory control to reduce soft drink consumption.

The meta-analysis focused on the Go/No-Go and Stop-Signal tasks, as these tasks are commonly used to measure inhibitory control (McGreen et al., 2023) in food consumption research. Additionally, “inhibitory control” training most commonly uses modified versions of these tasks (Allom et al., 2016; Aulbach et al., 2019; Jones et al., 2016; Yang et al., 2019). Although the Go/No-Go and Stop-Signal tasks have generally been used interchangeably to assess inhibitory control (Littman & Takács, 2017; Raud et al., 2020), recent studies suggest that response inhibition in these tasks may rely on different mechanisms (Littman & Takács, 2017; Raud et al., 2020). Specifically, Raud et al. (2020) proposed that inhibitory control in the Go/No-Go and Stop-Signals tasks may involve response selection and automatic response inhibition, respectively. Therefore, the meta-analysis aimed to determine whether differences exist between the Go/No-Go and Stop-Signal tasks in both the relationship between inhibitory control and non-alcoholic beverage consumption, and in the effectiveness of such inhibitory control interventions in reducing such consumption.

However, due to a lack of studies on non-alcoholic beverage consumption, the focus of the meta-analysis shifted to food consumption. The revised objective was to examine the relationship between inhibitory control, as measured by the Go/No-Go and Stop-Signal Tasks, and food consumption, a behaviour similar to non-alcoholic beverage consumption, and to identify the most effective training protocol for reducing such consumption. The findings were intended to inform the development of an eventual intervention targeting inhibitory control to reduce soft drink consumption, which would be tested in a subsequent experimental study (Study 5; Chapter 6).

Due to the broad scope of the original protocol, the meta-analysis was divided into two separate, independent studies, each with distinct research questions, sets of studies,

and data sets. This modification was made prior to any data extraction or analysis. The first meta-analysis (Study 3; Chapter 4) used correlational data to determine the relationship between inhibitory control, as measured by the Go/No-Go and Stop-Signal tasks, and food consumption. The second meta-analysis (Study 4; Chapter 5) comprised experimental studies to determine whether Go/No-Go and Stop-Signal task inhibitory control "training" effectively reduces food consumption, while also determining the moderating roles of within-task methodological differences.

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CHAPTER FOUR: THE RELATIONSHIP BETWEEN INHIBITORY CONTROL AND FOOD CONSUMPTION OR CHOICE: A SYSTEMATIC REVIEW AND META-ANALYSIS

For the published version of this chapter, see:

McGreen, J., Kemps, E., & Tiggemann, M. (2023). The relationship between inhibitory control and food consumption or choice: A systematic review and meta-analysis. *Appetite*, *183*, 106466. https://doi.org/10.1016/j.appet.2023.106466

Abstract

Excess consumption of unhealthy foods has become a major public health problem. Although one potential contributor to unhealthy consumption is poor inhibitory control, findings have been inconsistent. A meta-analysis of 35 studies was conducted to determine whether, and under which conditions, inhibitory control, as measured by the Go/No-Go and Stop-Signal tasks, is associated with food consumption/choice. Moderators included the type of stimuli (neutral or food-specific) used in measuring inhibitory control, sample differences (e.g., age, gender, and weight), and the measure of food consumption or choice. Overall, there was a small positive association between inhibitory control and food consumption/choice, r = .09, CI_{95} = [0.04, 0.14], p = .001. This held for the Stop-Signal Task in general, and for the Go/No-Go Task for children and when food consumption/choice was measured objectively. The present meta-analysis provides the first comprehensive evidence that inhibitory control, as measured by the Go/No-Go and Stop-Signal tasks, is associated with food consumption or choice, and points to inhibitory control as a potential target for reducing unhealthy food consumption.

Keywords: inhibitory control, go/no-go task, stop-signal task, food consumption, food choice, meta-analysis.

Introduction

Excess food consumption, whereby energy intake exceeds energy expenditure, is an acknowledged contributor to obesity (World Health Organization, 2020). In particular, excess intake of unhealthy foods (i.e., those high in sugar, fat, and salt) has become a major public health problem, contributing to the rapid increase in the worldwide prevalence of obesity over the past 40 years (Cecchini et al., 2010; Machado et al., 2020). Eating too much of such food has also been linked to high blood pressure (Margerison et al., 2020), tooth decay (Mobley et al., 2009), diabetes (Sami et al., 2017), heart disease and stroke (Anand et al.,

2015), as well as depression (Ljungberg et al., 2020). The role of inhibitory control, the ability to regulate behaviour or inhibit behavioural impulses in accordance with higher order goals (Houben, Nederkoorn, & Jansen, 2012), has been identified as an important contributor to unhealthy food intake. A number of studies have centred on the idea that individuals with poorer inhibitory control may be more susceptible to food cues in the environment, leading to increased consumption. The present study aimed to combine and evaluate data from multiple studies investigating the relationship between inhibitory control and food consumption.

The idea that individuals with poorer inhibitory control may be more vulnerable to environmental cues fits with dual-process models (Strack & Deutsch, 2004), which suggest that behaviour is in part governed by controlled processing (Strack & Deutsch, 2004). Controlled processes are slow and reflective, involving conscious decision-making. Inhibitory control is one type of controlled processing. According to dual-process models, consumption of food in response to external food cues may be regulated by inhibitory control. Thus, individual differences in inhibitory control may play a role in the differential behavioural responses to environmental food cues and subsequent food consumption. Inhibitory control is likely to be particularly important in the contemporary food environment, where individuals are exposed to an overabundance of food cues, including 24/7 access to unhealthy foods in supermarkets, vending machines, and petrol stations, and through advertising. For example, spending on unhealthy food advertising has been shown to be approximately 30 times that for healthy foods (O'Dowd, 2017), and in the United States the fast-food industry spent 5 billion dollars on advertising in 2019 (UConn Rudd Center for Food Policy & Health, 2021). Furthermore, exposure to television advertising has been shown to be associated with consumption of unhealthy foods (Kelly et al., 2016).

Inhibitory control, including in food consumption research, is commonly measured by computerised tasks such as the Go/No-Go Task (Donders, 1969) and Stop-Signal Task (Logan & Cowan, 1984). Both tasks ask participants to respond to designated “go” signals (e.g., the letter “f”) and not respond to designated “stop” or “no-go” signals (e.g., the letter “p” or a sound). For both tasks, the majority of trials are “go” signal trials, such that “go” becomes the prepotent response and a “stop” or “no-go” response requires cancelling that initiated “go” response. The key difference between the two tasks is the timing of the “stop” or “no-go” signal relative to the “go” signal. In the Go/No-Go Task, the “go” and “no-go” signals are presented at the same time, namely at the start of “go” and “no-go” trials, respectively, and inhibitory control is calculated using the number of commission errors (incorrectly responding to a “no-go” signal), with a higher number of errors indicating poorer

inhibitory control. In contrast, in the Stop-Signal Task, the “stop” signal is presented approximately 300 ms after the “go” signal and inhibitory control is measured using stop-signal reaction time (SSRT), which is calculated by subtracting the mean stop-signal delay from the mean go-trial reaction time (Logan, 1994), where longer SSRTs are indicative of poorer inhibitory control. Furthermore, the Stop-Signal Task often uses an adaptive stop signal delay, where the delay is individually set so that participants successfully inhibit their responses on 50% of “stop” trials. The Go/No-Go and Stop-Signal tasks have largely been used interchangeably to measure inhibitory control (Littman & Takács, 2017; Raud et al., 2020). However, it has recently been suggested that response inhibition in these tasks relies on different mechanisms, including different neural dynamics (Littman & Takács, 2017; Raud et al., 2020), despite also some overlap in neural activation between the two tasks (Rubia et al., 2001). Specifically, Raud et al. (2020) proposed that inhibitory control performance in the Go/No-Go Task may be comparable to response selection, whereas in the Stop-Signal Task it may incorporate automatic response inhibition. The present study aimed to determine whether differences exist in the observed relationship between inhibitory control and food consumption as measured by the Go/No-Go and Stop-Signal tasks.

Weaker inhibitory control has been linked to higher BMI (Lavagnino et al., 2016). In addition, some previous studies have shown that individuals with poorer inhibitory control, as measured by the Go/No-Go and/or Stop-Signal tasks, eat more unhealthy food (e.g., Guerrieri, Nederkoorn, & Jansen, 2007; He et al., 2014; Lyu et al., 2017). However, the findings in this domain have been inconsistent, with other studies showing no such relationship (e.g., Aiello et al., 2018; Bennett & Blissett, 2019; Fonseca et al., 2020; Goldstein et al., 2014). Thus, it is important to determine whether inhibitory control, as measured by the Go/No-Go and Stop-Signal tasks, is related to food consumption. This will inform future investigations on the efficacy of inhibitory control training for reducing unhealthy food consumption.

Studies investigating the relationship between inhibitory control and unhealthy food consumption have utilized both general (Bennett & Blissett, 2019; Lowe et al., 2014; Powell et al., 2017) and food-specific (Carbine et al., 2018; Oomen et al., 2018; Zhang et al., 2017) versions of the Go/No-Go and Stop-Signal tasks. General versions use neutral stimuli (i.e., non-food images such as household objects) to measure general inhibitory control, whereas food-specific versions use food stimuli (e.g., images of unhealthy foods) to capture food-specific inhibitory control. As noted by Bartholdy et al. (2016) and Wu et al. (2013), the issue here is that inhibitory control performance may differ based on the stimuli presented. For example, greater impairments in inhibitory control were observed in bulimic patients when

they were shown food stimuli, in comparison to general stimuli (Wu et al., 2013). Findings from studies that have measured both general and food-specific inhibitory control have been inconsistent. Some studies have shown that food-specific, but not general inhibitory control, was associated with food consumption or choice (Kelly et al., 2020; Price et al., 2016; Zhang et al., 2017), whereas other studies have shown the opposite (Houben, Nederkoorn, & Jansen, 2012; Meule, 2011). Therefore, it is important to determine whether and how the use of neutral or food stimuli (i.e., measurement of general or food-specific inhibitory control) in measuring inhibitory control impacts the observed relationship between inhibitory control and food consumption.

Furthermore, studies investigating the relationship between inhibitory control and unhealthy food consumption have utilized a large variety of samples, including clinical (Fonseca et al., 2020; Oomen et al., 2018), student (Allom & Mullan, 2014; Kakoschke et al., 2015), healthy weight (Goldstein et al., 2014; Zhang et al., 2017), overweight (Carbine et al., 2021; Price et al., 2016), child (Bennett & Blissett, 2019; Levitan et al., 2015), and young adult (Allom & Mullan, 2014; Giesen et al., 2012) samples. A systematic review conducted by Bartholdy et al. (2016), which investigated the relationship between inhibitory control as measured by the Stop-Signal Task and eating/weight, noted that inhibitory control performance differs across demographic groups. For example, restrained eaters were consistently reported to have poor inhibitory control, whereas there was no obvious difference in inhibitory control performance between weight categories (Bartholdy et al., 2016). Furthermore, inhibitory control ability has been shown to change with age, with inhibitory control being poorest in young children and older adults (Ferguson et al., 2021). Thus, the present study aimed to determine whether sample demographical characteristics, such as age, impact the relationship between inhibitory control and food consumption.

Finally, there is inconsistency across the literature in the way unhealthy food consumption is measured, with some studies utilizing objective measures (e.g., a taste test; Kakoschke et al., 2015; Nederkoorn et al., 2015) and others employing self-report measures (e.g., naturalistic consumption over a set time; Carbine et al., 2018; He et al., 2014). Correlations between objective and self-report measures are consistently low (Dang et al., 2020), indicating poor correspondence between objective and self-report measures. In addition, some studies have measured food consumption (e.g., a taste test), whereas others have measured food choice (e.g., choosing items from an online grocery store; Nederkoorn, 2014).

Thus, the overarching aim of the present review was to combine and evaluate data from multiple studies to determine whether, and under which conditions, inhibitory control, as

measured by the Go/No-Go and Stop-Signal tasks, is associated with food consumption/choice. Accordingly, we conducted a meta-analysis of relevant studies to address the following questions.

1. Is inhibitory control, as measured by the Go/No-Go and Stop-Signal tasks, associated with food consumption/choice?
2. Does the use of neutral stimuli or food-specific stimuli in measuring inhibitory control impact the relationship between inhibitory control and food consumption/choice?
3. Does the food consumption or choice measure (e.g., objective or self-report) impact the relationship between inhibitory control and food consumption/choice?
4. Do sample differences (e.g., age, gender, and weight) impact the relationship between inhibitory control and food consumption/choice?

Method

The present meta-analysis was conducted in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines (Page et al., 2021). The initial protocol was registered with the Open Science Framework (OSF) (registration DOI https://doi.org/10.17605/OSF.IO/NPJ8A), and subsequently modified following full-text screening because it was deemed too large in scope for a single review. Specifically, the protocol was separated into two distinct, independent meta-analyses, which although derived from the same search strategy, addressed different research questions, included different sets of studies, and used different data sets. The first meta-analysis (the present study) addressed the question of the relationship between inhibitory control, as measured by the Go/No-Go and Stop-Signal tasks, and food consumption/choice, using correlational data. It also investigated the broader moderating roles of sample characteristics (e.g., age, gender, weight). A second future meta-analysis will address the question as to whether inhibitory control training is effective in reducing food consumption, and thus the data set will consist of experimental studies. This analysis will also investigate the more finely-grained moderating roles of within-task methodological differences of the Go/No-Go and Stop-Signal tasks (e.g., stimuli used, trial duration, ratio of go/no-go trials, go/no-go cues, within task feedback, comparison control condition). The modification was actioned prior to any data extraction or analysis.

Search Strategy

The search strategy was developed in consultation with a research librarian at Flinders University. The strategy included key terms and thesaurus terms related to the Go/No-Go Task, the Stop-Signal Task, and consumption of food (see Table 1). Searches

were conducted on June 25, 2020 from the following databases: Medline, ProQuest, PsycINFO, PubMed, Scopus, and Web of Science. Searches were limited to English language articles published in peer-reviewed journals. Title and abstract screening was undertaken by two independent reviewers to determine the eligibility of all retrieved papers. Disagreements were resolved in a meeting between the reviewers, where resolution outcomes/explanations were noted for each paper. Full-text screening of the remaining papers was then undertaken by the primary author. Finally, forward and backward searching were performed to identify any further potentially relevant articles. An updated search was conducted on 16th February 2022, which identified two additional relevant articles.

Eligibility Criteria

Inclusion criteria of eligible papers were: (1) a focus on food consumption or choice; (2) use of the Go/No-Go Task and/or Stop-Signal Task to measure inhibitory control; (3) measurement of inhibitory control using the number of commission errors for target trials for the Go/No-Go Task, or SSRT for the Stop-Signal Task; and (4) provision of the Pearson correlation coefficient for the relationship between inhibitory control and food consumption/choice.

Information extracted

The following data were extracted and tabulated: sample characteristics (number of participants; clinical or general; university or community; age; gender; weight), the inhibitory control measure used (Go/No-Go Task or Stop-Signal Task), the version of the Go/No-Go and/or Stop-Signal task used (food-specific or general), the measure of food consumption/choice (e.g., taste test, self-reported consumption), the type of food included in the measure(s) of consumption/choice (e.g., unhealthy foods, all foods), whether or not the study controlled for participant hunger, and the Pearson correlation coefficient for the relationship between inhibitory control and food consumption or choice.

If a paper did not provide some of the above information, the corresponding author was contacted, and the missing details requested. In the event that the contact e-mail address provided in the article was no longer active, extensive internet searches were undertaken to contact the corresponding author using all their registered e-mail addresses. If the corresponding author did not reply, they were re-contacted one month following the initial e-mail. If they still did not reply, co-authors were contacted. This process was undertaken over a period of 6 months to give authors sufficient time to respond to maximize the number of relevant studies included in the systematic review and meta-analysis.

Data Coding

Variable coding was conducted by the lead author. Following Borenstein et al. (2009), for studies that included multiple variable categories (e.g., used both the Go/No-Go and Stop-Signal tasks), the weighted mean of the Pearson correlation coefficients was calculated and used in the overall-meta-analysis investigating the relationship between inhibitory control and food consumption or choice. Such studies were then excluded from any relevant moderator analyses if the same participants were used for each subgroup.

Inhibitory Control Measure

Studies were coded on the basis of their use of the Go/No-Go or Stop-Signal task. They were also coded based on whether they measured general inhibitory control (i.e., neutral stimuli) or food-specific inhibitory control (i.e., food stimuli).

Food Consumption/Choice Measure

Objective or Self-Report. Studies were coded based on whether they used an objective (e.g., a taste test or food choice task) or a self-report measure (e.g., asked participants to report naturalistic food consumption) to measure food consumption or choice.

Food Consumption or Choice. Studies that used an objective measure were further coded based on whether they measured food intake (e.g., a taste test) or choice (e.g., a food choice task).

Unhealthy or All Food Consumption/Choice Measured. Studies were coded based on whether they measured unhealthy (high calorie) food consumption or all food consumption.

Hunger Controlled. Studies were coded based on whether they controlled for hunger during the in-lab session (either by having participants eat prior to or refrain from eating prior to the in-lab session).

Sample Characteristics

Age. Studies were coded based on whether they recruited children only, adolescents and young adults, young adults (18–39 years) only, or young adults and older adults (i.e., the sample included participants at least 40 years of age).

Type. Studies were coded based on whether they recruited a general sample (i.e., a non-specific sample or a sample comprising clinical and non-clinical participants) or a clinical sample (e.g., participants with a reported eating disorder, restrained eaters).

Pool. Studies were coded based on whether they recruited university students, community members, or a combination of university students and community members.

Gender. The proportion of participants who were women was calculated as a continuous measure for each study.

Weight. Studies were coded based on whether they recruited healthy weight participants only (BMI 18.5 to 24.9), overweight participants only (BMI >24.9), underweight participants only (BMI <18.5), or participants of all weight categories (any BMI; Weir & Jan, 2021).

Quality Assessment

The quality of all included studies was evaluated by two reviewers using the Mixed Methods Appraisal Tool (Hong et al., 2018). The MMAT was used as it can evaluate various study designs, including quantitative, qualitative, and mixed methods models. Each included study was appraised according to the criteria of the relevant study design category. For example, for quantitative non-randomized study designs, methodological quality criteria included questions such as “Are the participants representative of the target population?” and “Are measurements appropriate regarding both the outcome and intervention (or exposure)?”. For each study, a quality score (ranging from 0 to 5 stars) was calculated using the percentage of quality criteria met, where 0 stars represents 0% of criteria met, 1 star 20%, 2 stars 40%, and so on (Hong et al., 2018). Disagreements between the reviewers were resolved in a meeting.

Statistical Analyses

Comprehensive Meta-Analysis Version 3 (Borenstein et al., 2013) was used to calculate effect sizes and run all analyses, including subgroup (moderator) analyses for categorical moderator (e.g., task type) analyses and meta-regression for continuous moderator (sample gender) analyses. Following Higgins et al. (2021), random-effects analyses were used because there was heterogeneity across the studies. Higgins et al. (2021) further suggest that subgroup analyses be based on random-effects models due to the high risk of false-positive results when testing for subgroup differences in a fixed-effect model.

The effect size employed in the present meta-analysis was Pearson's correlation coefficient (r). For each effect size, 95% confidence intervals (CI_{95}) were calculated. Cochran's Q (Cochran, 1954) and the I^2 statistic (Higgins & Thompson, 2002) were used to measure heterogeneity in effect sizes across studies. The I^2 statistic is the percentage of heterogeneity in the effect sizes, where 25%, 50%, and 75% correspond to small, medium, and large heterogeneity (Higgins et al., 2003). Unlike Cochran's Q (Cochran, 1954), the I^2 statistic is not sensitive to changes in the number of studies included (Harrer et al., 2021).

Subgroup effects were compared using the value of *Q* (Harrer et al., 2021), where a significant *Q* indicates that there is a difference in the true effect size between the subgroups (Harrer et al., 2021). Following Fu et al. (2011), moderator subgroups with less than four studies were not included in moderator analyses.

Outliers were investigated using a “leave-one-out” analysis, which calculates the impact of each study by performing a series of meta-analyses that leave out one of the studies at each instance. Publication bias was assessed by visual examination and Egger's regression test of funnel plot asymmetry, where a significant *p*-value indicates the presence of publication bias (Egger et al., 1997).

Results

Study Selection

The search strategy identified 5990 papers, after duplicates were removed, which were all screened for eligibility using title and abstract screening. Many papers were clearly ineligible (e.g., studies investigating sea surface temperature, which happens to have the same acronym as the Stop-Signal Task (SST)). The search identified 171 relevant papers that were then further assessed for eligibility using full-text screening. Full-text screening identified 37 papers that were eligible for inclusion. A further 22 papers were identified as eligible following forward and backward searching. Two additional papers were identified following the final search, resulting in a total of 61 eligible papers. A substantial number of studies investigated brain activity while completing the Go/No-Go or Stop-Signal tasks, rather than actual task performance. Of the 61 eligible papers, 27 were excluded because the Pearson correlation coefficient for the relationship between inhibitory control and food consumption or choice was not a focus or was not provided (in the paper or supplementary materials); nor was it made available following requests for additional information from authors. Thus, the meta-analysis included 34 papers (35 studies) with 35 independent Pearson correlation coefficients. Figure 1 shows the number of articles identified at each stage of the search, including reasons for exclusion following full-text screening.

Study Characteristics

Sample size for included studies ranged from 19 to 205 (M = 76.74, SD = 48.97). Of the 35 included studies, 17 used the Go/No-Go Task, 16 used the Stop-Signal Task, and two (Kelly et al., 2020; Powell et al., 2017) used both tasks. Most of the studies using the Stop-Signal Task measured general inhibitory control, with only two (Houben & Jansen, 2014; Zhang et al., 2017) measuring both food-specific and general inhibitory control. In contrast, more (k = 9) of the studies using the Go/No-Go Task measured food-specific inhibitory

control, with six measuring both general and food-specific inhibitory control and only four (Adise et al., 2021; Bennett & Blissett, 2019; Lowe et al., 2014; Powell et al., 2017) measuring general inhibitory control. All studies that used the Stop-Signal Task implemented an adaptive stop signal delay whereby the delay was increased or decreased based on performance until participants successfully inhibited their response on 50% of "stop" trials. Table 2, Table 3 provide a summary of included studies.

Most studies (*k* = 26) used an objective measure of food consumption or choice, six used only a self-report measure of food consumption, and three (Aiello et al., 2018; Carbine et al., 2018; Fonseca et al., 2020) both an objective and self-report measure. Specifically, 24 studies used either a taste test or buffet to measure food consumption; seven studies asked participants to self-report their naturalistic consumption for the previous day (Carbine et al., 2017, 2018, 2021; He et al., 2014), week (Oomen et al., 2018), 2–3 months (Powell et al., 2017), or year (Fonseca et al., 2020); three studies (Giesen et al., 2012; Nederkoorn, 2014; Nederkoorn et al., 2009) used an internet-based supermarket task where participants were instructed to buy groceries that they would need for either 1 or 3 days; two asked participants to self-report how often they consumed specific foods (Aiello et al., 2018; Allom & Mullan, 2014); and two studies used a food choice task (Aiello et al., 2018; Zhang et al., 2017). Moreover, most studies (*k* = 28) measured consumption of unhealthy foods, with only six studies measuring consumption of all foods, and one measuring consumption of unhealthy foods with one measure and consumption of all foods with a second measure (Fonseca et al., 2020). Lastly, most studies (*k* = 25) controlled for participant hunger during the in-lab session, whereas eight did not, and two (Nederkoorn et al., 2009; 2015) included both hungry and sated participants.

Finally, most studies recruited a general sample (*k* = 29), with only three (Biehl et al., 2019; Lyu et al., 2017; Meule et al., 2011) recruiting a combination of clinical and non-clinical participants, one recruiting participants with reported loss of control over eating (Oomen et al., 2018), one recruiting restrained eaters (Zhang et al., 2017), and one recruiting individuals with generalized anxiety disorder (according to DSM-5 criteria; Fonseca et al., 2020). Furthermore, most studies (*k* = 18) recruited young adults, with eight recruiting young and older adults, eight recruiting children, and only one (He et al., 2014) recruiting adolescents and young adults. Additionally, most studies (*k* = 23) used a sample made up of predominantly women, with only 12 studies using a sample including roughly an even number of men and women. Moreover, most studies (*k* = 19) recruited university students, with 13 studies recruiting participants from the community, and three (Carbine et al., 2017, 2021; Powell et al., 2017) recruiting a combination of university students and community

members. Lastly, most studies (k = 32) used a sample including healthy weight and overweight participants, with only two studies (Guerrieri, Nederkoorn, & Jansen, 2007; Zhang et al., 2017) using healthy weight participants only, and one study (Carbine et al., 2021) using overweight participants only. However, six of these studies (Adise et al., 2021; Aiello et al., 2018; Carbine et al., 2018; Goldstein et al., 2014; Nederkoorn, 2014; Price et al., 2016) investigated healthy weight and overweight participants separately and as such, provided separate Pearson correlation coefficients for the relationship between inhibitory control and food consumption or choice for healthy weight and overweight participants.

Overall Relationship between Inhibitory Control and Food Consumption

Addressing the major aim of the present study, a meta-analysis showed that overall, there was a significant correlation for the relationship between inhibitory control and food consumption, r = .09, CI_{95} = [0.04, 0.14], p = .001, with small effect size (see Figure 2 for a forest plot of included studies). A leave-one-out analysis showed little variability in the Pearson correlation coefficient when each study was individually removed, all r's > 0.08 and < .10, all p's < 0.003, indicating that there were no outliers. Egger's regression test was not significant, Z = 0.813, p = .129, indicating no evidence of publication bias (see Figure 3 for funnel plot). Tests for heterogeneity showed that there was significant heterogeneity in the Pearson correlation coefficients across studies, $Q(34)$ = 56.697, p = .009, I^2 = 40.032. This heterogeneity may suggest the presence of moderators. Accordingly, moderator analyses were subsequently conducted.

Task Type (Go/No-Go versus Stop-Signal) and the Relationship between Inhibitory Control and Food Consumption

A moderator analysis was conducted to explore the impact of task type (Go/No-Go versus Stop-Signal) on the relationship between inhibitory control and food consumption. Moderator analysis statistics are shown in Table 4.

It can be seen that there was a small significant correlation for studies that used the Stop-Signal Task, r = .15, CI_{95} = [0.07, 0.23], p < .001. In contrast, the correlation for studies that used the Go/No-Go Task was not significant, r = 0.03, CI_{95} = [-0.04, 0.10], p = .407. Comparison of the subgroup correlations showed that the correlation for studies that used the Stop-Signal Task was significantly larger than for those that used the Go/No-Go Task, Q = 4.789, p = .029.

Interestingly, the two studies that were excluded for including both the Go/No-Go and Stop-Signal tasks produced inconsistent results. Kelly et al. (2020) showed that inhibitory control was significantly associated with food consumption when measured by the Go/No-Go

Task, r = .23, p < .05, but not the Stop-Signal Task, r = 0.10, p > .05. However, Powell et al. (2017) showed that neither measure of inhibitory control was associated with food consumption (Go/No-Go Task, r = 0.08, p = .526, Stop-Signal Task, r = 0.14, p = .290). Separate meta-analyses were run including Kelly et al. (2020) and Powell et al. (2017). The correlations remained significant for studies that used the Stop-Signal Task, r = 0.14, CI_{95} = [0.07, 0.21], p < .001, and not significant for those that used the Go/No-Go Task, r = 0.05, CI_{95} = [-0.02, 0.12], p = .163.

There was significant heterogeneity in the correlations across studies that used the Go/No-Go Task, $Q(18) = 30.559$, p = .032, I^2 = 41.097. Heterogeneity approached significance for studies that used the Stop-Signal Task, $Q(17) = 26.325$, p = .069, I^2 = 35.423. For both groups of studies, heterogeneity was small to medium (Higgins et al., 2003). Accordingly, separate moderator analyses were conducted for the Go/No-Go and Stop-Signal tasks. All moderator analysis statistics are shown in Table 5, Table 6.

Moderator Analyses for the Relationship between Inhibitory Control and Food Consumption

Moderator Analyses for Go/No-Go Task

Food-specific or general inhibitory control. There was no significant difference between the subgroup correlations when comparing studies that measured food-specific inhibitory control and those that measured general inhibitory control, Q = 0.007, p = .933. Separate meta-analyses were run including those studies (k = 6) previously excluded for having multiple measures. The correlations were not significant for studies measuring food-specific inhibitory control, r = 0.07, CI_{95} = [-0.02, 0.15], p = .121, or general inhibitory control, r = 0.05, CI_{95} = [-0.05, 0.14], p = .320.

Food Consumption/Choice Measure.

Objective or self-report. The correlation for studies that used an objective measure was significantly larger than for studies that used a self-report measure, Q = 5.009, p = .025. Specifically, there was a small significant correlation for studies that measured food consumption or choice using an objective measure, r = 0.12, CI_{95} = [0.04, 0.19], p = .002. In contrast, the correlation for studies that used a self-report measure was not significant, r = −0.05, CI_{95} = [-0.18, 0.08], p = .425. The correlations were homogenous among studies that used an objective measure, $Q(10) = 12.482$, p = .254, I^2 = 19.885, as well as those that used a self-report measure, $Q(4) = 5.612$, p = .230, I^2 = 28.722. For both subgroups, there was less heterogeneity than for all studies that used the Go/No-Go Task combined ($Q(18) = 30.559$, p = .032, I^2 = 41.097).

Separate meta-analyses were run including those studies (k = 3) previously excluded for having multiple measures. Again, there was a small significant correlation for studies that measured food consumption or choice using an objective measure, r = 0.10, CI_{95} = [0.03, 0.17], p = .006. In contrast, the correlation for studies that used a self-report measure was not significant, r = −0.07, CI_{95} = [-0.17, 0.02], p = .140.

Type of food consumption or choice measure. As only one study used an objective food choice measure, this subgroup was excluded from the moderator analysis investigating type of food consumption/choice measure. After further excluding those studies that used the same participants for multiple subgroups, the same grouping of studies emerged for type of food consumption/choice measure as for the objective or self-report measures. Accordingly, the same findings emerged. Specifically, the correlation for studies that used an objective food consumption measure was significantly larger than for studies that used a self-report food consumption measure, Q = 5.009, p = .025.

Unhealthy or all food consumption/choice, and hunger. A moderator analysis could not be conducted for the type of food measured as only three studies using the Go/No-Go Task measured all food consumption or choice. Nor for hunger as only two studies using the Go/No-Go Task did not control for hunger.

Sample Differences.

Sample age. Studies that used a combination of adolescents and young adults were excluded from the moderator analysis as there was only one such study. There was a significant difference between the correlations when comparing studies based on age group, Q = 12.969, p = .002. Specifically, there was a significant correlation for studies that used children, r = 0.18, CI_{95} = [0.10, 0.26], p < .001. In contrast, the correlation was not significant for studies that used young adults, r = 0.01, CI_{95} = [-0.13, 0.15], p = .893, nor for studies that included older adults, r = −0.03, CI_{95} = [-0.12, 0.05], p = .425. Pairwise comparisons showed that the correlation for studies that used children was significantly larger than for studies that used young adults, Q = 4.034, p = .045, or included older adults, Q = 12.362, p < .001. However, the difference in the correlations between studies that used children and those that used young adults did not survive a Bonferroni correction for multiple testing. The correlations were homogenous among studies that used children, $Q(4)$ = 2.892, p = .576, I^2 = 0.000, young adults, $Q(5)$ = 9.730, p = .083, I^2 = 48.612, and young adults and older adults, $Q(6)$ = 3.946, p = .684, I^2 = 0.000. However, only studies that used children and those that used young adults and older adults showed less heterogeneity than for all studies that used the Go/No-Go Task combined ($Q(18)$ = 30.559, p = .032, I^2 = 41.097).

Sample type, sample pool, sample weight, and sample gender. There was no significant difference between the correlations when comparing studies based on sample type, $Q = 0.001$, $p = .975$, or sample weight, $Q = 2.764$, $p = .251$. For sample pool, studies that recruited a combination of university students and community members were excluded from the moderator analysis as there were only three such studies. There was no significant difference between the correlations when comparing studies that recruited university students and those that recruited community members, $Q = 0.001$, $p = .982$. A meta-regression moderator analysis showed that the proportion of women did not explain any significant variance in the correlations for the relationship between inhibitory control and food consumption, $R^2 = 0.00$, $B = 0.00$, $SE = 0.00$, $p = .996$.

Moderator Analyses for Stop-Signal Task

Food-specific or general inhibitory control. A moderator analysis could not be conducted for form of inhibitory control because only two Stop-Signal studies measured food-specific inhibitory control.

Food Consumption/Choice Measure.

Type of food consumption or choice measure. As only two studies used a self-report food consumption measure, this subgroup was excluded from the moderator analysis investigating type of food consumption/choice measure. There was no significant difference between the correlations for studies that used an objective food consumption and an objective food choice measure, $Q = 0.592$, $p = .442$.

Objective or self-report, unhealthy or all food consumption/choice, and hunger. A moderator analysis for type of measure could not be conducted because only two studies measured food consumption using a self-report measure. Nor for the type of food measured as only three studies measured all food consumption or choice. There was no significant difference when comparing studies that controlled for hunger versus those that did not, $Q = 2.767$, $p = .096$.

Sample Differences.

Sample age. Studies that used a combination of young adults and older adults were excluded from the moderator analysis as there were only two such studies. Comparison of the subgroup correlations showed that the difference between the correlations bordered on significance, $Q = 3.848$, $p = .050$. Examination of the subgroup correlations showed that there was a small significant correlation for studies that used young adults, $r = .19$, $CI_{95} = [0.10, 0.28]$, $p < .001$, but not for studies that used children, $r = 0.06$, $CI_{95} = [-0.04,$

0.15], p = .235. The correlations were homogenous among studies that used children, $Q(3) = 3.481$, p = .323, I^2 = 13.821, and those that used young adults, $Q(11) = 17.303$, p = .099, I^2 = 36.428. However, only for studies that used children was there less heterogeneity than for all studies that used the Stop-Signal Task combined ($Q(17) = 26.325$, p = .069, I^2 = 35.423).

***Sample pool*.** Studies that recruited a combination of university students and community members were excluded from the moderator analysis as there was only one such study. The correlation for studies that used a university sample was significantly larger than for those that used a community sample, $Q = 4.858$, p = .028. Specifically, there was a small significant correlation for studies that used a university sample, $r = 0.19$, CI_{95} = [0.10, 0.28], $p < .001$, but not for studies that used a community sample, $r = 0.05$, CI_{95} = [-0.03, 0.13], p = .208. The correlations were homogenous among studies that used a university sample, $Q(11) = 17.303$, p = .099, I^2 = 36.428, and those that used a community sample, $Q(4) = 3.519$, p = .475, I^2 = 0.000. However, only for studies that used a community sample was heterogeneity less than for all studies that used the Stop-Signal Task combined ($Q(17) = 26.325$, p = .069, I^2 = 35.423).

Sample type, sample weight, and sample gender. A moderator analysis was not conducted to investigate subgroup differences based on sample type as only one study used a clinical sample. Similarly, a moderator analysis was not conducted to investigate subgroup differences based on sample weight as only three studies recruited participants of healthy weight only, and only one study recruited participants with overweight only. A meta-regression moderator analysis showed that the proportion of women did not explain any significant variance in the correlations between inhibitory control and food consumption, R^2 = 0.16, B = 0.00, SE = 0.00, p = .176.

Quality Assessment

Of the 35 included studies, most received 4 (n = 16) or 5 (n = 15) stars, indicating high quality (Hong et al., 2018; see Table 4). The remaining four studies (Allom & Mullan, 2014; Goldstein et al., 2014; Guerrieri, Nederkoorn, & Jansen, 2007; Kakoschke et al., 2015) scored 3 stars, indicating medium quality (Hong et al., 2018). Of these, three studies (Allom & Mullan, 2014; Goldstein et al., 2014; Kakoschke et al., 2015) used a young adult undergraduate sample without clear justification for doing so in terms of the study's research question. In addition, Guerrieri, Nederkoorn, and Jansen (2007) did not indicate whether participant groups were comparable at baseline nor whether experimenters were blinded to participant group, despite experimenters weighing bowls to measure food intake in the taste test.

Discussion

The present study is the first meta-analysis to comprehensively investigate the relationship between inhibitory control, as measured by the Go/No-Go and Stop-Signal tasks, and food consumption or choice. The findings showed that there is a small association between inhibitory control and food consumption or choice. More specifically, inhibitory control was associated with food consumption/choice when it was measured using the Stop-Signal Task. When measured by the Go/No-Go Task, inhibitory control was associated with food consumption or choice for children and when food consumption or choice was measured objectively (e.g., a taste test).

The major finding that, overall, inhibitory control, as measured by the Go/No-Go and Stop-Signal tasks, is indeed associated with food consumption or choice, indicates that individual differences in inhibitory control do play a role in food consumption. However, the size of the association was small. This likely reflects the inconsistency in findings in this domain, in that poorer inhibitory control has been shown to be associated with food consumption in some studies (e.g., Guerrieri, Nederkoorn, & Jansen, 2007; Lyu et al., 2017), but not others (e.g., Aiello et al., 2018; Fonseca et al., 2020). Because of small sample sizes, individual previous studies may have lacked the statistical power to detect an association. Thus, the benefit of this meta-analysis is clear, as the greater statistical power and pooled estimate of effect has allowed the establishment of statistical significance among conflicting literature.

The finding that inhibitory control was associated with food consumption/choice more for the Stop-Signal Task than the Go/No-Go Task may be because the tasks rely on different cognitive mechanisms. Raud et al. (2020) have suggested that performance in the Go/No-Go Task is indicative of response selection, rather than inhibitory control. In the Go/No-Go Task the presentation of “go” and “no-go” signals is fixed at the start of the trials, whereas in the Stop-Signal Task, the “stop” signal is presented after the “go” signal, commonly with an adaptive individualized delay (as was the case for all studies included in the present review). However, closer examination of the studies included in this meta-analysis suggests another potential explanation, namely the way food consumption or choice was measured. All except one of the studies using the Stop-Signal Task measured food consumption or choice objectively. In contrast, five of the 16 studies that used the Go/No-Go Task employed self-report measures. Indeed, when food consumption or choice was measured objectively in studies using the Go/No-Go Task, the effect size for its association with inhibitory control was comparable to the effect size for studies that used the Stop-Signal Task. Therefore, it appears that inhibitory control, no matter how it is measured, is associated with food

consumption or choice when the latter is measured objectively. This may be because objective measures, such as the taste test, have been shown to be valid measures of consumption (Robinson et al., 2017), whereas self-reported consumption has been shown to suffer from systematic underreporting of energy intake (Ravelli & Schoeller, 2020). Another contributing factor may be the timing of the food consumption/choice measure. In all cases, objective measurement of food consumption/choice occurred immediately following the measurement of inhibitory control, whereas self-report measures involved participants either recalling preceding consumption or reporting consumption over the following days. In other words, the objective measures of food consumption/choice were temporally closer to their respective measure of inhibitory control. As it has been shown to fluctuate in response to internal (e.g., stress and depletion of self-control resources) and external (e.g., exposure to environmental cues) events (Jones et al., 2013, 2018; Muraven et al., 2002; Tsegaye et al., 2022), inhibitory control (as measured by tasks such as the Go/No-Go and Stop-Signal) may be associated only with immediate food consumption or choice rather than subsequent consumption more generally.

The results further showed that the use of neutral or food stimuli in the Go/No-Go Task did not impact the observed relationship between inhibitory control and food consumption/choice. Thus, it appears that general and food-specific inhibitory control are equally (un)related to food consumption/choice. However, no such conclusion can be drawn for the Stop-Signal Task as only two studies (Houben & Jansen, 2014; Zhang et al., 2017) measured food-specific inhibitory control – too few studies to carry out a moderator analysis. Following the suggestion of Bartholdy et al. (2016) and Wu et al. (2013) that inhibitory control performance may differ based on the stimuli presented, future studies could investigate the impact of using neutral versus food stimuli in the Stop-Signal Task.

The relationship between inhibitory control and food consumption or choice was consistent across men and women, general and clinical populations, and, for the Go/No-Go Task, different weight categories. However, there were differences between age groups. Specifically, for the Go/No-Go Task, the relationship was stronger in children, whereas for the Stop-Signal Task, it was stronger in young adults. There was also a difference between community and university samples, but only for studies that used the Stop-Signal Task. However, this likely has been driven by age differences in the community and university samples, as all community samples used children or older adults and all university samples used young adults. Interestingly, for the Go/No-Go Task, all studies that used children measured food consumption or choice objectively. In contrast, several of the studies that recruited samples from other age groups used self-report measures. Thus, again, it may be

the nature of the measure that is critical. Alternatively, it is possible that the Go/No-Go Task may be particularly useful in capturing inhibitory control in children, but not older samples. The Go/No-Go Task is a relatively easy task (Meule, 2017), in which children make more commission errors than young adults (Jonkman et al., 2003). The opposite may be true for the Stop-Signal Task, which is comparatively difficult (Johnstone et al., 2007; Meule, 2017). Accordingly, the Stop-Signal Task may be particularly useful for young adults, and less so for children (Christ et al., 2001; Verbruggen & Logan, 2008; Williams et al., 1999) or older adults (Christ et al., 2001; Hsieh & Lin, 2017; Verbruggen & Logan, 2008) who have each been shown to have slower reaction times in the Stop-Signal Task (Hsieh & Lin, 2017; Johnstone et al., 2007). In saying this, children's performance in the Go/No-Go and Stop-Signal tasks has not been formally compared, scope for future research.

The present meta-analysis has some important implications. First, it shows that inhibitory control, as measured by the Go/No-Go and Stop-Signal tasks, is associated with food consumption or choice. Although the association is small, this has practical relevance as studies have, on the basis of this assumed relationship, investigated the efficacy of inhibitory control training for reducing unhealthy food consumption. The present study now provides comprehensive evidence supporting the investigation of such interventions. Second, the findings provide important insights for future studies investigating the relationship between inhibitory control, as measured by the Go/No-Go and Stop-Signal tasks, and food consumption or choice. In particular, they show that the Go/No-Go and Stop-Signal tasks can both be used when food consumption or choice is measured objectively (e.g., a taste test) in the immediate setting. In addition, for the Go/No-Go Task, it appears that neutral or food-specific stimuli can be used to measure inhibitory control. For the Stop-Signal Task, however, we know only that the use of neutral stimuli appears to be effective. Finally, the findings showed that there were few differences in the strength of the relationship between inhibitory control and food consumption/choice among samples of varying demographics, including men, women, and different weight categories. The one exception here was age, where the Go/No-Go Task may be particularly useful for capturing the relationship in children, and the Stop-Signal Task for doing so in young adults. Thus, future research should be mindful of the match between sample and measure of inhibitory control.

As with all research, there are some limitations that need to be acknowledged. In particular, there are additional within-task moderator variables that could have been investigated. For the Go/No-Go and Stop-Signal tasks, these could include variations in response mode (unimanual/bimanual), number of trials, and ratio of stop/go trials. For the food consumption measures, such as the taste test, potential variables could include the

amount of food provided and the duration of the test (Robinson et al., 2017). Future research could investigate how such variables may impact the relationship between inhibitory control, as measured by the Go/No-Go and/or Stop-Signal tasks, and food consumption.

In conclusion, the present meta-analysis provides the first comprehensive evidence that inhibitory control, as measured by the Go/No-Go and Stop-Signal tasks, is associated with food consumption or choice. However, for the Go/No-Go Task, this relationship was only found when food consumption or choice was measured objectively and in the same session as the inhibitory control measure. Overall, although all observed associations were of a small effect size, the results provide comprehensive evidence pointing to inhibitory control as a potential target for reducing unhealthy food consumption.

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Contributors

All authors contributed to the design of the study and writing the manuscript. Joshua McGreen was responsible for data collection, under supervision of Eva Kemps. Joshua McGreen conducted the statistical analyses and wrote the first draft of the manuscript. All other authors edited subsequent drafts of the manuscript, and have approved the final manuscript.

Ethical statement

The study protocol was approved by the Flinders University Social and Behavioural Research Ethics Committee.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Data and code availability

Data will be made available on request.

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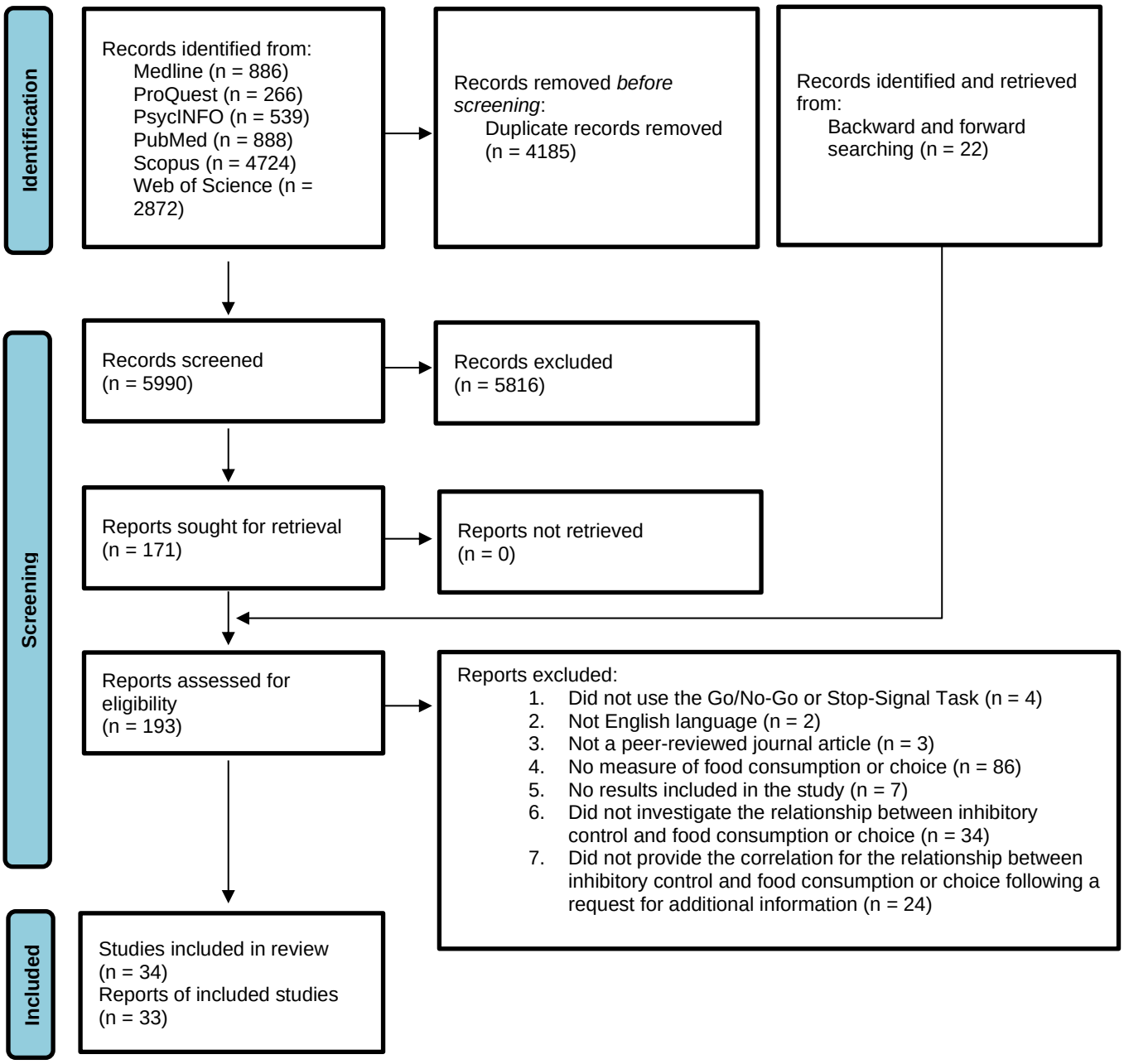
Table 1

Keywords used for the database searches

Construct	Keywords
The Go/No-Go Task and/or Stop-Signal Task	Go/no-go, go no go, go–nogo, GNG, stop signal, stop-signal, and SST.
Food	Sugar, food*, chip*, snack*, sweet*, loll*, choc*, cand*, and unhealthy.
Consumption and/or Choice Outcome	Consumption, consum*, intake, imbibe, eat, eating, drink*, choice*, select*, choose, chose, pick*, vote*, take*, and prefer*.

Figure 1

PRISMA flowchart (Page et al., 2021) showing the number of articles identified at each stage of the first search



Note. The flowchart does not include the additional study included following the updated search conducted on 16th February 2022.

Table 2

Summary of included studies: sample characteristics

Study title	Subgroups	*N*	Sample type	Sample age	Sample gender (% women)	Sample pool	Sample weight
Adise et al. (2021)		66	General	Children	53%	Community	General
	Healthy weight	34					
	Overweight	32					
Aiello et al. (2018)		30	General	Older adults	56%	Community	General
	Healthy weight	8					
	Overweight	22					
Allom & Mullan (2014)		115	General	Young adults	72%	University	General
Bennett & Blissett (2019)		50	General	Children	56%	Community	General
Biehl et al. (2019)		34	General	Children	53%	Community	General
	LOC	15					

	No LOC	19					
Byrne et al. (2021)		181	General	Children	55%	Community	General
Carbine et al. (2017)		145	General	Young and older adults	50.94%	Combination	General
Carbine et al. (2018)		54	General	Young and older adults	50%	Community	General
	Healthy weight	17					
	Overweight	37					
Carbine et al. (2021)		100	General	Young and older adults	53%	Combination	Overweight
Fonseca et al. (2020)		51	Anxiety disorder	Young and older adults	100%	Community	General
Giesen et al. (2012)		70	General	Young adults	76%	University	General
Goldstein et al. (2014)		95	General	Young adults	100%	University	General
	Healthy weight	72					
	Overweight	22					
Guerrieri, Nederkoorn & Jansen (2007).		44	General	Young adults	100%	University	General

Monotony condition only						
Guerrieri et al. (2007). Baseline session only	38	General	Young adults	100%	University	Healthy weight
Guerrieri et al. (2008). Monotony group only	40	General	Children	45%	Community	General
He et al. (2014)	30	General	Adolescents and young adults	57%	University	General
Hofmann et al. (2009)	118	General	Young adults	100%	University	General
Houben et al. (2012). Control condition only	24	General	Young adults	100%	University	General
Houben & Jansen (2014). Control condition only	19	General	Young adults	100%	University	General
Kakoschke et al. (2015)	146	General	Young adults	100%	University	General
Kelly et al. (2020)	205	General	Children	54%	Community	General

Levitan et al. (2015)		193	General	Children	47%	Community	General
Lowe et al. (2014). Sham session only		21	General	Young adults	100%	University	General
Lyu et al. (2017)		62	General	Young adults	100%	University	General
	Binge-eaters	31					
	No binge-eating control	31					
Meule et al. (2011)		61	General	Young adults	100%	University	General
	Restrained eaters	31					
	Not restrained eaters	30					
Nederkoorn et al. (2009). Study 1		57	General	Young adults	100%	University	General
Nederkoorn et al. (2009). Study 2		94	General	Young adults	82%	University	General
Nederkoorn (2014)		70	General	Young and older adults	86%	Community	General

	Healthy	31					
	Overweight	39					
Nederkoorn et al. (2015)		88	General	Children	64%	Community	General
Oomen et al. (2018)		41	LOC	Young adults	76%	Community	General
Powell et al. (2017)		64	General	Young and older adults	77%	Combination	General
Price et al. (2016)		115	General	Young and older adults	81%	University	General
	Healthy	83					
	Overweight	32					
van Strien et al. (2014). Control session only		54	General	Young adults	100%	University	General
Wang et al. (2016). No-depletion control only		47	General	Young adults	100%	University	General

Zhang et al. (2017)	64	Restrained eaters	Young adults	100%	University	Healthy weight

Note. LOC = loss of control over eating. For sample weight, healthy = participants of healthy weight (BMI 18.5 to 24.9); overweight = participants with overweight (BMI > 24.9); and general = participants of all weight categories (any BMI; Weir & Jan, 2021).

Table 3

Summary of included studies: inhibitory control task, food consumption or choice measure and the correlation for the relationship between inhibitory control and food consumption/choice

Study title	Task	Task: Food-specific or general	Food consumption or choice measure	Food consumption or choice measured	Hunger controlled	*r*	MMAT quality rating
Adise et al. (2021)	GNG	General	In-laboratory buffet	Unhealthy food intake (kcal)	Yes	.01	*****
Aiello et al. (2018)	GNG	Food-specific and general	Food preference task; Self-report "How often do you eat this food?"	Percentage of high calorie food choices in the food preference task; Mean rating for high calorie foods: "How often do you eat this food?"	Yes	-.21	*****
Allom & Mullan (2014)	SST	General	Self-report how often they ate 17 meat and snack items (e.g., bacon, full-fat ice	Saturated fat intake	No	.27	****

			cream, fried potatoes)				
Bennett & Blissett (2019)	GNG	General	Snack session	Snack intake (kcal)	No	.19	****
Biehl et al. (2019)	GNG	Food-specific and general	Taste test	Snack intake	Yes	.28	*****
Byrne et al. (2021)	GNG	Food-specific and general	In-laboratory buffet	Snack intake (kcal)	Yes	.16	****
Carbine et al. (2017)	GNG	Food-specific	24-hour dietary recall	All intake (kcal)	Yes	-.08	*****
Carbine et al. (2018)	GNG	Food-specific	24-hour dietary recall; Mock food intake task	All intake (kcal)	Yes	-.14	*****
Carbine et al. (2021)	GNG	Food-specific and general	24-hour dietary recall	All intake (kcal)	Yes	-.08	*****
Fonseca et al. (2020)	GNG	Food-specific	Food frequency questionnaire; Bogus snack test	All intake (kcal); Number of biscuits consumed during 5 minutes	Yes	.09	*****

Giesen et al. (2012)	SST	General	Internet supermarket task: grocery shopping for the whole day	All intake (kcal)	Yes	.12	*****
Goldstein et al. (2014)	GNG	Food-specific	Taste test	Chocolate intake (grams)	Yes	.01	***
Guerrieri, Nederkoorn & Jansen (2007). Monotony condition only	SST	General	Taste test	Sugar bean intake (grams)	Yes	.11	***
Guerrieri et al. (2007). Baseline session only	SST	General	Taste test	Milkshake intake (grams)	No	.42	*****
Guerrieri et al. (2008). Monotony condition only	SST	General	Taste test	Marshmallow intake (grams)	No	.15	****
He et al. (2014)	GNG	Food-specific	24-hour dietary recall	High-calorie food intake (calories)	Yes	.23	****
Hofmann et al. (2009)	SST	General	Taste test	Candy intake (grams)	Yes	.06	***

Houben et al. (2012). Control condition only	SST	Food-specific and general	Taste test	High calorie food intake (calories)	Yes	.24	****
Houben & Jansen (2014). Control condition only	SST	General	Taste test	Crisps intake (calories)	Yes	.70	****
Kakoschke et al. (2015)	GNG	Food-specific	Taste test	Snack intake (calories)	Yes	.01	***
Kelly et al. (2020)	GNG and SST	GNG: Food-specific SST: General	In-laboratory buffet	All intake (calories)	Yes	.17	*****
Levitan et al. (2015)	SST	General	Snack session	All intake (calories)	Yes	-.05	*****
Lowe et al. (2014). Sham session only	GNG	General	Snack session	Snack intake (calories)	Yes	-.18	*****
Lyu et al. (2017)	GNG	Food-specific	Snack session	Snack intake (calories)	Yes	.30	*****
Meule et al. (2011)	GNG	Food-specific and general	Taste test	Snack intake	Yes	.04	****
Nederkoorn et al. (2009) Study 1	SST	General	Taste test	High calorie food intake (calories)	No	.28	****

Nederkoorn et al. (2009) Study 2	SST	General	Internet supermarket task: grocery shopping for 3 days	Snacks purchased (calories)	No	.20	****
Nederkoorn (2014)	SST	General	Internet supermarket task: grocery shopping for 3 days	Snacks purchased (calories)	No	.03	****
Nederkoorn et al. (2015)	SST	General	Taste test	High calorie food intake (calories)	No	.14	****
Oomen et al. (2018)	GNG	Food-specific	Self-report naturalistic consumption per week	Frequency of chocolate and crisps intake per week	Yes	-.30	****
Powell et al. (2017)	GNG and SST	GNG: General SST: General	Self-report usual diet over the preceding 2–3 months	Snack intake (calories) per day	No	.10	*****
Price et al. (2016)	GNG	Food-specific and general	Taste test	Biscuit intake (grams)	Yes	.05	*****
van Strien et al. (2014). Control session only	SST	General	Taste test	Snack intake (grams)	Yes	.05	****

Wang et al. (2016). No-depletion control only	SST	General	Taste test	Chocolate intake (grams)	No	.21	****
Zhang et al. (2017)	SST	Food-specific and general	Food choice task	Likelihood to choose high calorie food	Yes	-.02	****

Note. GNG = Go/No-Go Task; SST = Stop-Signal Task

Figure 2

Forest plot of included studies showing the correlation for the relationship between inhibitory control and food consumption/choice and the 95% confidence interval

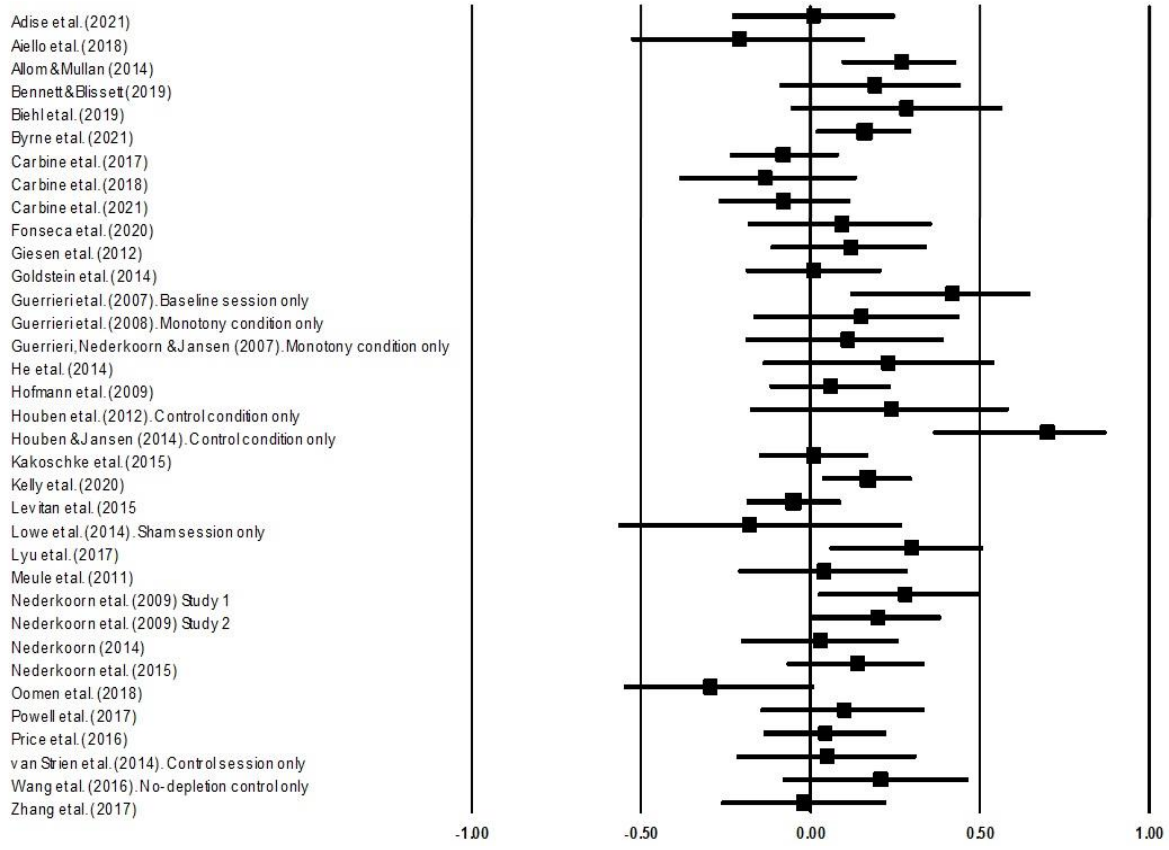


Figure 3

Funnel plot of Fisher's Z plotted against standard error, showing included studies

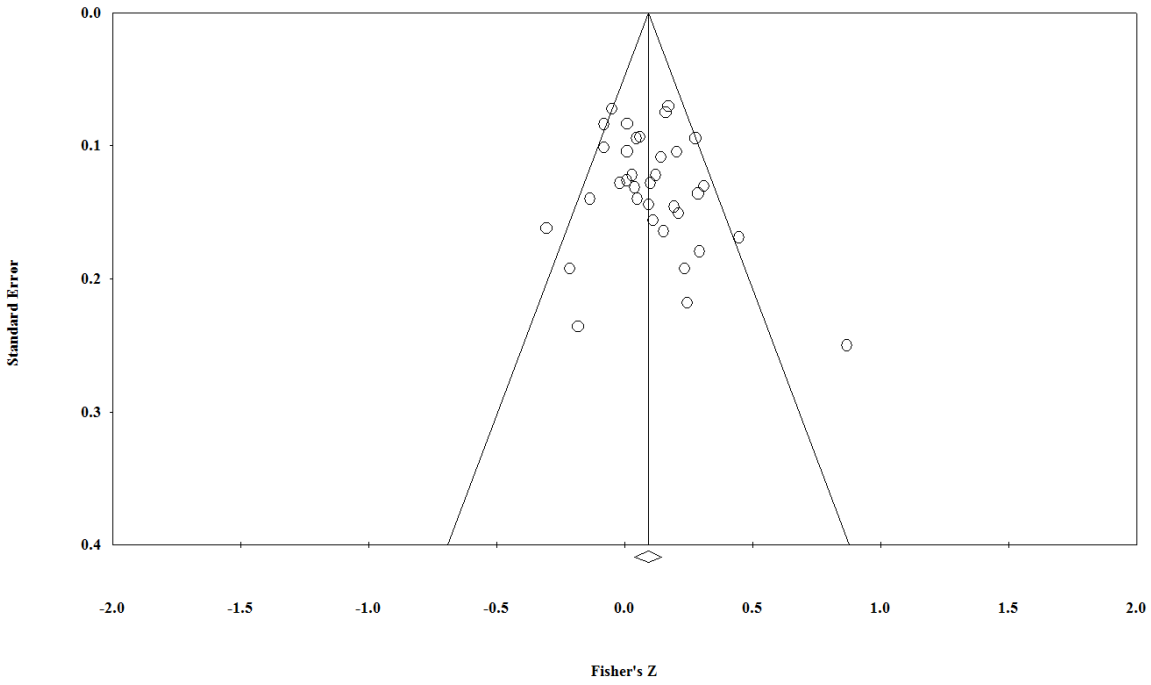


Table 4

Moderator analyses of the correlation between inhibitory control and food consumption/choice

				r			Subgroup Difference	
Moderator	***k***	***N***	***r***	**LL**	**CL**	***p***	***Q***	***p***
Inhibitory control measure							4.789	.029
Go/No-Go Task	17	1282	.03	-.04	.10	.407		
Stop-Signal Task	16	1135	.15	.07	.23	< .001		

Table 5

Subgroup moderator analyses of the correlation between inhibitory control as measured by the Go/No-Go Task and food consumption/choice

				r			Subgroup Difference	
Moderator	***k***	***N***	***r***	**LL**	**CL**	***p***	***Q***	***p***
Go/No-Go Task							0.007	.933
Food-specific	9	875	.05	-.07	.16	.456		
General	4	201	.05	-.09	.19	. 462		
Food consumption measure							5.009	.025
Objective	11	1036	.12	.04	.19	.002		
Self-report	5	380	-.05	-.18	.08	.425		
Sample type							0.001	.975
General	17	1383	.06	-.02	.13	.118		
Clinical	5	168	.06	-.17	.27	.625		
Sample Age							12.969	.002
Children	5	524	.18	.10	.26	< .001		
Young adults	6	426	.01	-.13	.15	.893		
Included older adults	7	559	-.03	-.12	.05	.425		
Sample Pool							0.001	.982
University	7	530	.06	-.03	.15	.173		

Community	9	712	.06	-.06	.18	.312		
Sample Weight							2.764	.251
Normal	14	1157	.09	.00	.17	.044		
Healthy weight	4	180	.03	-.12	.18	.696		
Overweight	5	213	-.05	-.19	.09	.477		

Note. Food-specific = food-specific stimuli used in inhibitory control task to measure inhibitory control; General = neutral stimuli used in inhibitory control task; Objective = objective measure of food consumption or choice; Self-report = self-report measure used to measure food consumption or choice; Unhealthy = unhealthy consumption measured; All = all consumption measured.

Table 6

Subgroup moderator analyses of the correlation between inhibitory control as measured by the Stop-Signal Task and food consumption/choice

				r			Subgroup Difference	
Moderator	***k***	***N***	***r***	**LL**	**CL**	***p***	***Q***	***p***
Type of Food Measure							0.592	.442
Objective food consumption	12	927	.15	.06	.25	.002		
Food choice	4	298	.10	-.02	.21	.106		
Hunger							2.767	.096
Controlled	9	791	.20	.12	.28	< .001		
Not controlled	9	613	.09	-.02	.19	.093		
Sample Age							3.848	.050
Children	4	526	.06	-.04	.15	.235		
Young adults	12	744	.19	.10	.28	< .001		
Sample Pool							4.858	.028
University	12	744	.19	.10	.28	< .001		
Community	5	596	.05	-.03	.13	.208		

CHAPTER FIVE: THE EFFECTIVENESS OF GO/NO-GO AND STOP-SIGNAL TRAINING IN REDUCING FOOD CONSUMPTION AND CHOICE: A SYSTEMATIC REVIEW AND META-ANALYSIS

For the published version of this chapter, see:

McGreen, J., Kemps, E., & Tiggemann, M. (2024). The effectiveness of Go/No-Go and Stop-Signal training in reducing food consumption and choice: A systematic review and meta-analysis. *Appetite*, *195*, 107215. https://doi.org/10.1016/j.appet.2024.107215

Abstract

The Go/No-Go and Stop-Signal tasks have been used to reduce excess food intake via repeated pairing of food cues with response inhibition. A meta analysis of 32 studies was conducted to determine whether, and under which conditions, the Go/No-Go and Stop-Signal training tasks are effective in reducing food consumption or choice. Moderators included task parameters (e.g., number of sessions, stop signal), sample differences (e.g., age, weight), and the measure of food consumption or choice. Overall, there was a small effect for Go/No-Go and Stop-Signal training in reducing food consumption or choice, g = −0.21, CI_{95} = [-0.31, −0.11], p < .001, with this holding individually only for a single session of the Go/No-Go Task, g = −0.31, CI_{95} = [-0.45, −0.18], p < .001. Comprehensive investigation of the impact of varying moderators indicated that the effect for Go/No-Go training was robust. Nevertheless, there was significant variation in the specific parameters of the task. Overall, the present meta-analysis extends previous findings by providing comprehensive evidence that the Go/No-Go Task is effective in reducing food consumption and choice, as well as providing optimal parameter recommendations for the task.

Keywords: inhibitory control, devaluation, go/no-go task, stop-signal task, food consumption, food choice, meta-analysis.

Introduction

Overconsumption, particularly of unhealthy foods, that is those high in sugar, fat, and salt, has been shown to be an important contributor to the increase in worldwide obesity prevalence (Cecchini et al., 2010; Machado et al., 2020). It is also associated with other negative health outcomes, including diabetes (Sami et al., 2017), high blood pressure (Margerison et al., 2020), heart disease and stroke (Anand et al., 2015), tooth decay (Mobley et al., 2009), and depression (Ljungberg et al., 2020).

One potential contributor to overconsumption of unhealthy foods is inhibitory control, where people have difficulty controlling their responses to food cues (Hofmann et al., 2009; Lawrence et al., 2012). In support, inhibitory control has been shown to be associated with unhealthy food intake (Guerrieri et al., 2007; He et al., 2014; Lyu et al., 2017; McGreen et al., 2023) and weaker inhibitory control has been linked to a higher BMI (Lavagnino et al., 2016). Thus, research has investigated the impact of training inhibitory control via repeated pairing of food cues with response inhibition, with such training protocols having been shown to reduce subsequent intake and choice of those foods (Aulbach et al., 2019; Yang et al., 2019). Although such training protocols were originally thought to train general or food-specific inhibitory control, more recent conceptualisations suggest that they instead reduce food consumption via a devaluation effect whereby repeated pairing of food cues with response inhibition results in a devaluation of the associated food items (Houben, 2023; Veling et al., 2017; Veling et al., 2022). Accordingly, it has been suggested that such tasks should be considered as training protocols that change the valuation of food items (Veling et al., 2022), or motor response training tasks (Johannes et al., 2021).

In food consumption research, “inhibitory control” training has most commonly used modified versions of the Go/No-Go (Donders, 1969) and Stop-Signal (Logan & Cowan, 1984) tasks (Allom et al., 2016; Aulbach et al., 2019; Jones et al., 2016; Yang et al., 2019), computerized tasks designed to objectively measure inhibitory control. For inhibitory control training, the Go/No-Go and Stop-Signal tasks are used to repeatedly pair stimuli (e.g., food cues) with response inhibition (Allom et al., 2016; Jones et al., 2016). The tasks ask participants to respond to designated “go” signals (e.g., the letter “f”) and inhibit responses to designated “stop” or “no-go” signals (e.g., the letter “p” or a sound). Training is achieved by repeatedly pairing target stimuli (e.g., unhealthy foods) with “no-go” signals and control stimuli (e.g., healthy foods) with “go” signals. This repeated pairing of stimuli with “no-go” signals has been suggested to create automatic stop associations and reduce explicit evaluations of the paired stimuli (Veling et al., 2017), which may then impact behaviour, such as food consumption. The main distinctions between the Go/No-Go and Stop-Signal tasks are the timing of the “stop” or “no-go” signal in relation to the “go” signal and the cue-inhibition contingency. In the Go/No-Go Task, the “go” and “no-go” signals are presented simultaneously at the beginning of the “go” and “no-go” trials, respectively. In contrast, in the Stop-Signal Task, the “stop” signal is presented roughly 300 ms after the “go” signal (Logan, 1994). In addition, in the Go/No-Go Task, the “no-go” signal is commonly presented on all target trials, in contrast to the Stop-Signal Task which generally pairs the “stop” signal with target stimuli on 50% of such trials (Allom et al., 2016; Aulbach et al., 2019; Jones et al., 2016; Yang et al., 2019).

Although both the Go/No-Go and Stop-Signal protocols were originally intended to target inhibitory control, it has subsequently been suggested that the two tasks rely on different mechanisms (Raud et al., 2020). Specifically, it has been argued that the Stop-Signal Task involves action cancellation after a prepotent response has been initiated (or top-down response inhibition) because the “stop” signal is presented after a “go” signal (Littman & Takács, 2017; Veling et al., 2017). In contrast, as the Go/No-Go Task involves the presentation of either a “go” or “no-go” signal, it has been argued to be a simpler task involving automatic or bottom-up response inhibition (Littman & Takács, 2017; Veling et al., 2017).

To date, four previous meta-analyses of the effectiveness of inhibitory control training have included food consumption and choice (Allom et al., 2016; Aulbach et al., 2019; Jones et al., 2016; Yang et al., 2019). These have shown that the Go/No-Go Task protocol was more effective than the Stop-Signal Task protocol in reducing such consumption. However, the reviews by Allom et al. (2016) and Jones et al. (2016) also focused on alcohol intake, and those by Aulbach et al. (2019) and Yang et al. (2019) also included other training protocols, such as Approach Avoidance training and Evaluative Conditioning. Consequently, it is difficult to gauge the effectiveness specifically of Go/No-Go and Stop Signal Training for reducing excess food intake. In addition, the quantity of literature specifically focused on food consumption has grown considerably since these reviews (Adams et al., 2021; Ahn et al., 2019; Aulbach et al., 2020; Carbine et al., 2021; Masterton et al., 2021; Masterton & Jones, 2023; Porter et al., 2021). Accordingly, the present review and meta-analysis focuses specifically on the Go/No-Go and Stop-Signal Task training protocols for reducing food consumption and choice.

Despite the Go/No-Go Task protocol being used as a training protocol in the food consumption domain, there appears to be little consistency across studies in the specific task parameters (Young et al., 2018). For example, studies vary in their trial durations, from 1000 ms (Bongers et al., 2018) to 1800 (Love et al., 2020) millisecond durations. Such studies provide no explanation as to why specific parameters were chosen. Although the impact of some individual parameter differences has previously been explored (Allom et al., 2016; Aulbach et al., 2019; Jones et al., 2016; Yang et al., 2019), this has been piecemeal and none of the four previous reviews completed a systematic and comprehensive investigation of a wide range of parameters for the Go/No-Go Task protocol. Consequently, these reviews provide a somewhat fragmented account of parameter effects. As an important next step, the current meta-analysis sought to provide a more comprehensive investigation of the impact of a wider range of parameter differences for the Go/No-Go Task

specific to the food and eating domain. In so doing, the current paper sought also to extend the previous reviews by identifying Go/No-Go Task parameters that are effective in reducing food consumption or choice. Specific factors that vary widely across studies that have not been systematically investigated include: (i) the control condition used (e.g., target stimuli paired with “go” signals on all trials and non-target stimuli paired with “no-go” signals on all trials; participants instructed not to respond to stimuli); (ii) the number of training sessions; (iii) the “go” and “no-go” signals used (e.g., shapes, colours); (iv) the non-target stimuli presented in the training task (e.g., healthy foods, neutral images)**;** (v) whether task performance feedback is provided (e.g., response too slow, correct response); (vi) the inter-trial duration; and (vii) the inter-trial stimulus (e.g., blank screen, fixation cross). Thus, our aim was to update and extend the findings of Allom et al. (2016), Jones et al. (2016), Aulbach et al. (2019), and Yang et al. (2019) by conducting a focused, systematic, and comprehensive investigation of the impact of parameter differences on the inhibitory control training effect size in the food realm.

Another difference across studies is in the way food consumption is measured. For example, some studies utilized objective measures (e.g., a taste test; Kakoschke et al., 2017; Porter et al., 2018), whereas others employed self-report measures (e.g., self-reported naturalistic consumption; Camp & Lawrence, 2019; Carbine et al., 2021). Consistently low correlations are reported between objective and self-report measures (Dang et al., 2020), indicating poor correspondence between these measures. In addition, some studies have measured food consumption, whereas others have measured food choice, actual or hypothetical (Masterton et al., 2021; Porter et al., 2021). Further, studies differ in when food consumption or choice is measured, with some studies completing such measures immediately following the intervention (Kakoschke et al., 2017) and others at subsequent time-points (e.g., one week after; Camp & Lawrence, 2019). Investigation of the training effect at different time points helps indicate the longevity of the training effect in reducing food consumption. In their report on alcohol intake and eating behaviour combined, Allom et al. (2016) concluded that the largest effect occurred when outcomes were measured objectively, rather than subjectively, and that the training effect appears to be only short-term. The present meta-analysis aimed to extend this work by testing such differences with a specific focus on food consumption/choice.

Overall, the present meta-analysis aimed to combine and evaluate data from multiple studies to provide a comprehensive investigation of the impact of parameter differences on the effectiveness of inhibitory control training tasks in reducing excess food intake. Ultimately, it was aimed that findings could inform the standardization of inhibitory control

training protocols for reducing excess food intake. Accordingly, we conducted a meta-analysis of relevant studies to address the following questions.

1. Do the Go/No-Go and Stop-Signal tasks reduce food consumption/choice?
2. Is there a difference between the Go/No-Go and Stop-Signal tasks in any such reduction in food consumption/choice?
3. Do task parameter differences in the Go/No-Go and Stop-Signal tasks (e.g., trial duration; number of training sessions; the type of “go” and “no-go” signals used) impact any such reduction in food consumption/choice?
4. Does the food consumption or choice measure (e.g., objective or self-report measure; when food intake is measured; the type of food measured) impact any such reduction in food consumption/choice?

Method

The present meta-analysis was conducted in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines (Page et al., 2021). As per McGreen et al. (2023), the initial protocol was registered with the Open Science Framework (OSF) (registration DOI https://doi.org/10.17605/OSF.IO/NPJ8A), but was modified following full-text screening because the scope was deemed too large for a single review. Specifically, the initial protocol was split into two separate, independent meta-analyses with different research questions, sets of studies, and data sets. The modification occurred before any data extraction or analysis. The first meta-analysis used correlational data to investigate the relationship between inhibitory control, as measured by the Go/No-Go and/or Stop-Signal tasks, and food consumption/choice.

The second meta-analysis (the present study) addressed the question as to whether Go/No-Go and Stop-Signal task training is effective in reducing food consumption, and as such, the data set comprised experimental studies. The present analysis also investigated the moderating roles of within-task methodological differences of the Go/No-Go Task (e.g., comparison control condition, go/no-go cues, ratio of go/no-go trials, stimuli used, trial duration).

Search Strategy

The search strategy was developed under the direction of a research librarian at Flinders University, and included key terms and synonyms for the Go/No-Go Task, the Stop-Signal Task, and food consumption (see Table 1). The initial search was conducted on June 25, 2020, with the following databases searched: Medline, ProQuest, PsycINFO, PubMed,

Scopus, and Web of Science. Searches were limited to English-language papers published in peer-reviewed journals. Two impartial reviewers then independently checked the eligibility of each retrieved paper's title and abstract. In a meeting between the reviewers, disagreements were settled, and resolution outcomes and justifications were recorded for each paper. The primary author then completed full-text screening of the remaining eligible papers. Finally, to find any further potentially relevant papers, backward and forward searches were conducted. On February 16th, 2022, a second search was done, with four additional papers identified (Adams et al., 2021; Carbine et al., 2021; Masterton et al., 2021; Porter et al., 2021). On September 24th, 2023, a third and final search was done, with one additional paper (Masterton & Jones, 2023) identified.

Eligibility Criteria

Inclusion criteria of eligible papers were: (1) a focus on food consumption or choice; (2) use of the Go/No-Go Task and/or Stop-Signal Task as the training task; (3) inclusion of an appropriate control condition; and (4) provision of the mean and standard deviation for post-training food consumption or choice, as well as the number of participants, for both the training condition and the control condition.

Information Extracted

The following data were extracted and tabulated: sample characteristics (number of participants; clinical or general; university or community; age; gender; weight), training task (Go/No-Go Task or Stop-Signal Task), version of the Go/No-Go and/or Stop-Signal task (food-specific or general), control comparison condition (e.g., pairing unhealthy foods with both “go” and “no-go” signals equally), number of training sessions, number of trials for the training task, trial duration, the “go” and “no-go” signals (e.g., letters, sounds), percentage of target trials paired with “no-go” signals, percentage of “no-go” signal trials paired with target stimuli, non-target stimuli presented in the training task (e.g., healthy foods, neutral objects), whether task performance feedback was provided to participants (e.g., response too fast, correct response), inter-trial duration, inter-trial stimulus (e.g., blank screen, fixation object), measure of food consumption/choice (e.g., taste test, self-reported intake), type of food measured (e.g., unhealthy foods, all foods), timing of food consumption or choice measure (e.g., immediately after training, one day after), and the mean(s) and standard deviation(s), as well as the number of participants, for both the training condition and the control condition, for the measure(s) of post-training food consumption or choice outcome, for each condition.

In cases where a paper lacked some of the above information, the corresponding author was contacted and the information requested. If the contact e-mail address provided in the paper was no longer active, the author was contacted using all associated e-mail addresses (sought via extensive internet searchers). If the author had not responded within one month of the initial email request, they were emailed again. Co-authors were then contacted if they still did not respond. To provide authors with enough time to respond and to increase the number of relevant papers included in the systematic review and meta-analysis, this approach was undertaken over a 6-month period.

Data Coding

Variable coding was conducted by the lead author. Following Borenstein et al. (2009), for studies that included multiple training and/or control conditions, a combined weighted mean and standard deviation were calculated. These were then used to calculate the effect size, which was subsequently used in the overall meta-analysis investigating the effect of training in reducing food consumption or choice. Studies were excluded from any relevant moderator analyses if the same participants were used for each subgroup.

Inhibitory Control Training Task

Studies were coded based on their use of the Go/No-Go or Stop-Signal task.

Go/No-Go and Stop-Signal Task Parameters

Food-Specific or General Stimuli. Studies were coded based on whether the target stimuli used were food-specific or neutral.

Number of training sessions. As most studies used only one training session (i.e., completion of the training task once), studies were coded based on whether they used one training session or two or more training sessions.

Number of trials. The number of trials was coded based on whether the training task included 100 trials or less; 101 to 200 trials; 201 to 300 trials; or more than 300 trials. Broad categories were used because there was no consistency across studies in the number of trials used. Subgroups were used so that findings might potentially inform the design of future inhibitory control training task parameters by indicating an approximate number of trials for the largest reduction in food consumption or choice. The number of trials was also calculated as a continuous measure for each study.

Trial duration. As common trial durations emerged during the review of relevant studies, studies were coded based on whether they used a trial duration of 1000 ms, 1250 ms, or 1500 ms.

Non-target stimuli presented in the training task. Studies were coded based on whether the non-target stimuli used in the training task were healthy foods only, a combination of non-food filler images and healthy foods, or non-food images only.

Task performance feedback. Studies were coded based on whether participants received feedback about their task performance (e.g., response too slow, correct response).

Inter-trial duration. As common inter-trial durations emerged during the review of relevant studies, studies were coded based on whether they used an inter-trial duration of 100 ms, 250 ms, 500 ms, 1000 ms, 1250 ms, 1500 ms, or a variable duration (e.g., varying between 500 and 1500 ms).

Inter-trial stimulus. Studies were coded based on whether a blank screen, fixation object (e.g., fixation cross), or a blank screen followed by a fixation object, was presented during the inter-trial duration.

Go/No-Go Task Parameters Only

Control condition. As common control conditions emerged during the review of relevant studies, studies were coded based on whether they used the following control conditions: (i) target stimuli paired with "go" signals on all trials and non-target stimuli paired with "no-go" signals on all trials; or (ii) target stimuli paired with "go" signals on half of the trials and "no-go" signals on half of the trials (i.e., no training); or (iii) neutral stimuli paired with "no-go" signals on all trials; or (iv) all trials were no-signal (go) trials; or (v) participants were instructed to watch the stimuli only and as such, not respond to the stimuli.

"Go" and "no-go" signals. As common "go" and "no-go" signals emerged during the review of relevant studies, studies were coded based on whether they used neutral signals (e.g., letters, shapes), positive/negative signals (e.g., green/red, tick/cross), or sounds.

Percentage of target trials paired with "no-go" signals. As most studies paired target stimuli with "no-go" signals on all target trials, studies were coded based on whether they paired target stimuli with "no-go" signals on all target trials or less than 100% of trials (in this case, 75 to 90 percent of target trials).

Stop-Signal Task Parameters Only

Control condition. As common control conditions emerged during the review of relevant studies, studies were coded based on whether they used the following control conditions: (i) double response on stop trials (i.e., participants instructed to press the

keyboard key twice on stop trials, rather than inhibit responses); (ii) non-target stimuli paired with stop signals and target stimuli not paired with stop signals; (iii) target stimuli paired equally with stop signals and "go" signals (i.e., no training); (iv) observe only (i.e., participants instructed not to respond on any trials); (v) participants instructed to ignore stop signals (participants instructed to indicate whether the stimuli appeared on the left or right of the screen only); or (vi) completion of a neutral reading task.

Stop signal. As common stop signals emerged during the review of relevant studies, studies were coded based on whether the stop signal used was a sound or visual bolding of the image (stimuli) border.

Stop signal delay. All studies used a stop signal delay of 250 ms that was automatically adjusted (increased or decreased) so that participants successfully inhibited responses on 50% of stop trials.

Food Consumption/Choice Measure

Objective or self-report. Studies were coded based on whether they used an objective (e.g., a taste test or food choice task) or self-report measure (e.g., asked participants to report naturalistic food consumption) to measure food consumption or choice.

Food consumption or choice. Studies that used an objective measure were further coded based on whether they measured food consumption or choice.

Unhealthy or all food consumption/choice measured. Studies were coded based on whether they measured unhealthy (high calorie) food consumption or all food consumption.

If studies provided results separately for unhealthy (high calorie) food consumption and healthy food consumption and/or all food consumption, the effect for unhealthy (high calorie) food consumption was used for meta-analyses. The was done because the conventional objective for Go/No-Go and Stop-Signal task interventions in the food-domain is to reduce excess intake of targeted unhealthy foods.

Trained or novel food consumption/choice measured. Studies were further coded based on whether the food consumption/choice measure consisted of trained (i.e., food included as stimuli in the training task) or novel (i.e., food not included as stimuli in the training task) foods, or a combination of both.

As with unhealthy or all food consumption/choice measured, if studies provided results separately for trained and novel food consumption, the effect for trained food consumption was used for meta-analyses.

When food consumption/choice was measured. Studies were coded based on whether they measured food consumption or choice directly following completion of the training task, one day after, or at least one week after.

Sample Characteristics

Age. Studies were coded based on whether they recruited children only, young adults (18–39 years) only, or young adults and older adults (i.e., the sample included participants at least 40 years of age).

Type. Studies were coded based on whether they recruited a general sample (i.e., a non-specific sample or a sample comprising clinical and non-clinical participants) or a clinical sample (e.g., participants with a reported eating disorder, restrained eaters).

Pool. Studies were coded based on whether they recruited university students or community members.

Gender. The proportion of participants who were women was calculated as a continuous measure for each study.

Weight. Studies were coded based on whether they recruited healthy weight participants only (BMI 18.5 to 24.9), overweight participants only (BMI >24.9), underweight participants only (BMI <18.5), participants of all weight categories (any BMI), or all participants except underweight participant (Weir & Jan 2021).

Quality Assessment

Using the Mixed Methods Appraisal Tool (Hong et al., 2018), two reviewers assessed the quality of all included studies. The MMAT was used because it can assess different study designs. Each study was assessed using specific study design criteria as per MMAT guidelines. For example, for randomized controlled trials study designs, methodological quality criteria included questions such as “Are the groups comparable at baseline?” and “Are outcome assessors blinded to the intervention provided?“. A quality score (0–5 stars) was calculated for each study, where 0 stars indicates 0% criteria met, 1 star 20%, 2 stars 40%, etc. (Hong et al., 2018). Disagreements between reviewers (27% of quality criteria questions) were resolved in a meeting.

Statistical Analyses

Comprehensive Meta-Analysis Version 3 (Borenstein et al., 2013) was used to run all analyses. These analyses included subgroup analyses for categorical moderators (e.g., go/no-go signal) and meta-regression for continuous moderators (e.g., number of trials). Random-effect analyses were used following Higgins et al. (2021). Specifically, random-effects analyses are recommended when heterogeneity exists across the studies, as was the case in the present study, and because of the high risk of false-positive results when testing for subgroup differences in a fixed-effect model (Higgins et al. (2021).

The effect size used in the present meta-analysis was Hedges' *g,* which is the difference between means in units of the pooled standard deviation adjusted for sample size (Hedges, 1981). In this case, Hedges' *g* measured the effect of inhibitory control training in reducing food consumption or choice, compared to a control, where a negative *g* indicated that the training condition reduced food consumption or choice more than the control condition. Hedges' *g* was used, rather than Cohen's *d*, because it accounts for unequal condition sample sizes (Marfo & Okyere, 2019). The I^2 statistic (Higgins & Thompson, 2002) and Cochran's *Q* (Cochran, 1954) were used concurrently to measure across study heterogeneity in effect sizes. The I^2 statistic measures the percentage of such heterogeneity, where 25%, 50%, and 75% indicate small, medium, and large heterogeneity, respectively (Higgins et al., 2003) and, unlike Cochran's *Q* (Cochran, 1954), is not sensitive to the number of studies included (Harrer et al., 2021). The value of *Q* was used to measure subgroup (moderator) effects (Harrer et al., 2021), where a significant *Q* indicated a significant moderator effect (Harrer et al., 2021). Following Fu et al. (2011), moderator subgroups with fewer than four studies were excluded from moderator analyses.

A “leave-one-out” approach was used to investigate outliers. This approach calculates the impact of each study on the overall effect size by running a series of meta-analyses but omitting one of the studies at a time. Visual inspection of funnel plot asymmetry, Duval and Tweedie's (2000) trim and fill method, and Egger's regression test (Egger et al., 1997) were used concurrently to assess publication bias. The trim and fill method imputes missing studies and then re-computes the overall effect size including any imputed studies (Duval & Tweedie, 2000). For Egger's regression test, a significant *p*-value indicates publication bias (Egger et al., 1997).

Results

Study Selection

The initial search strategy identified 5990 unique papers (i.e., following removal of duplicates) which were all subsequently assessed for eligibility via title and abstract screening. Many identified papers were clearly ineligible (e.g., studies that contained phrases that were abbreviated in the same way as the Stop-Signal Task (SST), such as studies on sea surface temperature (SST)). Title and abstract screening identified 171 potentially relevant papers which were then assessed further for eligibility using full-text screening. Full-text screening identified 26 papers that were eligible for inclusion. A further 6 papers were identified as eligible following forward and backward searching, resulting in a total of 32 eligible papers. Of the 32 eligible papers, nine were excluded because required information (means and standard deviations, and/or the number of participants) was not available (in the paper or supplementary materials) and was not provided by the authors following request. Thus, the meta-analysis included 23 papers (32 studies) with 32 independent measures of the effect of inhibitory control training in reducing food consumption or choice. Figure 1 shows the number of articles found at each stage of the first search, including reasons why articles were excluded following full-text screening.

Study Characteristics

Sample size for included studies ranged from 30 to 366 (M = 94.65, SD = 67.58). Of the 32 included studies, 24 used the Go/No-Go Task, seven used the Stop-Signal Task, and one (Adams et al., 2017) used both tasks. All (k = 25) studies using the Go/No-Go Task used a food-specific training protocol. For the Stop-Signal task, two studies (Guerrieri et al., 2012; Lawrence, Verbruggen, et al., 2015b, Study 3) used a general training protocol, with the remaining studies using a food-specific training protocol. Table 2, Table 3, Table 4, Table 5, Table 6, Table 7, Table 8 provide a summary of included studies, with Table 3, Table 4, Table 5 and Table 6, Table 7, Table 8 focusing specifically on included studies that used the Go/No-Go Task and the Stop-Signal Task, respectively.

Go/No-Go Task

For studies using the Go/No-Go Task, 10 studies used a control condition where neutral stimuli were paired with “no-go” signals on all trials; five studies used a control where target stimuli were paired with “go” signals on all trials and non-target stimuli paired with “no-go” signals on all trials; four studies used a control where target stimuli were paired with “go” signals on half of the trials and “no-go” signals on half of the trials (i.e., no training); four studies had two control conditions of those listed above; and one study (Adams et al., 2017, Study 2) had two control conditions where all trials were no-signal (go) trials or participants were instructed to observe the stimuli in the task only. One study (Masterton et al., 2021) had four conditions (100%, 75%, 50%, and 25%), where the percentage indicated the

proportion of unhealthy images the participants were required to not respond to, with the 100% and 75% conditions being training conditions and the 50% and 25% conditions, control conditions. For example, in the 100% condition, participants were instructed to not respond to 100% of unhealthy food images and respond to 100% of healthy food images (Masterton et al., 2021).

The number of trials for the Go/No-Go Task ranged from 72 to 480 (*M* = 204, *SD* = 112.77). Specifically, 10 studies used 101 to 200 trials; six used 100 or fewer trials; five used more than 300 trials; and four used 201 to 300 trials. Most studies (*k* = 20) used only one training session; with two studies using four training sessions; and one study each using five (Veling et al., 2014), six (Oomen et al., 2018), and 16 (Carbine et al., 2021) sessions. Most studies (*k* = 13) used a trial duration of 1500 ms; with seven using 1250 ms; four using 1000 ms; and one study using two different tasks, where one had a trial duration of 1250 ms and the other 1500 ms (Porter et al., 2021, Study 2). Most studies (*k* = 21) used neutral cues (e.g., letters or shapes) for the “go” and “no-go” signals; with four using positive/negative cues (happy/sad faces or green/red colours); two using sounds; and one (Masterton & Jones, 2023) used the type of food stimuli presented (e.g., unhealthy or healthy food). Most studies (*k* = 22) paired target stimuli with “no-go” signals on all target trials; with one (Aulbach et al. (2020) using a pairing of 83.33%; one (Kakoschke et al., 2017), 90%; and one (Masterton et al., 2021) including two training conditions, with pairings of either 75% or 100%. Most studies (*k* = 10) used non-food (neutral) images as the non-target stimuli in the training task; with eight using non-food filler images and healthy foods; six using healthy foods only; and one (Porter et al., 2021, Study 2) using two different tasks, where one used healthy food and the other a combination of healthy food and non-food images.

Just over half of studies (*k* = 13) did not provide participants with feedback about their task performance in the training task. In contrast, 11 studies provided participants with feedback on task accuracy or response time either trial by trial or at the end of each block. The inter-trial duration used in the training task varied widely, with seven studies using a duration of 1000 ms; seven studies using 1250 ms; six studies using 500 ms; two studies (Ahn et al., 2019) using a variable duration (300, 400, 500, or 700 ms); two studies using 250 ms; and one study (Porter et al., 2021, Study 2) using two different Go/No-Go task parameters, where one had an inter-trial duration of 500 ms and the other 1000 ms. Finally, most studies (*k* = 13) used a blank screen for the inter-trial duration; with ten studies using a fixation object, including Masterton and Jones (2023) who used feedback during the inter-trial duration; and two studies (Veling et al., 2013) using a blank screen followed by a fixation object.

In terms of measured outcome, most studies (*k* = 22) used an objective measure of food consumption or choice, with only three (Adams et al., 2021; Carbine et al., 2021; Veling et al., 2014) using a self-report measure. Specifically, 11 studies used either a taste test or buffet to measure food consumption; seven studies used a food choice task; three studies asked participants to self-report their consumption for the previous day or month; one study (van Koningsbruggen et al., 2014, Study 2) used a computerized snack dispenser where participants were told that they could earn sweets by continuously pressing a button; one study (Veling et al., 2011, Study 2) gave participants a bag of sweets to take home overnight where the weight of the bag was then measured the following day; one study (Houben & Giesen, 2018) used the Concurrent Schedules Task (CST; Lappalainen & Epstein, 1990); and one study (Kakoschke et al., 2017) used both a taste test and a food choice task. Moreover, most studies (*k* = 23) measured consumption of unhealthy foods, with only two studies (Carbine et al., 2021; Veling et al., 2014) measuring consumption of all foods. Furthermore, just over half of studies (*k* = 15) included only trained foods (i.e., food included as stimuli in the training task) in the measure of food consumption or choice. In contrast, ten studies included a combination of trained and novel foods. Lastly, most studies (*k* = 22) first measured food consumption or choice immediately following the training task; with only two studies after measuring the outcome the day; and one study (Adams et al., 2021) two weeks after.

Finally, most studies (*k* = 13) recruited young adults, with seven recruiting young and older adults, and five recruiting children. Furthermore, most studies recruited a general sample (*k* = 21), with only two recruiting participants with reported loss of control over eating, one (Adams et al., 2017) recruiting restrained eaters, and one (Houben & Jansen, 2011) recruiting individuals with high trait chocolate craving. Additionally, most studies (*k* = 15) recruited university students, with eight studies recruiting participants from the community, and two (Carbine et al., 2021; Masterton et al., 2021) recruiting a combination of university students and community members. Moreover, most studies (*k* = 16) used a sample made up of predominantly women, with eight studies using a sample including roughly an even number of men and women, and only one study (Porter et al., 2018, Study 2) using a sample with more men than women. Lastly, most studies (*k* = 23) used a sample including healthy weight and overweight participants, with only one study (Carbine et al., 2021) using overweight participants only, and one (Adams et al., 2021) excluding underweight participants (BMI is less than 18.5 kg/m^2; Weir & Jan 2021).

Stop-Signal Task

For studies that used the Stop-Signal Task, two studies (Adams et al., 2017, Study 1; Lawrence, Verbruggen, et al., 2015b, Study 1) used a double response control condition where participants were instructed to press the keyboard key twice on stop trials; and, as shown in Table 7, the remaining six studies had two different control conditions of varying combinations.

The number of trials for the Stop-Signal Task ranged from 192 to 600 (*M* = 407, *SD* = 148.56). Specifically, five studies used more than 300 trials; two used 101 to 200 trials; and one (Adams et al., 2017, Study 2) used 201 to 300 trials. Most studies (*k* = 6) used only one training session; with two studies using 10 training sessions. Just over half of studies (*k* = 4) used a trial duration of 1250 ms; with three using 1500 ms; and one (Guerrieri et al., 2012) using 1000 ms. Most studies (*k* = 5) used bolding of the stimuli border for the stop signal, with three studies using sounds. Just over half of studies (*k* = 5) paired target stimuli with stop signals on 50% of target trials; with three using a pairing of approximately 87.50%; and one (Guerrieri et al., 2012) assigning participants to either an inhibition group, where the proportion of stop trials rose by 5% in each consecutive block (in block 6 the proportion of stop trials had risen to 50%), or the impulsivity group, where the proportion of go trials rose by 5% in each consecutive block (in block 6 the proportion of stop trials had fallen to 0%). Just over half of studies (*k* = 5) used non-food (neutral) images as the non-target stimuli in the training task; with two using healthy foods; and one (Adams et al., 2017, Study 2) using non-food filler images and healthy foods. Most studies (*k* = 7) did not provide participants with feedback about their task performance in the training task, with only one (Adams et al., 2017, Study 1) providing performance feedback. Half of the studies (k = 4) used an inter-trial duration of 1250 ms; three used 500 ms; and one (Guerrieri et al., 2012) used 1500 ms. Finally, half of the studies (k = 4) used a fixation object for the inter-trial duration; three used a blank screen; and one (Guerrieri et al., 2012) used a blank screen followed by a fixation object.

Most studies (*k* = 6) used an objective measure of food consumption or choice, with only two (Adams et al., 2017) using a self-report measure. Specifically, five studies used either a taste test or buffet to measure food consumption; two asked participants to indicate how often that ate various foods; and one (Lawrence, Verbruggen, et al., 2015, Study 1) provided refreshments for the participant to eat while completing filler questionnaires unrelated to food/eating. Moreover, most studies (*k* = 7) measured consumption of unhealthy foods, with only one study (Allom & Mullan, 2015, Study 2) measuring overall intake of fat. Furthermore, three studies included only trained foods (i.e., food included as stimuli in the training task) in the measure of food consumption or choice; three included a combination of

trained and novel foods; and two included only novel foods. Lastly, most studies (k = 6) first measured food consumption or choice immediately following the training task, with only two (Allom & Mullan, 2015) measuring the outcome the day after.

Finally, most studies (k = 7) recruited young and older adults, with only one study (Guerrieri et al., 2012) recruiting young adults exclusively. Furthermore, most studies recruited a general sample (k = 6), with only two (Adams et al., 2017) recruiting restrained eaters. All studies (k = 8) recruited university students. Moreover, most studies (k = 7) used a sample made up of predominantly women, with only one (Lawrence, Verbruggen, et al., 2015b, Study 1) using a sample including roughly an even number of men and women. Lastly, most studies (k = 7) used a sample including healthy weight and overweight participants, with only one (Guerrieri et al., 2012) using healthy weight participants only (BMI is between than 18.5 and 24.9 kg/m^2; Weir & Jan 2021).

Overall Go/No-Go and Stop-Signal task Training Effect

A meta-analysis showed that overall there was a significant effect of Go/No-Go and Stop-Signal task training in reducing food consumption or choice, g = −0.21, CI_{95} = [−0.31, −0.11], p < .001, with a small effect size (see Figure 2 for forest plot). A leave-one-out analysis showed little variability in the effect when each study was individually removed, all g's > −0.23 and < −0.20, all p's < 0.001, indicating that there were no outliers. Egger's regression test was significant, Z = −2.01, p = .009, indicating possible publication bias. Duval and Tweedie's (2000) trim and trill estimated that there were 7 unpublished studies, with the training effect estimated to be smaller after adjusting for possible publication bias, g = −0.12, CI95 = [−0.23, −0.01] (see Figure 3 for funnel plot). Tests for heterogeneity showed that there was significant heterogeneity in the effect size across studies, $Q(31)$ = 55.140, p = .005, I^2 = 43.779, suggesting that there may be moderators. Moderator analyses were thus conducted.

Two studies (Carbine et al., 2021; Lawrence, Verbruggen, et al., 2015b) included a follow-up measure of food consumption or choice at least 1 month after completion of the inhibitory control training task. Neither (Carbine et al., g = 0.26, p = .233; Lawrence et al., g = −0.05, p = .826), showed a significant effect of inhibitory control training in reducing food consumption or choice.

Inhibitory Control Training Task (Go/No-Go versus Stop-Signal)

A moderator analysis was conducted to examine the impact of task type (Go/No-Go versus Stop-Signal) on the effect of inhibitory control training in reducing food consumption or choice.

As can be seen, there was a small significant effect for studies using the Go/No-Go Task, $g = -0.24$, $CI_{95} = [-0.37, -0.11]$, $p < .001$. In contrast, the effect was not significant for studies using the Stop-Signal Task, $g = -0.08$, $CI_{95} = [-0.25, 0.09]$, $p = .339$. However, comparison of the subgroup effects showed that the effect for the Go/No-Go Task was not significantly larger than that for the Stop-Signal Task, $Q = 2.097$, $p = .148$. Separate meta-analyses were run including the study ($k = 1$; Adams et al., 2017, Study 2) previously excluded for having multiple measures. Again, there was a small significant effect for studies that used the Go/No-Go Task, $g = -0.25$, $CI_{95} = [-0.37, -0.12]$, $p < .001$, but the effect for the Stop-Signal Task fell short of significance, $g = -0.10$, $CI_{95} = [-0.25, 0.05]$, $p = .181$.

There was significant heterogeneity in the effects across studies that used the Go/No-Go Task, $Q(24) = 45.745$, $p = .005$, $I^2 = 47.535$, with the heterogeneity being small to medium (Higgins et al., 2003), but there was no significant heterogeneity for studies that used the Stop-Signal Task, $Q(7) = 7.642$, $p = .365$, $I^2 = 8.400$. Accordingly, separate moderator analyses were conducted for studies that used the Go/No-Go Task. All moderator analysis statistics are shown in Table 9.

Moderator Analyses for the Go/No-Go Task Inhibitory Control Training Effect

Go/No-Go Task Parameters

Food-specific or general stimuli. Because all studies used food-specific target stimuli, a moderator analysis was not conducted to investigate subgroup differences based on the use of food-specific or neutral target stimuli.

Control condition. There was no significant difference between the subgroup effect sizes when comparing studies based on the control comparison condition used, $Q = 1.888$, $p = .389$.

Number of training sessions. The effect for studies that had one training session for the training task was significantly larger than for studies that had more than one session, $Q = 7.875$, $p = .005$. Specifically, there was a small effect for studies that used one training session, $g = -0.31$, $CI_{95} = [-0.45, -0.18]$, $p < .001$. In contrast, the effect for studies that used more than one training session was not significant, $g = -0.01$, $CI_{95} = [-0.17, 0.15]$, $p = .919$. The effects were homogenous among studies that had more than one training session, $Q(4) = 4.187$, $p = .381$, $I^2 = 4.457$, but heterogeneity remained for studies that had one training session, $Q(19) = 33.028$, $p = .024$, $I^2 = 42.473$. For both subgroups, there was less heterogeneity than for all studies that used the Go/No-Go Task combined ($Q(24) = 45.745$, $p = .005$, $I^2 = 47.535$).

All other Go/No-Go Task parameter differences. There was no significant difference between subgroup effect sizes based on the number of trials, $p = .110$. This was confirmed by a meta-regression moderator analysis which showed that the number of trials measured continuously did not explain any significant variance in the effects, $R^2 = 0.00$, $B = 0.00$, $SE = 0.00$, $p = .777$.

There was no significant difference between subgroup effect sizes when comparing studies based on trial duration, $p = .446$, non-target stimuli presented in the training task, $p = .190$, task performance feedback, $p = .778$, inter-trial duration, $p = .140$, and inter-trial stimulus, $p = .507$.

Moderator analyses could not be conducted for the type of “go” and “no-go” signals used, nor the percentage of target trials paired with “no-go” signals, as the comparison subgroup/s included less than four studies, respectively. Effects for the most used parameter are provided to inform recommendations for effective Go/No-Go Task parameters: for the type of “go” and “no-go” signals used, non-emotive, neutral cues (e.g., letters or shapes; $k = 19$), $g = -0.20$, $CI_{95} = [-0.34, -0.06]$, $p = .005$; for the percentage of target trials paired with “no-go” signals, 100% pairing ($k = 23$), $g = -0.28$, $CI_{95} = [-0.41, -0.15]$, $p < .001$.

Food Consumption/Choice Measure

Moderator analyses could not be conducted for type of food measure, type of food measured, nor timing of food consumption/choice measure, as the comparison subgroup/s included less than four studies, respectively. Effects for the most used measure or parameter are provided: for the type of food measure, objective (e.g., taste test; $k = 22$), $g = -0.30$, $CI_{95} = [-0.43, -0.16]$, $p < .001$; for the type of food measured, unhealthy food ($k = 23$), $g = -0.27$, $CI_{95} = [-0.40, -0.14]$, $p < .001$; for when the food consumption/choice outcome was measured, immediately after completion of the Go/No-Go Task ($k = 22$), $g = -0.26$, $CI_{95} = [-0.40, -0.12]$, $p < .001$.

For studies that used an objective measure of food consumption or choice, there was no significant difference when comparing studies based on whether they measured food consumption or choice, $p = .781$. Likewise, there was no significant difference between subgroup effect sizes when comparing studies based on whether the food consumption/choice measure consisted of trained food only or a combination of trained and novel foods, $p = .281$.

Sample Differences

There was no significant difference between effects when comparing studies based on sample age, p = .268, sample type, p = .623, and sample pool, p = .510. A moderator analysis for sample weight could not be conducted because only two studies used overweight participants only. A meta-regression moderator analysis showed that the proportion of women did not explain any significant variance in the effects, R^2 = 0.00, B = 0.23, SE = 0.33, p = .478.

Moderator Analyses for the Stop-Signal Task Inhibitory Control Training Effect

Separate meta-regression moderator analyses showed that neither the number of trials measured continuously, R^2 = 0.00, B = 0.01, SE = 0.02, p = .728, nor the proportion of women, R^2 = 0.93, B = 0.85, SE = 0.67, p = .207, explained any significant variance in the effects.

Moderator analyses could not be conducted for the remaining variables as either all studies used the same parameters or there were less than four studies in the comparison subgroup/s.

Quality Assessment

Of the 32 included studies, most received 4 (n = 19) or 5 (n = 6) stars, indicating high quality (Hong et al., 2018; see Table 2). The remaining eight studies (Adams et al., 2017; Adams et al., 2021; Lawrence, Verbruggen, et al., 2015a; Lawrence, Verbruggen, et al., 2015b Study 1–3; Porter et al., 2018, Study 2) scored 3 stars, indicating medium quality (Hong et al., 2018). These all used pseudo randomization and did not indicate whether experimenters were blinded to participant group, despite experimenters weighing bowls to measure food intake in a taste test or buffet.

Following Cristea et al. (2016), who observed inverse relationships between risk of bias and effect sizes for outcomes, the association between quality rating and training effect size was investigated. There was no significant association, r = −.22, p = .227.

Discussion

The present study aimed to provide a comprehensive investigation of the impact of parameter differences in inhibitory control training tasks in reducing excess food intake. The findings showed that, overall, inhibitory control training tasks reduce food consumption or choice, although the effect size was small. Further investigation showed that this effect was only significant for training task protocols using the Go/No-Go Task. For Go/No-Go Task

protocols, using one training session (rather than two or more) showed greater reductions in food consumption or choice.

The initial finding that the training effect was only significant for protocols using the Go/No-Go Task is consistent with previous findings with more diverse outcomes (Allom et al., 2016; Aulbach et al., 2019; Jones et al., 2016; Yang et al., 2019). It is also consistent with the suggestion that, although intended to target inhibitory control, the two tasks in fact rely on different mechanisms (Littman & Takács, 2017; Raud et al., 2020). Specifically, Allom et al. (2016) suggested that the Go/No-Go and Stop-Signal tasks impact automatic and controlled response inhibition, respectively, and that training automatic response inhibition may be more effective in changing behaviour. It has further been suggested that the Stop-Signal Task may be less effective because "stop" food items are generally paired with "stop" signals on only 50% of such trials (Veling et al., 2017), as was the case for the studies included in the present paper. In contrast, Go/No-Go Task protocols most commonly pair "no-go" food items with "no-go" signals on 100% of such trials, which may lead to a stronger food-stop association and/or devaluation effect (Veling et al., 2017; 2022).

The results further showed that a single session of Go/No-Go training was more effective in reducing food consumption or choice than multiple sessions. The repeated pairing of unhealthy foods with "no-go" signals may be less obvious with fewer training sessions. In contrast, participants may be more aware of the intended association if the task involves more training sessions. The Go/No-Go Task has been thought to create automatic stop associations (Veling et al., 2017) and that behavioral change (caused by such associations) may only occur when people behave impulsively (Chen et al., 2019; Veling et al., 2017). Such impulsivity may be reduced if participants are aware of the pairing between unhealthy foods and "no-go" signals. It is important to note that almost all studies measured food consumption or choice outcomes immediately following completion of the training task. Accordingly, it is not clear whether having only one session would be effective in reducing food consumption or choice in the longer term.

All other investigated parameter variations did not significantly impact the effect of inhibitory control training in reducing food consumption or choice. Either the respective moderator analysis showed no significant difference in the effect between the moderator subgroups, or a moderator analysis could not be conducted due to an insufficient (fewer than four; Fu et al., 2011) number of studies in the comparison subgroups. It may well be that the training effect is robust across parameter variations. Alternatively, it may be that the small number of studies per subgroup limited the moderator analyses' ability to identify differences based on parameter variations. Regardless, the findings can provide directions for effective

Go/No-Go Task parameters via closer inspection of optimal effects. Specifically, the effect was largest (although not significant) when either a no training (i.e., “no-go” signals are paired equally for both target and non-target stimuli) or reverse training (i.e., “go” signals on all trials and non-target stimuli with “no-go” signals on all trials) control condition was used. This makes sense logically as this control condition trains participants to associate unhealthy foods with “go” signals. As such, a larger effect size would be expected relative to using a neutral or no training control condition. Further, the effect was largest (although again not significant) when the following parameters were used: neutral (non-emotive) cues for the “go” and “no-go” signals; 100% pairing for the percentage of target trials paired with “no-go” signals; neutral (non-food) stimuli as the non-target stimuli in the training task, a trial duration of 1500 ms, and an inter-trial duration of 500 ms. There was no noticeable difference in the effect for the remaining parameters, namely the number of trials, whether a fixation object or blank screen was presented during the inter-trial duration period, and whether or not participants were provided performance feedback. Although parameter recommendations are presented above, further research should focus on investigating the most effective and efficient parameters for reducing food consumption and choice, with a view to informing the standardization of such tasks for intervention purposes.

The findings can also provide directions regarding the measurement of food consumption or choice. Specifically, although not significant, the effect of inhibitory control training was largest when an objective measure was used. Objective measures have been shown to be valid measures of consumption (Robinson et al., 2017), in contrast to self-reported intake which can suffer from underreporting (Ravelli & Schoeller, 2020). Further, the effect was largest when unhealthy food consumption/choice was measured immediately following completion of the Go/No-Go Task, and for trained food (i.e., food included as stimuli in the training task). Overall, these findings are not surprising, as the effect of training, i.e., association of specific food cues with inhibition (Allom et al., 2016; Aulbach et al., 2019; Jones et al., 2016; Yang et al., 2019) and/or devaluation of the associated food items (Houben, 2023; Veling et al., 2017; Veling et al., 2022), would be expected to be largest immediately following completion of the inhibitory control training task and for those foods included as stimuli in the task.

The present meta-analysis has some important implications. First, it confirms and updates specifically in the food domain previous findings (Allom et al., 2016; Aulbach et al., 2019; Jones et al., 2016; Yang et al., 2019) that training task protocols using the Go/No-Go Task are effective in reducing consumption and choice; however, the effect is small. The small effect size observed here is consistent with that of the meta-analyses by Aulbach et al.

(2019) and Yang et al. (2019). Second, the findings provide directions for the most efficient and effective use of such interventions. Specifically, the findings indicate that short, single session training protocols are most effective in reducing food consumption or choice, at least in the short term. Finally, the findings showed that there were few differences in this reduction among varying demographic groups, including men, women, and different age groups, as well as both clinical and non-clinical populations.

In conclusion, the present meta-analysis extends previous findings with broader outcomes (Allom et al., 2016; Aulbach et al., 2019; Jones et al., 2016; Yang et al., 2019) showing that Go/No-Go Task protocols that repeatedly pair food stimuli with inhibition are effective in reducing food consumption or choice. However, the present study also showed that there was significant variation in the specific parameters used for the Go/No-Go Task and was able to offer recommendations for optimal parameter values.

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Ethical statement

The study protocol was approved by the Flinders University Social and Behavioral Research Ethics Committee.

CRediT authorship contribution statement

Joshua McGreen: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Project administration, Resources, Software, Validation, Visualization, Writing – original draft, Writing – review & editing. Eva Kemps: Conceptualization, Funding acquisition, Methodology, Supervision, Writing – review & editing. Marika Tiggemann: Conceptualization, Funding acquisition, Methodology, Supervision, Writing – review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Data availability

Data will be made available on request.

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Table 1

Keywords used for the database searches

Construct	Keywords
The Go/No-Go Task and/or Stop-Signal Task	Go/no-go, go no go, go–nogo, GNG, stop signal, stop-signal, and SST.
Food	Sugar, food*, chip*, snack*, sweet*, loll*, choc*, cand*, and unhealthy.
Consumption and/or Choice Outcome	Consumption, consum*, intake, imbibe, eat, eating, drink*, choice*, select*, choose, chose, pick*, vote*, take*, and prefer*.

Figure 1

PRISMA flowchart (Page et al., 2021) showing the number of articles identified at each stage of the first search

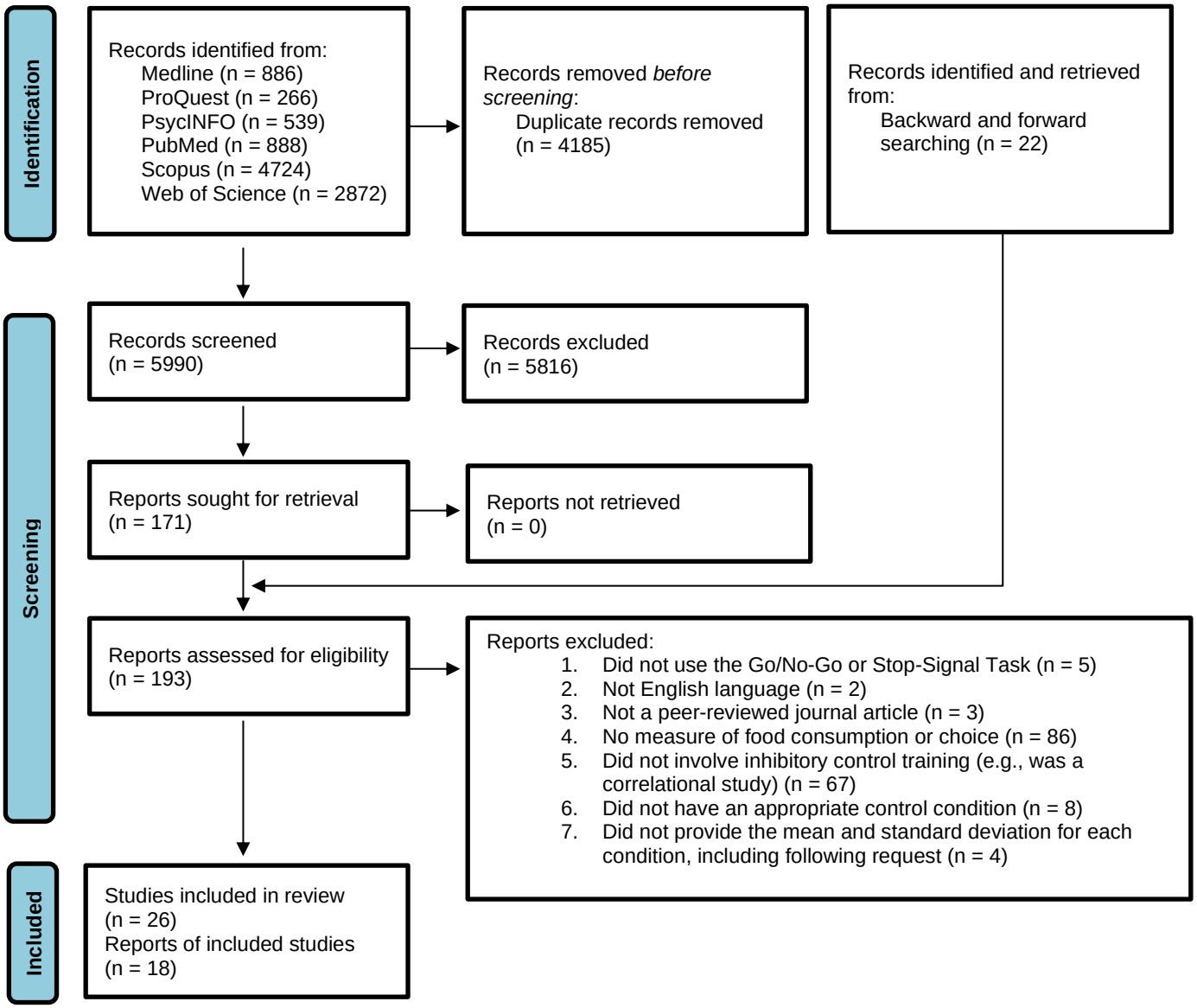


Table 2

Summary of included studies: inhibitory control training task and the effect of inhibitory control training in reducing food consumption or choice (compared to control)

Study title	Training task	Training task: Food-specific or general	Hedges' *g*	MMAT quality rating
Adams et al. (2017). Study 1	SST	Food-specific	0.21	***
Adams et al. (2017). Study 2	GNG and SST	Food-specific	-0.39	***
Adams et al. (2021)	GNG	Food-specific	-0.01	***
Ahn et al. (2019). Study 1	GNG	Food-specific	-0.77	****
Ahn et al. (2019). Study 2. Sham rTMS conditions only	GNG	Food-specific	-0.14	****
Allom & Mullan (2015). Study 1	SST	Food-specific	-0.07	****
Allom & Mullan (2015). Study 2	SST	Food-specific	-0.03	****
Aulbach et al. (2020). Time 1 only	GNG	Food-specific	0.19	*****
Carbine et al. (2021)	GNG	Food-specific	-0.02	****

Folkvord et al. (2016). Nonfood Advergame conditions only	GNG	Food-specific	-0.39	****
Guerrieri et al. (2012)	SST	General	-0.27	****
Houben & Jansen (2011)	GNG	Food-specific	-0.69	****
Houben & Jansen (2015)	GNG	Food-specific	-0.59	****
Houben & Geisen (2018)	GNG	Food-specific	-0.01	****
Kakoschke et al. (2017)	GNG	Food-specific	0.11	****
Lawrence et al. (2015). Study 1	SST	Food-specific	-0.56	***
Lawrence et al. (2015). Study 2	SST	Food-specific	-0.19	***
Lawrence et al. (2015). Study 3	SST	General	-0.02	***
Lawrence et al. (2015)	GNG	Food-specific	0.22	***
Masterton et al. (2021). Study 1	GNG	Food-specific	-0.15	****
Masterton & Jones (2023)	GNG	Food-specific	0.26	****
Oomen et al. (2018)	GNG	Food-specific	-0.55	*****

Porter et al. (2018). Study 1	GNG	Food-specific	-0.34	****
Porter et al. (2018). Study 2	GNG	Food-specific	-0.62	***
Porter et al. (2021). Study 1	GNG	Food-specific	-0.36	****
Porter et al. (2021). Study 2	GNG	Food-specific	-0.09	****
van Koningsbruggen et al. (2014). Study 1. Control implementation intention conditions only	GNG	Food-specific	-0.76	*****
van Koningsbruggen et al. (2014). Study 2. Control implementation intention conditions only	GNG	Food-specific	-0.75	*****
Veling et al. (2011). Study 2	GNG	Food-specific	-0.26	****
Veling et al. (2013). Study 1	GNG	Food-specific	-0.53	*****
Veling et al. (2013). Study 2	GNG	Food-specific	-0.70	****
Veling et al. (2014). Control implementation intention conditions only	GNG	Food-specific	0.08	*****

Note. GNG = Go/No-Go Task; SST = Stop-Signal Task. For *g*, a negative *g* indicates that the inhibitory control training reduced food consumption or choice more than the control condition.

Table 3

Summary of included Go/No-Go Task studies: sample characteristics

Study title	*N*	Sample type	Sample age	Sample gender (% women)	Sample pool	Sample weight
Adams et al. (2017). Study 2	96	Restrained eaters	Young and older adults	91.30	University	General
Adams et al. (2021)	366	General	Young adults	78.20	University	Exclude underweight
Ahn et al. (2019). Study 1	43	General	Young adults	100.00	University	General
Ahn et al. (2019). Study 2. Sham rTMS conditions only	30	General	Young adults	100.00	University	General
Aulbach et al. (2020). Time 1 only	50	General	Young and older adults	52.00	University	General
Carbine et al. (2021)	100		Young and older adults	53.00	Combination	Overweight
Folkvord et al. (2016). Nonfood Advergame conditions only	64	General	Children	59.50	Community	General

Houben & Jansen (2011)	63	Trait chocolate cravers	Young adults	100.00	University	General
Houben & Jansen (2015)	41	General	Young adults	100.00	University	General
Houben & Geisen (2018)	79	General	Young adults	100.00	University	General
Kakoschke et al. (2017)	119	General	Young adults	100.00	University	General
Lawrence et al. (2015)	83	LOC	Young and older adults	78.50	Community	General
Masterton et al. (2021). Study 1	170	General	Young and older adults	51.80	Combination	General
Masterton & Jones (2023)	80	General	Young and older adults	90.00	Community	General
Oomen et al. (2018)	41	LOC	Young adults	75.60	Community	General
Porter et al. (2018). Study 1	142	General	Children	52.10	Community	General
Porter et al. (2018). Study 2	81	General	Children	44.40	Community	General
Porter et al. (2021). Study 1	88	General	Children	54.80	Community	General
Porter et al. (2021). Study 2	187	General	Children	51.50	Community	General

van Koningsbruggen et al. (2014). Study 1. Control implementation intention conditions only	46	General	Young and older adults	59.30	University	General
van Koningsbruggen et al. (2014). Study 2. Control implementation intention conditions only	46	General	Young adults	62.50	University	General
Veling et al. (2011). Study 2	46	General	Young adults	60.90	University	General
Veling et al. (2013). Study 1	79	General	Young adults	62.00	University	General
Veling et al. (2013). Study 2	44	General	Young adults	61.40	University	General
Veling et al. (2014). Control implementation intention conditions only	55	General	Young adults	91.00	University	General

Note. LOC = loss of control over eating. For sample weight, overweight = participants with overweight (BMI > 24.9); general = participants of all weight categories (any BMI); and exclude underweight = all participants except those with underweight (BMI > 18.5; Weir & Jan, 2021).

Table 4

Summary of included Go/No-Go Task studies: inhibitory control training task protocol

Study title	Control	Number of training sessions	Number of trials	Trial duration (ms)	"Go" and "no-go" signals	Target trials "no-go" signals (%)	Non-target stimuli	Feedback	Inter-trial duration (ms)	Inter-trial stimulus
Adams et al. (2017). Study 2	Go and Observe	1	288	1250	Neutral	100.00	N and H	No	1250	F
Adams et al. (2021)	General	4	216	1250	Neutral	100.00	N and H	Yes	1250	F
Ahn et al. (2019). Study 1	NT and Reverse	1	480	1500	Neutral	100.00	N and H	No	Variable	F
Ahn et al. (2019). Study 2. Sham rTMS conditions only	NT	1	480	1500	Neutral	100.00	N and H	No	Variable	F
Aulbach et al. (2020). Time 1 only	Reverse	1	392	1000	Neutral	83.33	N and H	Yes	1000	F
Carbine et al. (2021)	Neutral	16	240	1250	Neutral	100.00	N and H	No	1250	B
Folkvord et al. (2016). Nonfood Advergame conditions only	Neutral	1	132	1000	Neutral	100.00	N	Yes	500	B
Houben & Jansen (2011)	NT and Reverse	1	320	1500	Neutral	100.00	N	Yes	500	B

Houben & Jansen (2015)	Reverse	1	320	1000	Neutral	100.00	N	Yes	500	B
Houben & Geisen (2018)	NT	1	160	1000	Neutral	100.00	H	Yes	500	B
Kakoschke et al. (2017)	NT	1	160	1500	Neutral	90.00	N	No	250	B
Lawrence et al. (2015)	Neutral	4	216	1250	Neutral	100.00	N and H	No	1250	B
Masterton et al. (2021). Study 1	[a]	1	200	1500	Neutral	75.00 and 100.00	H	Yes	500	B
Masterton & Jones (2023)	Passive and NT	1	100	1500	[b]	100.00	H	Yes	250	F
Oomen et al. (2018)	Neutral	6	192	1250	Neutral	100.00	N and H	Yes	1250	F
Porter et al. (2018). Study 1	NT	1	128	1250	+/-	100.00	H	No	1250	B
Porter et al. (2018). Study 2	NT and Neutral	1	160	1500	+/-	100.00	H	No	1000	B
Porter et al. (2021). Study 1	Neutral	1	160	1250	+/-	100.00	H	No	1250	B
Porter et al. (2021). Study 2										
App training task	Neutral	1	192	1500	+/-	100.00	N and H	Yes	500	B
Computer training task	Neutral	1	160	1250	+/-	100.00	H	Yes	1000	B

van Koningsbruggen et al. (2014). Study 1. Control implementation intention conditions only	Neutral	1	72	1500	Neutral	100.00	N	No	1000	F
van Koningsbruggen et al. (2014). Study 2. Control implementation intention conditions only	Neutral	1	72	1500	Neutral	100.00	N	No	1000	F
Veling et al. (2011). Study 2	Reverse	1	72	1500	Neutral	100.00	N	No	1000	F
Veling et al. (2013). Study 1	Reverse	1	96	1500	Sound	100.00	N	Yes	1000	B and F
Veling et al. (2013). Study 2	Reverse	1	96	1500	Sound	100.00	N	Yes	1000	B and F
Veling et al. (2014). Control implementation intention conditions only	Neutral	5	200	1500	Neutral	100.00	N	No	500	F

Note. ms = milliseconds. For control, Reverse = target stimuli paired with “go” signals on all trials and non-target stimuli paired with “no-go” signals on all trials; NT = target stimuli paired with “go” signals on half of the trials and “no-go” signals on half of the trials (i.e., no training); Neutral = neutral stimuli paired with “no-go” signals on all trials; Go = all trials were no-signal (go) trials; and Observe = participants instructed to watch the stimuli only. For “go” and “no-go” signals, neutral = neutral signals (e.g., letters, shapes); +/- = positive/negative signals (e.g., green/red, tick/cross); and sound = sounds, used for the “go” and “no-go” signals. For non-target stimuli, H = healthy food pictures; N = neutral stimuli; and N and H = neutral stimuli and healthy food pictures. For inter-trial stimulus, F = fixation object; B = blank screen; and B and F = blank screen then fixation object.

[a] Masterton et al. (2021) Study 1 had four conditions (100%, 75%, 50%, and 25%), where the percentage indicated the proportion of unhealthy images the participants were required to not respond to, with the 100% and 75% conditions being training conditions and the 50% and 25% conditions, control conditions.

[b] Masterton and Jones (2023) used the images of the foods as the “go” and “no-go” signals.

Table 5

Summary of included Go/No-Go Task studies: food consumption or choice measure

Study title	Food consumption or choice measure	Food consumption or choice measured	When food consumption/choice was measured
Adams et al. (2017). Study 2	In-laboratory buffet (chocolate, crisps, biscuits, cheese bites, grapes, carrots, rice cakes, breadsticks)	Unhealthy intake (calories)	Immediately after
Adams et al. (2021)	How often participants ate biscuits, chocolate, crisps, cake (trained foods); and ice-cream, chips, sweets, and pastries/sweet pies (untrained foods) within the last month.	Ratings were made on a 9-point scale (“4 or more times a day” to “never, I am allergic to this food so I avoid it”).	2 weeks after

Ahn et al. (2019). Study 1	Taste test (chocolate)	Chocolate intake (calories)	Immediately after
Ahn et al. (2019). Study 2. Sham rTMS conditions only	Taste test (chocolate)	Chocolate intake (calories)	Immediately after
Aulbach et al. (2020). Time 1 only	Snack session (chocolate)	Chocolate intake (calories)	Immediately after
Carbine et al. (2021)	ASA24 (Subar et al., 2012)	All food intake (calories)	Immediately after, 4-weeks after, 12-weeks after
Folkvord et al. (2016). Nonfood Advergame conditions only	Snack session (candy and chocolate)	Candy and chocolate intake (calories)	Immediately after
Houben & Jansen (2011)	Taste test (chocolate)	Chocolate intake (calories)	Immediately after
Houben & Jansen (2015)	Taste test (chocolate)	Chocolate intake (calories)	Immediately after
Houben & Geisen (2018)	Concurrent Schedules Task (CST; Lappalainen & Epstein, 1990)	The number of responses for high-caloric food (for FR2 only i.e., the reinforcement ratio for	Immediately after

		high- and low-caloric food were both set at a fixed ratio of 2)	
Kakoschke et al. (2017)	Taste test (M&Ms, chocolate-chip biscuits, potato chips, and pretzels); hypothetical food choice task (8 healthy and 8 unhealthy foods)	Unhealthy intake (calories); the % of participants who chose an unhealthy food as the first food chosen	Immediately after
Lawrence et al. (2015)	Taste test (chocolate and crisps)	Chocolate and crisps intake (calories)	Immediately after, 1-month after, 6-months after
Masterton et al. (2021). Study 1	Hypothetical food choice task (four sweet (e.g., chocolate) and savoury (e.g., cucumber sticks); four healthy (e.g., apple) and unhealthy options (e.g., crisps/chips). Participants	Unhealthy food items scored as 0, healthy food items scored as +1, which resulted in a combined score ranging from 0 (two	Immediately after

	instructed to select the two items that they would most like to consume at that moment in time.	unhealthy choices) to 2 (2 healthy choices).	
Masterton & Jones (2023)	Taste test (carrot sticks, grapes, crisps/chips, and cookies)	Crisps/chips and cookies intake (grams)	Immediately after
Oomen et al. (2018)	Taste test (chocolate and crisps)	Chocolate and crisps intake (calories)	1 day after
Porter et al. (2018). Study 1	Food choice shopping task (8 healthy and 8 unhealthy choices). Participants instructed to select 8 food options	Number of unhealthy foods chosen	Immediately after
Porter et al. (2018). Study 2	Food choice shopping task (6 healthy and 6 unhealthy choices). Participants instructed to select 6 food options	Number of unhealthy foods chosen	Immediately after

Porter et al. (2021). Study 1	Food choice shopping task (8 healthy and 8 unhealthy choices). Participants instructed to select 8 food options	Number of unhealthy foods chosen	Immediately after, 1-week after
Porter et al. (2021). Study 2	Food choice shopping task (6 healthy and 6 unhealthy choices). Participants instructed to select 6 food options	Number of unhealthy foods chosen	Immediately after
van Koningsbruggen et al. (2014). Study 1. Control implementation intention conditions only	Food-serving task (bowls of sweets). Participants instructed that they could serve themselves ad libitum, and that they could take home the sweets	Mean Z-score for amount of sweets (grams)	Immediately after

van Koningsbruggen et al. (2014). Study 2. Control implementation intention conditions only	Computerized snack dispenser. Participants told that they could earn sweets by continuously pressing a button and that the longer they would hold it the more sweets they would receive at the end of the experiment	Amount of snacks dispensed (score between 0 and 500)	Immediately after
Veling et al. (2011). Study 2	Participants given a bag of sweets to take home overnight	Sweets intake (grams)	1 day after
Veling et al. (2013). Study 1	Hypothetical food choice task (Told to select eight foods among an array of 16 healthy and unhealthy foods)	Number of unhealthy food choices	Immediately after
Veling et al. (2013). Study 2	Hypothetical food choice task (Told to select eight foods among	Number of unhealthy food choices	Immediately after

	an array of 16 healthy and unhealthy foods)		
Veling et al. (2014). Control implementation intention conditions only	Self-reported how many portions of food and drinks they consumed from 49 categories over last 24 hours (e.g., sandwiches, plates of pasta, meat, fish, fried snacks, carbonated beverages, candy bars, glasses of water).	All intake (calories), excluding water	Immediately after

Note. For when food consumption/choice was measured, immediately after = measured directly after completion of the inhibitory control training task.

Table 6

Summary of included Stop-Signal Task studies: sample characteristics

Study title	*N*	Sample type	Sample age	Sample gender (% women)	Sample pool	Sample weight
Adams et al. (2017). Study 1	139	Restrained eaters	Young and older adults	93.55	University	General
Adams et al. (2017). Study 2	117	Restrained eaters	Young and older adults	91.77	University	General
Allom & Mullan (2015). Study 1	82	General	Young and older adults	80.49	University	General
Allom & Mullan (2015). Study 2	70	General	Young and older adults	78.21	University	General
Guerrieri et al. (2012)	61	General	Young adults	100.00	University	Healthy
Lawrence et al. (2015). Study 1	54	General	Young and older adults	59.00	University	General
Lawrence et al. (2015). Study 2	136	General	Young and older adults	73.50	University	General

Lawrence et al. (2015). Study 3	146	General	Young and older adults	78.50	University	General

Note. LOC = loss of control over eating. For sample weight, healthy = participants of healthy weight (BMI 18.5 to 24.9); overweight = participants with overweight (BMI > 24.9); general = participants of all weight categories (any BMI); and exclude underweight = all participants except those with underweight (BMI > 18.5; Weir & Jan, 2021).

Table 7

Summary of included Stop-Signal Task studies: inhibitory control training task protocol

Study title	Control	Number of training sessions	Number of trials	Trial duration (ms)	Stop signal	Target trials "stop" signals (%)	Non-target stimuli	Feedback	Inter-trial duration (ms)	Inter-trial stimulus
Adams et al. (2017). Study 1	DR	1	480	1500	B	87.50	N	Yes	500	F
Adams et al. (2017). Study 2	DR, O	1	288	1250	B	88.89	N and H	No	1250	F
Allom & Mullan (2015). Study 1	NT, R	10	192	1500	S	50.00	H	No	500	F
Allom & Mullan (2015). Study 2	NT, R	10	192	1500	S	50.00	H	No	500	F
Guerrieri et al. (2012)	R CRT	1	600	1000	S	[a]	N	No	1500	B and F
Lawrence et al. (2015). Study 1	DR	1	480	1250	B	87.50	N	No	1250	B
Lawrence et al. (2015). Study 2	DR, I	1	512	1250	B	50.00	N	No	1250	B
Lawrence et al. (2015). Study 3	DR, NT	1	512	1250	B	50.00	N	No	1250	B

Note. ms = milliseconds. For control, DR = double response; NT = target stimuli paired with "go" signals on half of the trials and "no-go" signals on half of the trials (i.e., no training); R = target stimuli paired with "go" signals on all trials and non-target stimuli paired with stop signals on all

trials; I = ignore, where participants in the ‘ignore’ control group were simply instructed to respond to left/right location and ignore stop signals; O = participants instructed to watch the stimuli only; and CRT = control reading task. For stop signal, S = sound; B = bolding of the image (stimuli) border. For non-target stimuli, H = healthy food pictures; N = neutral stimuli; and N and H = neutral stimuli and healthy food pictures. For inter-trial stimulus, F = fixation object; B = blank screen; and B and F = blank screen then fixation object.

[a] For target trials “stop” signals (%), participants were either assigned to the inhibition group, where the proportion of stop trials rose by 5% in each consecutive block (in block 6 the proportion of stop trials had risen to 50%), or the impulsivity group, where the proportion of go trials rose by 5% in each consecutive block (in block 6 the proportion of stop trials had fallen to 0%).

Table 8

Summary of included Stop-Signal Task studies: food consumption or choice measure

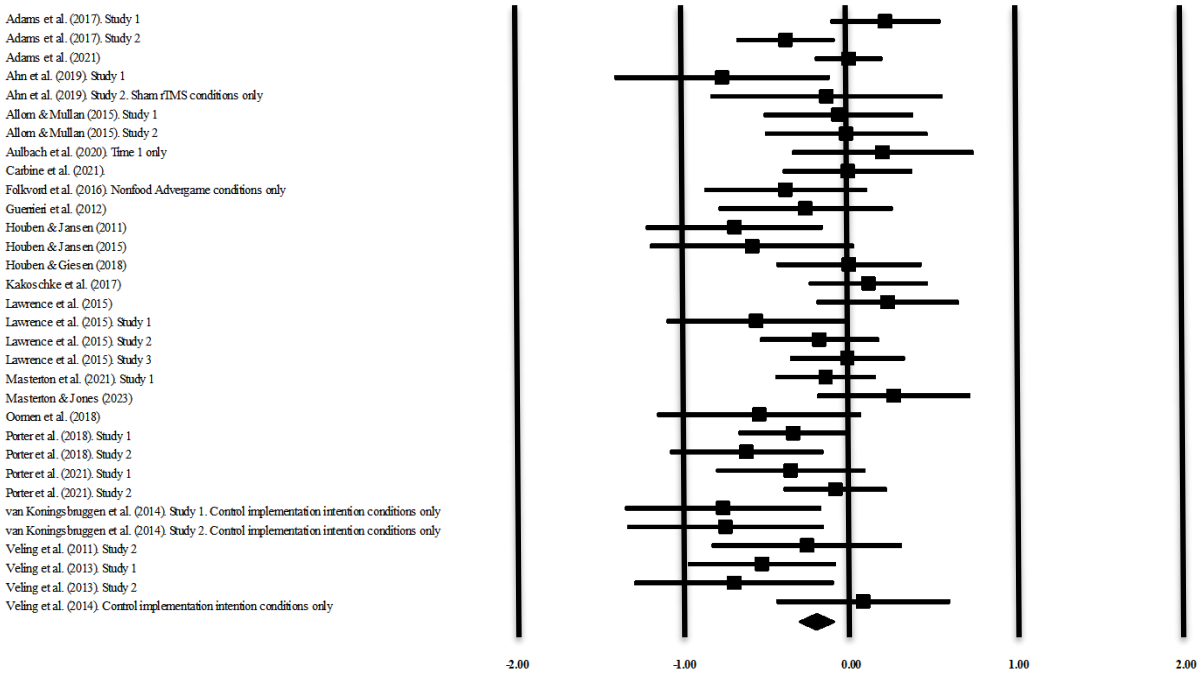
Study title	Food consumption or choice measure	Food consumption or choice measured	When food consumption/choice was measured
Adams et al. (2017). Study 1	Taste test (chocolate buttons and crisps)	Chocolate and crisps intake (calories)	Immediately after
Adams et al. (2017). Study 2	In-laboratory buffet (chocolate, crisps, biscuits, cheese bites, grapes, carrots, rice cakes, breadsticks)	Unhealthy intake (calories)	Immediately after
Allom & Mullan (2015). Study 1	Participants indicated how often they ate 17 meat and snack items (e.g. bacon, full-fat ice-cream, fried potatoes) on a 5 point scale ranging from never (0) to 5 or more times per week (4). g/day calculated from dietary fat items	g/day calculated from dietary fat items	1 day after

Allom & Mullan (2015). Study 2	Participants indicated how often they ate 15 food items (e.g., fruit, sausage or bacon, full fat cheese) on a 6-point scale ranging from 0 to 5: never (0), to 2 or more times per day (5).	Fat intake calculated (% energy from fat)	1 day after
Guerrieri et al. (2012)	Taste test (mini chocolate chip cookies, wine gums, paprika-flavoured crisps and saltines)	Unhealthy intake (calories)	Immediately after
Lawrence et al. (2015). Study 1	Provided refreshments (a large, clear plastic bowl filled with 125 g of crisps) while completing filler questionnaires measuring mood and personality traits (unrelated to food/eating)	Crisps intake (calories)	Immediately after
Lawrence et al. (2015). Study 2	Taste test (chocolate buttons and crisps)	Chocolate and crisps intake (calories)	Immediately after
Lawrence et al. (2015). Study 3	Taste test (chocolate buttons and crisps)	Chocolate and crisps intake (calories)	Immediately after

Note. For when food consumption/choice was measured, immediately after = measured directly after completion of the inhibitory control training task.

Figure 2

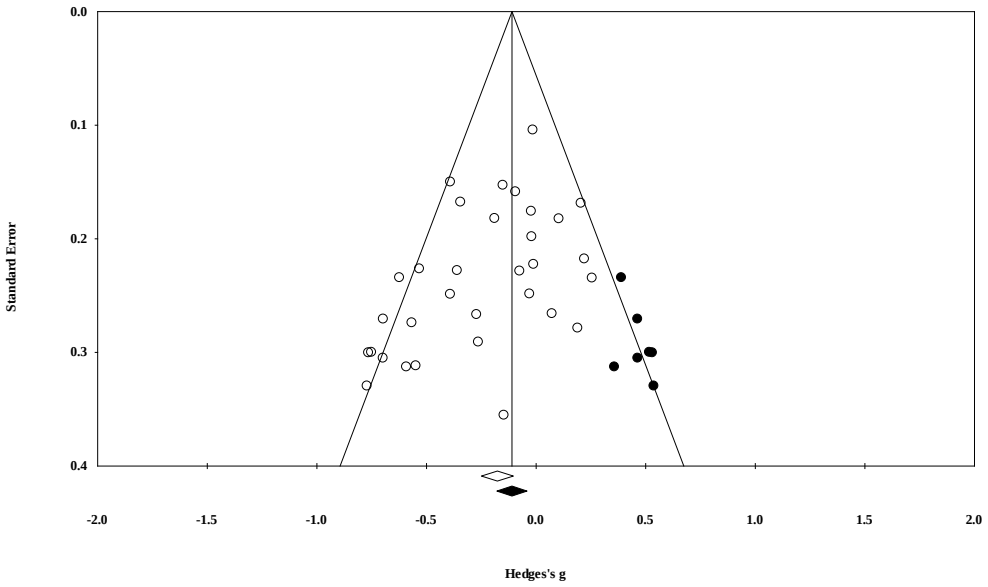
Forest plot of included studies showing Hedges' g for the effect of inhibitory control training in reducing food consumption or choice



Note. For *g*, a negative *g* indicates that the inhibitory control training reduced food consumption or choice more than the control condition.

Figure 3

Funnel plot of Hedges' g plotted against standard error, showing both included and imputed studies



Note. For *g*, a negative *g* indicates that the inhibitory control training reduced food consumption or choice more than the control condition. Imputed studies represented by the black circles.

Table 9

Subgroup moderator analyses for the effect of training task (Go/No-Go or Stop-Signal task) and Go/No-Go Task inhibitory control training in reducing food consumption or choice

				g			Subgroup Difference	
Moderator	***k***	***N***	***g***	**LL**	**UL**	***p***	***Q***	***p***
Training task							2.097	.148
Go/No-Go Task	24	2143	-0.24	-0.37	-0.11	< .001		
Stop-Signal Task	7	688	-0.08	-0.25	0.09	.339		
Control condition [a]							1.888	.389
Reverse	5	260	-0.37	-0.68	-0.06	.018		
NT	4	370	-0.11	-0.33	0.12	.358		
Neutral	10	1076	-0.20	-0.38	-0.01	.038		
Number of training sessions [a]							7.875	.005
1 session	20	1594	-0.31	-0.45	-0.18	< .001		
2+ sessions	5	645	-0.01	-0.17	0.15	.919		
Number of trials [a]							6.028	.110
<100 trials	6	341	-0.43	-0.77	-0.09	.013		
101-200 trials	9	971	-0.22	-0.37	-0.07	.004		
201-300 trials	5	700	-0.03	-0.22	0.15	.713		
300+ trials	5	227	-0.40	-0.77	-0.02	.038		
Trial duration [a]							1.613	.446
1000 milliseconds	4	234	-0.18	-0.50	0.15	.283		
1250 milliseconds	7	916	-0.17	-0.36	0.02	.071		

1500 milliseconds	13	902	-0.35	-0/55	-0.14	.001		
Non-target stimuli [a]							3.324	.190
Healthy foods	6	640	-0.21	-0.42	0.01	.063		
Non-food and healthy foods	8	809	-0.14	-0.35	0.08	.213		
Non-food	10	603	-0.41	-0.64	-0.19	< .001		
Task performance feedback [a]							0.079	.778
Yes	11	1077	-0.25	-0.43	-0.05	.014		
No	13	975	-0.28	-0.46	-0.10	.003		
Inter-trial duration [a]							3.929	.140
500 milliseconds	6	472	-0.25	-0.48	-0.02	.030		
1000 milliseconds	7	392	-0.49	-0.73	-0.24	< .001		
1250 milliseconds	7	916	-0.17	-0.36	0.02	.071		
Inter-trial stimulus [a]							0.439	.507
Fixation object	10	844	-0.28	-0.52	-0.04	.021		
Blank screen	13	1272	-0.19	-0.33	-0.04	.012		
Food consumption or choice [a]							0.078	.781
Consumption	13	729	-0.33	-0.55	-0.12	.003		
Choice	8	870	-0.30	-0.46	-0.14	< .001		
Trained or novel food [a]							1.161	.281
Trained	15	890	-0.30	-0.51	-0.09	.006		
Trained and novel	8	1189	-0.16	-0.30	-0.02	.025		

Sample age [a]							2.636	.268
Children	5	562	-0.31	-0.49	-0.14	< .001		
Young adults	13	1052	-0.32	-0.41	-0.12	.001		
Included older adults	7	625	-0.09	-0.33	0.16	.488		
Sample type [a]							0.242	.623
General	21	1956	-0.23	-0.36	-0.10	.001		
Clinical	4	283	-0.34	-0.76	0.08	.113		
Sample pool [a]							0.119	.510
University	15	1203	-0.31	-0.49	-0.13	.001		
Community	8	766	-0.22	-0.43	0.00	.010		

Note. For *g*, a negative *g* indicates that the inhibitory control training reduced food consumption or choice more than the control condition. For control, Reverse = target stimuli paired with “go” signals on all trials and non-target stimuli paired with “no-go” signals on all trials; NT = target stimuli paired with “go” signals on half of the trials and “no-go” signals on half of the trials (i.e., no training); Neutral = neutral stimuli paired with “no-go” signals on all trials; Go = all trials were no-signal (go) trials; and Observe = participants instructed to watch the stimuli only. Objective = objective measure of food consumption or choice; Self-report = self-report measure used to measure food consumption or choice.

[a] Subgroup moderator analysis included Go/No-Go Task studies only.

LINKING CHAPTER: CHAPTER SIX

Based on the findings of Study 1 (Chapter 2), which demonstrated that both evaluative bias and inhibitory control were linked to soft drink consumption, Study 5 (Chapter 6) aimed to investigate interventions targeting these factors to reduce soft drink consumption. Specifically, Study 5 (Chapter 6) aimed to examine the impact of evaluative conditioning (Houben et al., 2010) and inhibitory control "training" (Houben & Jansen, 2015; Houben, 2023; Veling et al., 2017; Veling et al., 2022) on reducing soft drink consumption.

The Method for Study 5 (Chapter 6) was partly guided by insights from Study 4 (Chapter 5). Specifically, the inhibitory control "training" intervention used in Study 5 (Chapter 6) was a modified version of the Go/No-Go Task, as Study 4 (Chapter 5) identified that this task is more effective in reducing food consumption compared to modified versions of the Stop-Signal Task. Additionally, the number of trials used in the inhibitory control "training" task was based on findings from Study 4 (Chapter 5), that short, single-session training protocols are most effective in reducing food consumption.

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CHAPTER SIX: THE EFFECT OF COMBINED EVALUATIVE BIAS AND INHIBITORY CONTROL TRAINING ON SOFT DRINK CONSUMPTION

Abstract

Despite sugar-based soft drinks providing no nutritional value and being laden with added sugars, their consumption remains high, posing a significant public health concern. Guided by dual-process models, the present study aimed to investigate the impact of evaluative conditioning and inhibitory control training for reducing soft drink consumption. Participants were 219 adults (17–39 years) who were randomly allocated to one of four conditions of a 2 (evaluative conditioning: training task vs. control task) x 2 (inhibitory control: training task vs. control task) between-subjects design. Modified versions of the Implicit Association Test and the Go/No-Go Task were used as the evaluative conditioning and inhibitory control training tasks, respectively. Soft drink choice and consumption were measured using a computerised beverage choice task and self-reported beverage intake over 7 days, respectively. Neither evaluative conditioning nor inhibitory control training was effective in reducing soft drink choice or consumption. Nor were the interventions effective in reducing the postulated mechanisms, namely evaluative bias and inhibitory control. Nonetheless, the current study provides a starting point and offers valuable insights into potential improvements and directions for future investigations of interventions aimed at reducing soft drink consumption.

Keywords: evaluative conditioning, inhibitory control, go/no-go task, devaluation, soft drink consumption, soft drink choice.

Introduction

Sugar-based soft drinks (carbonated non-alcoholic drinks containing sugar like Coca-Coca) provide no nutritional value and are high in added sugars (World Health Organization, 2017). Consequently, the World Health Organization (2017) suggests limiting the intake of such beverages, noting that even a single can of Coca-Cola surpasses daily sugar intake recommendations. Despite these suggestions, consumption of sugar-based soft drinks remains a significant public health concern, contributing to adverse health effects such as excess weight gain (Pan & Hu, 2011), dental caries (Vartanian et al., 2007), and diabetes (Bray & Popkin, 2013). A key reason is that global consumption of soft drink remains high. It is estimated that 40 to 50 percent of adults in Australia consume at least one soft drink per week (Miller et al., 2019; Roy Morgan Research, 2015), while roughly half of adults in the United States consume at least one glass of soft drink daily (Gallup Poll, 2012). As such,

exploring potential interventions to reduce soft drink consumption is an important goal for research.

Existing strategies to curb consumption of sugar-based soft drink include soft drink taxation and, more recently, the popularisation of sugar-free soft drinks (Khan et al., 2023). Soft drink taxation, however, does not address the mechanisms underlying soft drink consumption, and may not actually reduce sugar intake. For example, reductions in soft drink intake following soft drink taxation have been shown to be offset by increased intake of alternative high-calorie drinks (Fletcher et al., 2010; Sacks et al., 2021). Additionally, the World Health Organization (2023) has recently advised against replacing sugar with non-sugar sweeteners, which are found in sugar-free soft drinks, as they may not offer long-term benefits in reducing body fat and could potentially increase the risk of type 2 diabetes, cardiovascular diseases, and mortality. Consequently, developing alternative interventions that target the mechanisms underlying soft drink intake may lead to more effective strategies for reducing such consumption.

Following dual-process models (Strack & Deutsch, 2004), which suggest that behaviours are determined by a combination of automatic (fast, unconscious) and controlled (slow and involving conscious decision-making) processes, specific automatic and controlled processes have been explored as possible predictors of soft drink intake. Investigation of such processes has shown that one automatic process, evaluative bias for soft drink cues (McGreen et al., 2022a; Shaw et al., 2016), and inhibitory control (Ames et al., 2014; McGreen et al., 2022a) are related to soft drink consumption. Evaluative bias refers to the automatic positive judgement of stimuli/cues (Field et al., 2005), and inhibitory control is the ability to regulate behaviour or inhibit behavioural impulses (Houben et al., 2012).

In the only two studies to investigate the role of evaluative bias in soft drink consumption, it was found that negative evaluative bias for soft drink cues was associated with less self-reported soft drink intake (Shaw et al., 2016), and that evaluative bias for soft drink cues was associated with drinking more soft drink in a taste test (McGreen et al., 2022a). McGreen et al. (2022a), in their investigation of other automatic processes, found no effects for attentional bias (the automatic tendency to focus attention on one cue or stimulus over others; MacLeod & Mathews, 2012) or approach bias (the automatic tendency to approach rather than avoid cues or stimuli; Wiers et al., 2013).

Further, relationships between lower inhibitory control and greater soft drink intake have been demonstrated in two studies. Specifically, Ames et al. (2014) found that low scores on a measure of general self-regulatory control were associated with greater self-

reported consumption of sugar-sweetened beverages (including soft drinks and fruit juice), but only for men. Similarly, McGreen et al. (2022a) showed that poorer inhibitory control, as measured by a soft drink specific version of the Go/No-Go Task, was associated with drinking more soft drink in a taste test, for men. Ames et al. (2014) suggested that sex differences in inhibitory control and eating behaviour may translate into greater habitual responding to sugary foods/beverages in men.

Importantly, evaluative bias and inhibitory control are both potentially modifiable (Hofmann et al., 2010). Research has demonstrated that evaluative bias training (or conditioning) is effective in modifying evaluative biases for a number of substances (Bui & Fazio, 2016; Haynes et al., 2015; Hensels & Baines, 2016; Hofmann et al., 2010; Hollands et al., 2011; Lebens et al., 2011; Wang et al., 2017). Similarly, inhibitory control training protocols have been demonstrated to be effective (Houben & Jansen, 2015; Houben, 2023; Veling et al., 2017; Veling et al., 2022).

Evaluative conditioning involves changing unconscious attitudes due to repeated pairing of an object with positively or negatively valanced stimuli (Houben et al., 2010). For example, repeated pairing of soft drink pictures with negatively valanced pictures may make an individual's unconscious attitude to soft drinks more negative. Following dual-process models (Strack & Deutsch, 2004), this change in unconscious attitude may then reduce consumption as automatic processes (such as evaluative bias) are suggested to guide behaviour. Evaluative conditioning has been shown to be effective in reducing alcohol intake or purchases (Houben et al., 2010; Zerhouni et al., 2018), but its efficacy in reducing food consumption is inconsistent (Bui & Fazio, 2016; Haynes et al., 2015; Hensels & Baines, 2016; Hofmann et al., 2010; Hollands et al., 2011; Lebens et al., 2011; Wang et al., 2017). Nevertheless, in the only study to investigate the efficacy of evaluative conditioning in reducing soft drink intake, Shaw et al. (2016) showed that evaluative conditioning led to a larger reduction in reported soft drink consumption in the week following the intervention, compared to a control condition. They further showed that evaluative conditioning significantly increased negative evaluative bias for soft drink (i.e., affected the underlying mechanism) but only among participants with comparatively higher negative evaluative bias at baseline.

Inhibitory control training protocols involve repeatedly pairing stimuli with stop cues. These have been demonstrated to cause a devaluation effect whereby repeated pairing of cues with response inhibition diminishes explicit evaluations of the target stimuli and results in automatic inhibition associations (Houben & Jansen, 2015; Houben, 2023; Veling et al., 2017; Veling et al., 2022). Such protocols are therefore frequently termed motor response

training, as they focus on altering motor responses rather than directly modifying inhibitory control (Masterton et al., 2021). In the appetitive consumption domain, the Go/No-Go Task (Donders, 1969) is most commonly used to train inhibitory control (McGreen et al., 2024). It has been shown to be effective in reducing appetitive consumption, including unhealthy food consumption (Allom et al., 2016; Jones et al., 2016; McGreen et al., 2024) and alcohol intake (Allom et al., 2016; Jones et al., 2016; Veling et al., 2017). The Go/No-Go Task is a computerised task where participants are instructed to respond to “go” signals and to refrain from responding to “no-go” (stop) signals. Inhibitory control training is achieved by repeatedly pairing target stimuli with these “no-go” (or stop) signals. There has only been one study to investigate the efficacy of such training in reducing soft drink consumption and no such effect was found (Ames et al., 2016). However, participants who received Go/No-Go inhibitory control training and also practised a sugar-sweetened beverage implementation intention structured using the format ‘‘If I see X, then I will resist it”, did make fewer unhealthy drink choices compared to those in all other conditions (Ames et al., 2016).

To date, the effects of evaluative conditioning and Go/No-Go inhibitory control training on reducing soft drink consumption have been studied individually. Dual-process models (Strack & Deutsch, 2004) suggest that behaviours are determined by a combination of automatic (evaluative bias) and controlled (inhibitory control) processes. Accordingly, combining evaluative conditioning and Go/No-Go inhibitory control training should optimize their effectiveness in reducing soft drink consumption, as has been demonstrated in other interventions targeting both automatic and controlled processes in food consumption (e.g., Kakoschke et al., 2017). Thus, the present study aimed to offer the first investigation of the combined effects of evaluative conditioning and inhibitory control training in reducing soft drink choice and soft drink consumption. Specifically, it was predicted that:

1. Evaluative conditioning and inhibitory control training would each reduce the number of soft drink choices as well as the amount of soft drink consumed, compared to respective control tasks.
2. Following dual-process models (Strack & Deutsch, 2004), combined evaluative conditioning and inhibitory control training would reduce the number of soft drink choices as well as the amount of soft drink consumed, compared to all other conditions.
3. Evaluative conditioning would reduce evaluative bias for soft drinks, compared to the respective control task.
4. Inhibitory control training would inhibit motor responses to soft drink cues, compared to the respective control task.

Method

Participants

Participants were 219 adults (129 women, 82 men, and 8 “other”) recruited from Flinders University and Prolific (www.prolific.com). The sample comprised young adults aged between 17 and 39 years old (*M* = 24.35, *SD* = 6.20) because this age group represents the primary consumers of soft drinks among adults (Duncan et al., 2022). Mean BMI of the sample was 25.55 kg/m^2 (*SD* = 7.13), indicating slight overweight (Centers for Disease Control and Prevention, 2020). Only participants who reported drinking sugar-based soft drink at least once every 2 days were eligible to participate, as such participants were deemed to be regular soft drink consumers (Chen et al., 2020; Shaw et al., 2016). Regular soft drink consumers were used as they are the target population for effective interventions to reduce soft drink intake.

Sample size was adequate to detect at least a moderate-sized effect with an alpha level of 0.05 and 85% power for a two-way ANOVA, between-group comparisons involving four conditions, and for paired samples tests (Faul et al., 2009). A sample size large enough to detect a small-sized effect would have required more than 500 participants, which was not feasible due to limitations in resources and time.

Design

The present study used a 2 (evaluative conditioning: training task vs. control task) x 2 (inhibitory control training: Go/No-Go training task vs. Go/No-Go control task) mixed design. Participants were randomly assigned to complete either a training or control task for both the evaluative conditioning and inhibitory control training interventions, such that participants were randomly assigned to one of four conditions: (i) evaluative conditioning training task + Go/No-Go training task (ET+GT); (ii) evaluative conditioning training task + Go/No-Go control task (ET+GC).; (iii) evaluative conditioning control task + Go/No-Go training task (EC+GT); and (iv) evaluative conditioning control task + Go/No-Go control task (EC+GC).

The dependent variables included both post-test outcomes and repeated measures. Specifically, the post-test dependent variables were the type of beverage chosen (soft drink or water) in a choice task, and the total amount (mL) of soft drink drunk during the week following the intervention as reported using a 7-day beverage consumption diary. The repeated measures were evaluative bias for soft drinks and soft drink specific inhibitory control, which were taken immediately before and after completion of the evaluative conditioning and inhibitory control training tasks.

Measures

Task Stimuli

Following McGreen et al. (2022a), the stimuli for all computerised tasks comprised pictures of Cola or lemon sugar-based soft drinks and water. The water pictures comprised plain and sparkling water. Water images were used because water is a healthy, sugar-free alternative to soft drinks. The soft drink and water pictures used in the present study were the same pictures used in McGreen et al. (2022a) and were originally sourced from Google Images. To ensure visual consistency, all pictures were standardized to have the same size while preserving their original aspect ratio, set against a white background.

Evaluative Conditioning Task

A modified version of the recoding free version of the Implicit Association Test (IAT-RF, Rothermund et al., 2009) was used as the evaluative conditioning task. The task consisted of 4 practice trials and 120 test trials. The test trials used 6 soft drink pictures, 6 water pictures, 6 pictures with positive associations (e.g., a cute animal), and 6 pictures with negative associations (e.g., a dirty toilet). The task used the 6 most positive and 6 most negative pictures from the Implicit Association Task (described below) used in the present study, as per the valence ratings in the International Affective Picture System (IAPS) database (Lang et al., 2008). For each trial, a soft drink or water picture was presented in one of four quadrants on the computer screen (e.g., top left, bottom right). Following Shaw et al. (2016), participants were instructed to then press the “E” key when the soft drink or water picture appeared in one of the two top quadrants on the screen, and the “I” key when the picture appeared in one of the two bottom quadrants. This was done to reduce participant awareness of the picture pairings and the purpose of the task because contingency awareness has been shown to significantly reduce the intended evaluative conditioning effect on implicit attitudes (Hofmann et al., 2010). The designated keys were counterbalanced across participants. Following the key press, the soft drink or water picture disappeared, and either a positive or negative picture appeared immediately in the place of the first picture for 500 milliseconds. The inter-trial interval was 1000 milliseconds, during which a fixation cross was presented.

The task had two versions: (i) a “training” task designed to reduce evaluative bias for soft drinks; and (ii) a “control” task. In the training task, soft drink pictures were always replaced with negative pictures and water pictures were always replaced with positive pictures. In the control task, however, soft drink and water pictures were each replaced with positive pictures on half of the trials and negative pictures on half of the trials, respectively.

Go/No-Go Training Task

A modified version of a soft-drink specific version of the Go/No-Go Task (McGreen et al., 2022a) was used as the inhibitory control training task. The training task used the same task protocol as the Go/No-Go Task used in the present study (described below), with the following exceptions: (i) the task consisted of 8 practice trials and 96 test trials; (ii) the task used 6 soft drink and 6 water pictures; and (iii) the trials consisted of 48 "go" trials and 48 "no-go" trials. The number of trials used in the training task was informed by McGreen et al.'s (2024) meta-analysis which found that short, single session training protocols are most effective in reducing food consumption. The task had two versions: (i) a "training" task designed to improve automatic inhibition associations for soft drinks; and (ii) a "control" task. In the training task, soft drink pictures were always paired with "no-go" signals and water pictures were always paired with "go" signals. In the control, however, both soft drink and water pictures were paired with "go" signals on half of their trials and "no-go" signals on the other half of trials.

Evaluative Bias

Following McGreen et al. (2022a), evaluative bias for soft drinks was measured using a personalized, recoding free version of the Implicit Association Test (IAT-RF, Rothermund et al., 2009). The present study used the same Implicit Association Test protocol as McGreen et al. (2022a) and the same test images. Specifically, the test used 10 soft drink pictures, water pictures, pictures with positive associations (e.g., a cute animal), and pictures with negative associations (e.g., a dirty toilet), respectively. The pictures with positive and negative associations were sourced from the International Affective Picture System (IAPS) database (Lang et al., 2008) [1]. Participants completed three blocks: (i) associated attribute discrimination (Block 1), where participants categorized each positive or negative association picture based on the labels "I like" and "I dislike"; (ii) target-concept discrimination (Block 2), where participants categorized each beverage picture based on the labels "soft drink" and "water"; and (iii) combined task (Block 3), which was a combination of Block 1 and Block 2.

The D600 algorithm (Greenwald et al., 2003) was used to calculate evaluative bias. This score excludes response times over 10,000 milliseconds as delayed and participants with over 10% of trials faster than 300 milliseconds as anticipatory. For those trials where participants responded incorrectly (e.g., a participant categorized a soft drink picture as water), an error penalty was applied. Specifically, the response time for each incorrect trial was computed as the participant's mean response time in Block 3 plus an additional 600 milliseconds. Evaluative bias was measured using the D Score (Greenwald et al., 2003) which was calculated for each participant as the difference in mean response time between

congruent (i.e., “I like” and “soft drink” versus “I dislike” and “water”) and incongruent (i.e., “I like” and “water” versus “I dislike” and “soft drink”) trials in Block 3 divided by the standard deviation for all trials. As per Sriram and Greenwald (2009), scores between -0.15 and 0.15 are considered no evaluative bias, whereas scores 0.16 to 0.35, 0.36 to 0.65, and greater than 0.65, represent small, medium, and large evaluative bias, respectively. In the present study, a positive score indicated an evaluative bias for soft drinks.

Inhibitory Control

Following McGreen et al. (2022a), a soft drink specific version of the Go/No-Go Task (Houben & Jansen, 2011) was used to measure inhibitory control. The task consisted of 168 test trials, including 112 “go” trials and 56 “no-go” trials, which were presented in random order. These trials featured 7 images of soft drinks and 7 images of water. Participants were instructed to either press “the space bar” if they saw the “go” cue (the letter “p”) or withhold their response if they saw the “no-go” cue (the letter “f”), with the assigned letters counterbalanced across participants. Each trial automatically terminated after 1500 milliseconds if no response was given. The cues ("go" and "no-go") were randomly displayed in one of four locations over the picture (i.e., top right, top left, bottom right, or bottom left). Each image appeared four times in "no-go" trials and eight times in "go" trials, such that all possible combinations of cue, picture, and cue location were presented. Inhibitory control was measured using the number of commission errors (i.e., participant pressed the space bar in response to a “no-go” cue) for soft drink picture trials, where a higher number of errors indicates a lower level of inhibitory control (Houben & Jansen, 2011).

Soft Drink Choice

Soft drink choice was assessed using a computerised beverage choice task. Participants were told: “As a thank you for participating, we would like you to choose one drink. You will be sent a gift voucher to buy your chosen drink.”. This wording, namely that participants would be sent a gift voucher to buy their *chosen* drink, was used deliberately to make the soft drink choice genuine for participants. Participants were given the opportunity to choose a bottled drink from a selection of 4 drinks: Coca Cola, Schweppes Lemonade, plain water, or sparkling water. The choice of water or sparkling water was coded “0” (water), and Coca Cola or Schweppes Lemonade was coded “1” (soft drink).

Soft Drink Consumption

Soft drink consumption was measured using a 7-day self-report beverage consumption diary, in the form of a mobile phone application. At the end of each day, participants were sent a reminder message (approximately each evening at 8:00pm) to estimate their non-alcoholic beverage intake for the day. Participants received explicit

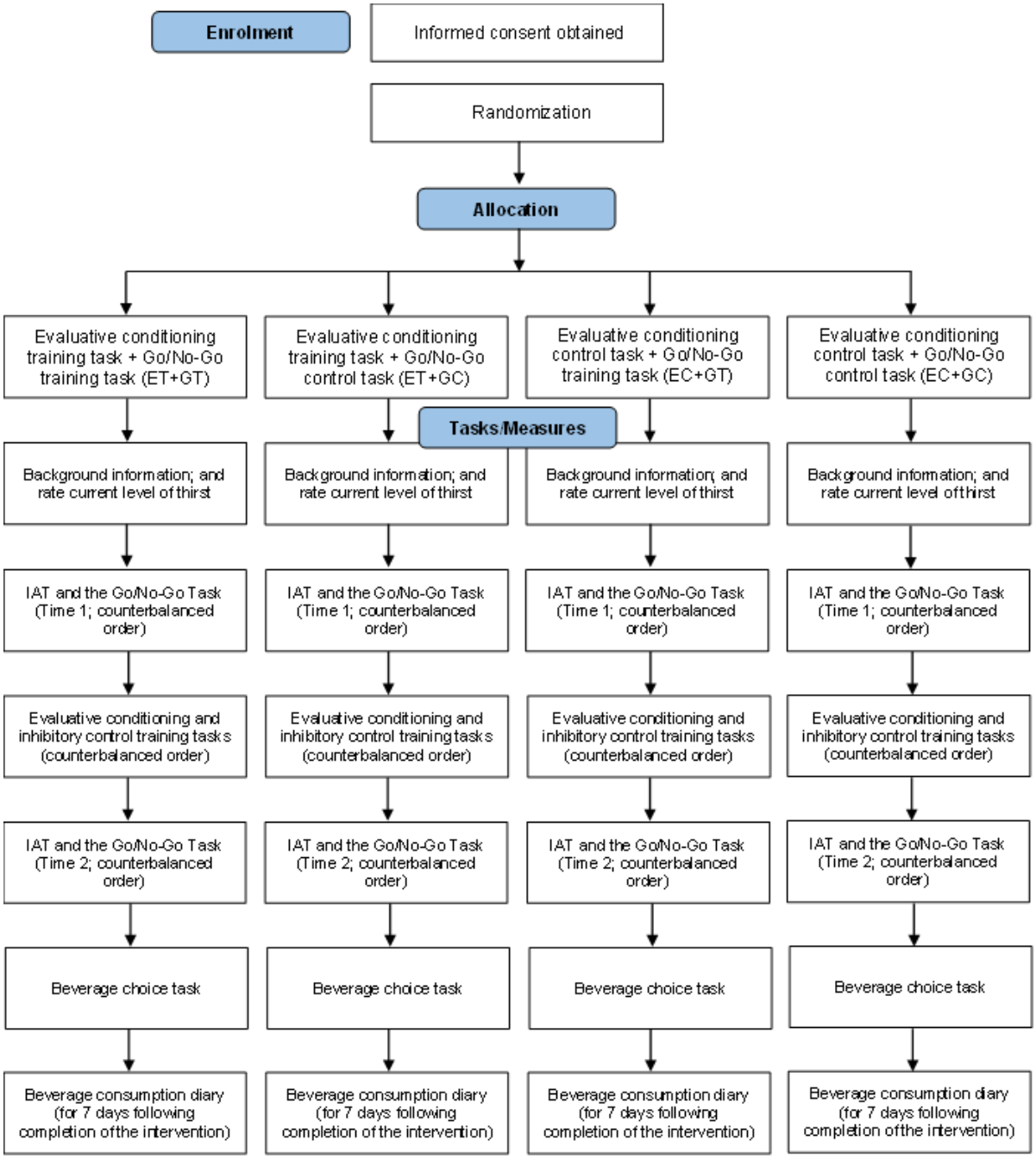
instructions not to include any alcoholic beverages in their reports. Participants were given a list of 11 beverage categories (such as energy drinks, juice, sugar-based soft drink, no-sugar soft drink), along with an "other" option, and were asked to indicate which beverages they had consumed throughout the day. For such beverages, participants also provided specific details about the beverages they consumed (such as "flat white" or "Coke") and estimated the total volume consumed in mL for the day separately for each indicated beverage category. Soft drink consumption was measured by calculating the total amount of sugar-based soft drinks drunk over the course of the week.

Procedure

Participants completed the study online (see Figure 1 for a flowchart of the study procedure). As shown in Figure 1, after providing informed consent, participants provided background information, including their height and weight, and rated their current level of thirst on a 100mm visual analogue scale (ranging from 0 to 100). They then completed the Implicit Association Test (IAT) and the Go/No-Go Task, in counterbalanced order. Next, participants completed the evaluative conditioning and inhibitory control training tasks, in counterbalanced order, with each task being either the “training” task or “control” task version based on the experimental condition assigned to the participant. However, following Kakoschke et al. (2017), in the two conditions that involved participants completing one “training” task and one “control” task, the “control” task was always completed first so as not to reduce any effect of training on soft drink choice and/or consumption. Participants then completed the IAT and the Go/No-Go Task for a second time, again in counterbalanced order. Next, participants completed the computerised beverage choice task. Finally, participants were asked to complete the beverage consumption diary for the week following completion of the intervention, starting the day after the intervention.

Figure 1

Flowchart of the study procedure



Results

Data Preparation

Of the 219 participants, 187 completed all components of the study. Specifically, 32 participants either partially completed (*N* = 19) or did not commence (*N* = 13) the beverage consumption diary following completion of the intervention. This equates to a participant dropout rate of 14.6% for the beverage consumption diary. Data analysis on the amount of

soft drink drunk used only those participants (*N* = 187) who completed the beverage consumption diary. Following Greenwald et al. (2003), evaluative bias data from one participant was excluded from the first IAT and three from the second IAT, because more than 10% of their trials were faster than 300 milliseconds.

Baseline Comparison Between Conditions

One-way ANOVA tests were used to investigate baseline differences between the four experimental conditions. There were no significant differences between the conditions based on age, $F(3, 215) = 0.64$, $p = .592$, BMI, $F(3, 213) = 0.06$, $p = .980$, baseline thirst, $F(3, 214) = 1.27$, $p = .285$, or the time since last drink, $F(3, 215) = 0.20$, $p = .900$. There was also no significant difference between the conditions based on the distribution of female and male participants, $\chi^2(3) = 1.63$, $p = .653$. The number of participants who identified as "other" ranged from 1-3 for each condition. The number of men and women and means for baseline measures, for each condition, are presented in Table 1. Further comparisons showed no significant differences between the Prolific and Flinders University participant groups on any of the baseline measures, *p's* > .326.

Table 1

The number of men and women, and means (standard deviations) for baseline age, BMI, thirst (ranging from 0 to 100), and time since last drink (minutes), for each condition

				Mean (*SD*)			
	N	**Men**	**Women**	**Age**	**BMI**	**Thirst**	**Last drink**
ET+GT	56	24	29	24.13 (5.42)	25.88 (7.20)	47.39 (24.56)	38.80 (41.58)
ET+GC	52	19	31	25.39 (6.19)	25.39 (6.52)	49.80 (23.77)	34.26 (39.79)
EC+GT	56	18	36	23.93 (6.56)	25.56 (6.75)	52.93 (24.12)	39.57 (45.97)
EC+GC	55	21	33	24.04 (6.62)	25.35 (8.09)	43.91 (27.83)	36.36 (32.17)

Note. ET+GT = evaluative conditioning training task + Go/No-Go training task; ET+GC = evaluative conditioning training task + Go/No-Go control task; EC+GT = evaluative conditioning control task + Go/No-Go training task; and EC+GC = evaluative conditioning control task + Go/No-Go control task.

In addition, there was no significant difference between the conditions on baseline evaluative bias, $F(3, 214) = 1.34$, $p = .263$, with each condition showing no evaluative bias

(i.e., a D Score between -0.15 and 0.15; Sriram & Greenwald, 2009). There was, however, a significant difference between the conditions on initial inhibitory control, $F(3, 215) = 2.78$, $p = .042$, with baseline inhibitory control in the ET+GC condition significantly greater than in the ET+GT condition, $p = .042$. Further investigation of the number of commission errors for soft drink trials showed that the number was low for all conditions. Means are presented in Table 2. Further comparisons showed no significant differences between the Prolific and Flinders University participant groups on baseline evaluative bias and inhibitory control, *p's* > .062.

Table 2

Means (standard deviations) for baseline evaluative bias (D Score) and inhibitory control (number of commission errors for soft drink trials), for each condition

	Mean (*SD*)	
	Evaluative bias	**Inhibitory control**
ET+GT	-0.08 (0.34)	0.02 (0.13)
ET+GC	-0.01 (0.37)	0.19 (0.45)
EC+GT	0.01 (0.33)	0.09 (0.29)
EC+GC	-0.10 (0.35)	0.20 (0.56)

Note. ET+GT = evaluative conditioning training task + Go/No-Go training task; ET+GC = evaluative conditioning training task + Go/No-Go control task; EC+GT = evaluative conditioning control task + Go/No-Go training task; and EC+GC = evaluative conditioning control task + Go/No-Go control task.
For evaluative bias, a positive score indicates positive valuative bias for soft drink cues.

The Impact of Training on Soft Drink Choice and Consumption

Across all conditions, 165 participants selected a soft drink in the beverage choice task, whereas 54 participants selected a water. Mean amount of sugar-based soft drink drunk during the week following completion of the intervention (derived from the 7-day beverage consumption diary) was 942.60 mL (*SD* = 1109.36), ranging from 0 to 9.25 L, indicating that there was a large spread in the amount drunk.

A hierarchical logistic regression was used to investigate the individual and combined impact of evaluative conditioning and inhibitory control training on soft drink choice. The number of participants who chose a soft drink (or water) in each condition is presented in

Table 3. Evaluative conditioning task (training task or control task) and inhibitory control training task (Go/No-Go training task or Go/No-Go control task) were entered in Step 1 as binary predictors. The interaction product variable was then entered in Step 2.

The regression analysis showed that neither evaluative conditioning, B = 0.27, SE = 0.32, p = .400, nor inhibitory control training, B = -0.34, SE = 0.32, p = .284, explained significant variance in soft drink choice, Nagelkerke R^2 = 0.012, $\chi^2(2) = 1.84$, p = .399. There was also no significant interaction between evaluative conditioning and inhibitory control training in predicting soft drink choice, as the product term did not explain any significant additional variance over the main effects, Nagelkerke R^2_{CHANGE} = 0.003, $\chi^2(1) = 0.39$, p = .530.

Table 3

The number of participants who chose a soft drink or water in the beverage choice task, for each condition

	Evaluative conditioning training		**Evaluative conditioning control**	
	GT (*N* = 56)	**GC (*N* = 52)**	**GT (*N* = 56)**	**GC (*N* = 55)**
Soft drink	41	43	40	41
Water	15	9	16	14

A two-way ANOVA was used to investigate the individual and combined impact of evaluative conditioning and inhibitory control training on the amount of sugar-based soft drink drunk during the week following completion of the intervention (derived from the 7-day beverage consumption diary). Means are presented in Table 4. The main effects of evaluative conditioning, $F(1, 183) = 2.85$, p = .093, and inhibitory control training, $F(1, 183)$ = 0.03, p = .855, were not significant. There was also no significant interaction between evaluative conditioning and inhibitory control training, $F(1, 183) = 1.05$, p = .307.

Table 4

Means and standard deviations for the amount of sugar-based soft drink drunk (mL) during the week following completion of the intervention (derived from the 7-day beverage consumption diary), for each condition, including the number of participants in each condition

	Evaluative conditioning training		Evaluative conditioning control	
Soft drink drunk	**GT (*N* = 47)**	**GC (*N* = 45)**	**GT (*N* = 44)**	**GC (*N* = 51)**
M	1017.84	1154.20	910.12	714.53
SD	1450.26	1167.79	1038.97	644.32

Note. GT = Go/No-Go training task; and GC = Go/No-Go control task.

As inhibitory control has been shown to be associated with amount of soft drink consumed specifically in men (McGreen et al., 2022a), the impact of inhibitory control training on soft drink choice and the amount of sugar-based soft drink drunk during the week following completion of the intervention (derived from the 7-day beverage consumption diary) was investigated for men and women separately. Specifically, hierarchical logistic regression analyses and two-way ANOVAs were again conducted but separately for men (*N* = 82) and women (*N* = 129).

For men, the main effect of inhibitory control training on soft drink choice fell just short of significance, *B* = -1.17, *SE* = 0.61, *p* = .053. Specifically, as can be seen in Table 5, 71% of men who completed the training task chose a soft drink, compared to 88% who completed the respective control task. In addition, the interaction between evaluative conditioning and inhibitory control training in predicting soft drink choice was not significant, *p* = .673. There were also no significant main effects or interaction for amount of sugar-based soft drink drunk, *p's* > .179. For women, there were no significant main effects or interaction for either soft drink choice, *p*'s > .653, or amount of sugar-based soft drink drunk during the week following completion of the intervention, *p*'s > .123.

Table 5

The number of men who chose a soft drink or water in the beverage choice task, for each inhibitory control training condition

	Go/No-Go training task (*N* = 42)	Go/No-Go control task (*N* = 40)
Soft drink	30	35
Water	12	5

Mixed ANOVAs were used to investigate differences from baseline to post intervention for evaluative bias and inhibitory control. Mean differences from baseline to post intervention are presented in Table 6.

For evaluative bias, there was no significant difference between those who completed the evaluative conditioning training task ($M_{difference}$ = 0.01) and those who completed the respective control task ($M_{difference}$ = 0.00), $F(1, 211) = 0.01$, $p = .915$. Further, there was no significant overall effect of time, $F(1, 211) = 0.01$, $p = .939$. The mean difference scores indicate that there was no change from baseline.

For inhibitory control, there was no significant difference between those who completed the Go/No-Go training task ($M_{difference}$ = 0.63) and those who completed the respective control task ($M_{difference}$ = 1.02), $F(1, 215) = 3.55$, $p = .061$. There was a significant overall effect of time, $F(1, 215) = 63.07$, $p < .001$, where participants in all conditions made more commission errors on soft drink trials post intervention, compared to baseline (as indicated by positive mean difference scores, Table 3).

Table 6

The mean difference from baseline to post-intervention for evaluative bias and inhibitory control (number of commission errors for soft drink trials), for each condition

	Evaluative conditioning training		**Evaluative conditioning control**	
Evaluative bias	GT (*N* = 55 [a])	GC (*N* = 51 [a])	GT (*N* = 56)	GC (*N* = 53 [a])
Mean difference	-0.03	-0.03	-0.09	0.09
Inhibitory control	GT (*N* = 56)	GC (*N* = 52)	GT (*N* = 56)	GC (*N* = 55)
Mean difference	0.48	0.85	0.77	1.18

Note. ET+GT = evaluative conditioning training task + Go/No-Go training task; ET+GC = evaluative conditioning training task + Go/No-Go control task; EC+GT = evaluative conditioning control task + Go/No-Go training task; and EC+GC = evaluative conditioning control task + Go/No-Go control task.

For mean difference, a negative score indicates a more negative evaluative bias for soft drinks (i.e., a decrease in positive evaluative bias) or a reduction in the number of commission errors for soft drink trials.

[a] One, one, and two participants were excluded from the ET+GT, ET+GC, and EC+GC conditions, respectively, because more than 10% of their trials were faster than 300 milliseconds.

Following Shaw et al.'s (2016) finding that evaluative conditioning increased negative evaluative bias for soft drink specifically for participants with higher negative evaluative bias at baseline, the difference from baseline to post intervention for evaluative bias was investigated separately for participants with a negative evaluative bias score at baseline (i.e., D score < -0.15; Sriram & Greenwald, 2009). Among these participants (N = 76), just as in the total sample, there was no significant difference from baseline to post intervention between those who completed the evaluative conditioning training task ($M_{difference}$ = 0.27) and those who completed the respective control task ($M_{difference}$ = 0.27), p = .994.

Discussion

The present study aimed to investigate the impact of evaluative conditioning and Go/No-Go inhibitory control training for reducing soft drink choices and consumption. It also sought to provide the first investigation of a combined evaluative conditioning and inhibitory control training on soft drink choice and consumption. The results showed that neither evaluative conditioning, inhibitory control training, nor a combination of both interventions, were effective in reducing soft drink choice or consumption, relative to a neutral control task. Nevertheless, although not statistically significant, the results suggest that inhibitory control training may be effective in reducing the number of soft drink choices specifically in men. Further, the results showed that neither evaluative conditioning nor inhibitory control training were effective in reducing the hypothesized underlying mechanisms, namely evaluative bias and motor responses for soft drink cues.

The finding that evaluative conditioning was not effective in reducing soft drink choice or consumption is not consistent with Shaw et al. (2016), who showed that evaluative conditioning reduced reported soft drink consumption. A key difference between the present study and that of Shaw et al. (2016) is in participant recruitment. Specifically, Shaw et al. (2016) included participants who reported consuming at least 36 ounces (approximately 1 litre) of sugar-based soft drink per week, whereas the present study included participants if they reported drinking soft drink at least once every 2 days, with no specification of the amount drunk. Although we have no pre-study data about soft drink consumption, in the combined control condition (no training) only 22% of participants consumed at least 1 litre of soft drink per week. Thus, our results may have been hampered by a floor effect.

Additionally, the absence of overall evaluative bias at baseline may likewise reflect a sample who were not heavy consumers of soft drink.

Regarding inhibitory control, the finding that such training was not effective in reducing soft drink choice or consumption aligns with the findings of Ames et al. (2016). Specifically, they showed that Go/No-Go training alone did not reduce sugar-sweetened beverage or calorie consumption. However, they found that participants who received Go/No-Go training and also practised a sugar-sweetened beverage implementation intention made fewer unhealthy drink choices. Thus, it may be that inhibitory control training alone is not effective in reducing soft drink consumption. This conclusion does, however, contrast with the findings of meta-analyses in other areas of appetitive consumption, such as unhealthy food consumption (Allom et al., 2016; Jones et al., 2016; McGreen et al., 2024) and alcohol intake (Allom et al., 2016; Jones et al., 2016; Veling et al., 2017), which demonstrated that Go/No-Go training was effective in reducing consumption in these domains. It may be that the role of inhibitory control in soft drink consumption is different from that in food or alcohol consumption. One possible explanation is that food and alcohol are each often consumed by themselves, whereas soft drinks are often an addition to food consumption. For example, it has been shown that one of the most common triggers for craving soft drink (i.e., a strong desire to consume a soft drink) is food consumption or food cues (McGreen et al., 2022b). When soft drinks are consumed alongside food, they may be seen as part of a cohesive meal experience rather than as distinct items to be regulated separately. Further exploration into these differences may provide valuable insights into how interventions targeting inhibitory control could be tailored to soft drinks more effectively. Nevertheless, the current findings do suggest that inhibitory control training targeting soft drink intake may be effective specifically for men, although this result fell just short of statistical significance. This fits with previous findings showing that inhibitory control was associated with soft drink intake, but only in men (Ames et al., 2014; McGreen et al., 2022a). Thus, such interventions may be uniquely effective for men.

Overall, contrary to expectations, the current study found that the combined effects of evaluative conditioning and inhibitory control training were not effective in reducing soft drink choices and consumption. Importantly, the interventions in this study did not successfully modify the postulated underlying mechanisms (evaluative bias and motor responses for soft drink cues). In this way, the findings are actually consistent with dual-process models (Strack & Deutsch, 2004). According to this theoretical framework, behaviours (including soft drink consumption) are determined by a combination of automatic and controlled processes. As the interventions in the present study did not modify evaluative bias nor motor responses for

soft drink cues, according to dual-process models (Strack & Deutsch, 2004), one would not expect any impact on soft drink choice or consumption.

The finding that evaluative conditioning was not effective in reducing the hypothesized underlying mechanism of evaluative bias is not consistent with Shaw et al. (2016). This only other study to investigate the impact of evaluative conditioning for reducing soft drink consumption showed that evaluative conditioning significantly increased negative evaluative bias among individuals with comparatively higher negative evaluative bias at baseline. However, when we investigated such individuals separately in the present study, evaluative conditioning still did not prove effective in reducing the hypothesized underlying mechanism of evaluative bias. Notably, Shaw et al. (2016) used unipolar attribute categories (e.g. positive vs. neutral; and negative vs. neutral), rather than a bipolar category (e.g. positive vs. negative; or water vs. soft drink) as was used in the present study, which could explain the conflicting findings.

Regarding the underlying mechanism of inhibitory control, the baseline number of commission errors (on soft drink trials) for participants in the present study was low across all conditions, suggesting that the intervention may have had limited potential for impact as participants already exhibited reduced motor responses to soft drinks. Alternatively, the findings could be explained by participant fatigue or disengagement. Further investigation showed that for all conditions, commission errors in the Go/No-Go Task increased from baseline to post-intervention. While a greater number of commission errors typically suggests poorer inhibitory control (or greater impulsivity; Bezdjian et al., 2009; Houben & Jansen, 2011), in this instance, the increase in commission errors across all trials and conditions may suggest a broader trend of participant fatigue or disengagement with the tasks or intervention over the length of the intervention. Such disengagement may have undermined the effectiveness of inhibitory control training in inducing the desired devaluation effect through repeated pairing of soft drink cues with response inhibition.

The current findings have some practical implications. In particular, they provide valuable insights for improving future investigations into the impact of evaluative bias and inhibitory control interventions for reducing soft drink consumption. The current study aimed to recruit habitual or regular consumers of soft drinks. Although participants exceeded intake recommendations (World Health Organization, 2017), most did not consume what may be considered a “large” amount of soft drink. It is likely that interventions would be more effective for those who drink larger quantities and/or drink soft drink every day, as these individuals would be more likely to have stronger evaluative biases and greater difficulties with inhibitory control. Therefore, future research could focus on recruiting samples with

higher consumption rates. Finally, findings suggest that inhibitory control interventions targeting soft drink consumption may be uniquely effective for men, highlighting a potential area for investigation in future studies.

In conclusion, the present study showed that neither evaluative conditioning nor inhibitory control training were effective in reducing soft drink consumption or choice. Further, the interventions were not effective in reducing the underlying mechanisms, namely decreasing evaluative bias and motor responses for soft drink cues. Nevertheless, the current study provides a preliminary investigation of the impact of a combined evaluative bias and inhibitory control intervention for reducing soft drink consumption. In so doing, it provides valuable insights for future investigation of the impact of such interventions for reducing soft drink consumption.

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Contributors

All authors contributed to the design of the study and writing the manuscript. Joshua McGreen was responsible for data collection, under supervision of Eva Kemps. Joshua McGreen conducted the statistical analyses and wrote the first draft of the manuscript. All other authors edited subsequent drafts and have approved the final manuscript.

Conflict of interest

None.

Data and code availability

All data used in the study are available from the corresponding author who has full access to the data reported in the manuscript.

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CHAPTER SEVEN: GENERAL DISCUSSION

Chapter Overview

The primary goal of this thesis was to examine the underlying mechanisms associated with the consumption of soft drinks and unhealthy foods, and to evaluate interventions aimed at reducing such consumption. Each chapter in the thesis had specific objectives that built upon the findings of previous chapters. Chapter 1 provided a general introduction to the background of the studies. Chapter 2, a cross-sectional study (Study 1), investigated the roles of cognitive biases (evaluative, attentional, and approach biases) and inhibitory control in the consumption of soft drinks. Chapter 3, a second cross-sectional study (Study 2), aimed to provide a thorough examination of cravings for non-alcoholic beverages and their link to consumption. Chapter 4, a meta-analysis (Study 3), sought to determine whether inhibitory control, as assessed by the Go/No-Go and Stop-Signal tasks, is associated with food consumption. Chapter 5, a second meta-analysis (Study 4), evaluated the efficacy of Go/No-Go and Stop-Signal training in reducing food consumption. Chapter 6, an experimental study (Study 5), examined both the individual and combined effects of evaluative conditioning and inhibitory control training for reducing soft drink consumption. The current chapter will summarise the findings of the present thesis and discuss theoretical implications, practical applications, limitations of the thesis findings, and recommendations for future research directions.

Summary of Findings

Study 1 (Chapter 2) sought to examine the roles of evaluative, attentional, and approach biases for soft drink cues, as well as inhibitory control, in soft drink consumption. Evaluative bias was the only cognitive bias shown to be associated with soft drink consumption, with that bias associated with more soft drink consumed during an experimental taste test. Lower inhibitory control was associated with greater consumption in the same taste test, but only for men. However, there was no evidence of an interaction between strong biases for soft drink cues and low inhibitory control in predicting soft drink choice or consumption. Thus, Study 1 demonstrated that each of automatic (evaluative bias) and controlled processes (inhibitory control) independently predict soft drink consumption.

Study 2 (Chapter 3) provided the first comprehensive investigation into cravings for non-alcoholic beverages. Participants reported cravings for a variety of non-alcoholic beverages, with coffee, soft drink, and water by far the most frequently craved. Such cravings were found to be triggered by a range of different factors. Unlike water, which was primarily driven by thirst, cravings for coffee were most often triggered by tiredness, while cravings for soft drink were predominantly triggered by external environmental cues e.g., “beverage advertising” and “food”. Across all non-alcoholic beverages, stronger cravings were associated with both a higher likelihood of drinking

and consuming more of the craved beverage after the craving. This association was individually statistically significant for soft drink, but not for coffee or water. Additionally, the number of cravings for coffee and soft drink each uniquely predicted the total amount of these beverages consumed over the course of a week. Overall, Study 2 provided a novel demonstration of the existence of cravings for non-alcoholic beverages, including soft drink, and their link to such consumption.

Study 3 (Chapter 4) involved a comprehensive meta-analysis of the relationship between inhibitory control, as measured by the Go/No-Go and Stop-Signal tasks, and food consumption. Overall, there was a small association between inhibitory control and food choice or consumption. Separately, inhibitory control was associated with food choice or consumption when measured by the Stop-Signal Task. However, when inhibitory control was measured using the Go/No-Go Task, this association was only observed in children and when food choice or consumption was measured objectively. Thus, Study 3 provides comprehensive evidence that inhibitory control is linked to food consumption.

Study 4 (Chapter 5) involved another meta-analysis designed to provide a thorough examination of how parameter differences in inhibitory control training tasks impact the effectiveness of such tasks in reducing food consumption. Overall, inhibitory control training was shown to reduce food choices or consumption. However, this effect was significant only for training protocols using the Go/No-Go Task. Among these protocols, using a single training session produced greater reductions in food choices or consumption, compared to multiple sessions. The effect of training protocols using the Go/No-Go Task in reducing food choices or consumption was shown to be robust across different demographic groups, including men, women, various age groups, and both clinical and non-clinical populations. Accordingly, Study 4 presents comprehensive evidence that the Go/No-Go Task effectively, and robustly, reduces food consumption.

Finally, based on the findings of Studies 1, 3, and 4, Study 5 (Chapter 6) investigated the individual and combined effects of evaluative conditioning and Go/No-Go inhibitory control training for reducing soft drink choices and consumption. Neither evaluative conditioning nor inhibitory control training effectively altered the targeted mechanisms (evaluative bias and motor responses to soft drink cues, respectively). Moreover, neither of the interventions, whether alone or combined, was effective in reducing soft drink choice or consumption. However, there was a (not statistically significant) trend for inhibitory control training to reduce soft drink choices among men. It was concluded that Go/No-Go inhibitory control training targeting soft drink consumption may be especially effective for men.

Theoretical and Practical Implications

The findings of the present thesis have some theoretical implications. First, Study 1 supports the application of dual-process models (Strack & Deutsch, 2004) to soft drink consumption by showing that both automatic processes (evaluative bias) and controlled processes (inhibitory control) are related to soft drink intake, albeit independently. Thus, the findings suggest that evaluative bias and inhibitory control may be important factors that individually influence soft drink consumption. The association between evaluative bias for soft drink cues and soft drink consumption aligns with the findings of the only other study to investigate evaluative bias in soft drink consumption (Shaw et al., 2016). This suggests that automatic evaluations of these cues may be an important factor in soft drink intake, similar to patterns observed in food and alcohol consumption (de Bruijn et al., 2012; Ostafin & Palfai, 2006). Study 1 suggested that evaluative bias for soft drink cues might be especially associated with such consumption because these cues may become linked to the intrinsically rewarding aspects of soft drink consumption, such as sugar (Avena et al., 2008; Volkow & Wise, 2005; Volkow et al., 2008), which may enhance evaluation of these cues. Alternatively, it was suggested that affective responses, like evaluative bias, might play a more significant role in soft drink consumption because of the extensive marketing of soft drinks, which frequently connects soft drinks with positive emotions such as 'having fun with friends', 'being cool', or 'happiness' (Brownbill et al., 2018). In addition, the finding from Study 1 that inhibitory control was associated with soft drink consumption exclusively among men parallels the results of Ames et al. (2014), the only other study to investigate inhibitory control in sugar-sweetened beverages. This suggests that inhibitory control may be specifically related to soft drink consumption among men.

The findings of Studies 3, 4, and 5 also align with dual-process models (Strack & Deutsch, 2004). Study 3, in demonstrating that inhibitory control, as measured by the Go/No-Go and Stop-Signal tasks, is associated with food consumption, highlights the role of individual differences in inhibitory control in food consumption. Furthermore, Study 4 highlights the importance of reducing motor responses to food cues for reducing food consumption by demonstrating the effectiveness of Go/No-Go inhibitory control interventions. Such interventions aim to reduce motor responses and, thereby, consumption by establishing automatic inhibition associations and diminishing explicit evaluations of the target (e.g., food; Veling et al., 2017). Thus, the findings of Studies 3 and 4 fit with dual-process models (Strack & Deutsch, 2004), which propose that behaviour is influenced both by automatic processes, such as unconscious associations, and controlled processes, such as inhibitory control or motor responses. According to these models, individuals with poorer inhibitory control may be more susceptible to environmental cues, and changing their unconscious attitudes or response inhibition can reduce consumption. However, in Study 5, the interventions failed to alter the proposed underlying mechanisms of evaluative bias and motor responses for soft drink cues. Nevertheless, the findings are also consistent with dual-process models (Strack & Deutsch, 2004). Since the interventions caused no change in the targeted automatic (evaluative

bias) and controlled processes (motor responses), no impact on soft drink choice or consumption would be expected.

Additionally, the finding in Study 4 that the inhibitory control training effect was significant only for protocols using the Go/No-Go Task aligns with previous research findings (Allom et al., 2016; Aulbach et al., 2019; Jones et al., 2016; Yang et al., 2019) and supports the suggestion that the Go/No-Go and Stop-Signal tasks rely on different mechanisms (Littman & Takács, 2017; Raud et al., 2020). Specifically, it has been suggested that the Go/No-Go and Stop-Signal tasks affect automatic and controlled response inhibition, respectively (Allom et al., 2016). Alternatively, it has been suggested that the Stop-Signal Task may be less effective than the Go/No-Go Task due to how "stop" food items are paired with stop signals in each task. Specifically, Stop-Signal Tasks typically pair "stop" food items with "stop" signals only 50% of the time (Veling et al., 2017), as was observed in Study 4, whereas Go/No-Go Task protocols usually pair "no-go" food items with "no-go" signals 100% of the time. This consistent pairing in Go/No-Go Task protocols may create a stronger association between food and stopping, or a greater devaluation effect (Veling et al., 2017; 2022), potentially resulting in their greater effectiveness in reducing food consumption.

Finally, the findings of Study 2 support theoretical models of craving (Berridge & Robinson, 1995; Kavanagh et al., 2005; Tiffany, 1990) in their proposition that cravings drive consumption, and in so doing extend these models to non-alcoholic beverages. Study 2 further suggests that there may be differences among such beverages in terms of how cravings affect consumption in that they may be triggered by unique factors, and that cravings may play a particularly strong role in soft drink consumption. For soft drink specifically, the observation that external cues like seeing food, soft drink advertisements, or social settings can trigger cravings aligns with several theoretical models of craving. These models view craving as a conditioned response resulting from repeated associations between cues and consumption, which then drives consumption (Berridge & Robinson, 1995; Kavanagh et al., 2005; Tiffany, 1990). Consequently, it was suggested that soft drinks may be particularly craved and hard to resist due to the widespread and pervasive presence of external cues such as soft drink advertising (NCES, 2020).

The findings of the present thesis also have some important practical implications. First, the results from Studies 1 and 2 point to three specific targets for reducing soft drink consumption, namely evaluative bias (Study 1), inhibitory control (Study 1), and cravings (Study 2). The identification of these potential targets is significant given the substantial rise in global soft drink consumption over the past 50 years, which has evolved into a major public health issue (Cecchini et al., 2010; Machado et al., 2020; Pan & Hu, 2011; World Health Organization, 2017). Importantly, evaluative bias (Bui & Fazio, 2016; Haynes et al., 2015; Hensels & Baines, 2016; Hofmann et al., 2010; Hollands et al., 2011; Lebens et al., 2011; Wang et al., 2017), inhibitory control (Houben & Jansen, 2015; Houben, 2023; Veling et al., 2017; Veling et al., 2022), and cravings (Berridge &

Robinson, 1995; Kavanagh et al., 2005; Tiffany, 1990; Tiffany & Conklin, 2000) have all been identified as modifiable predictors of consumption in areas such as food and alcohol intake. Specifically, techniques such as evaluative conditioning (Hofmann et al., 2010), Go/No-Go inhibitory control training (McGreen et al., 2024), and guided imagery or cognitive defusion (Hamilton et al., 2013; Kemps & Tiggemann, 2009; Schumacher et al., 2017) have been used to modify evaluative bias, motor responses, and cravings, respectively. These will need to be tested in the soft drink domain.

Study 3 is practically relevant as it demonstrates that inhibitory control is associated with food consumption. Based on this assumed relationship, previous studies have investigated the effectiveness of inhibitory control training for reducing unhealthy food intake. The meta-analysis now provides clear evidence to support the investigation into such interventions. Moreover, Study 3 offers valuable insights for future research using the Go/No-Go or Stop-Signal tasks to investigate the relationship between inhibitory control and food consumption. Specifically, it demonstrates that both the Go/No-Go and Stop-Signal tasks can be effectively employed when measuring food consumption or choice as the outcome variable in objective, immediate settings, such as with a taste test. Objective measures have been validated as reliable indicators of consumption (Robinson et al., 2017), unlike self-reported intake, which can often be underreported (Ravelli & Schoeller, 2020). Therefore, future research should prioritize the use of objective consumption measures. Further, Study 4 showed that the Go/No-Go Task can use either neutral or food-specific stimuli to measure inhibitory control, while the Stop-Signal Task has confirmed effectiveness only with neutral stimuli. Additionally, the study found minimal variation in the relationship between inhibitory control and food consumption/choice across different demographic groups, including gender and weight categories, indicating that the Go/No-Go and Stop-Signal tasks can be used to investigate the relationship between inhibitory control and food consumption across a diverse range of people. However, age emerged as a factor, with the Go/No-Go Task being particularly useful for children and the Stop-Signal Task being more effective for young adults. Consequently, future research should consider the match between the sample characteristics and the type of inhibitory control measure used.

Study 4 both confirms and updates previous research (Allom et al., 2016; Aulbach et al., 2019; Jones et al., 2016; Yang et al., 2019) on the effectiveness of Go/No-Go Task training protocols for reducing food consumption. The study also offers insights for the optimal protocol for such interventions, suggesting that short, single-session training protocols are particularly effective for reducing food consumption or choice, at least in the short term. Additionally, the largest effect (although not statistically significant) for reducing food consumption or choice was observed when Go/No-Go Tasks used neutral (non-emotive) cues for “go” and “no-go” signals; 100% pairing of target trials with “no-go” signals; neutral (non-food) stimuli as non-targets; a trial duration of 1500 milliseconds; and an inter-trial duration of 500 milliseconds.

Finally, Study 5 offers valuable insights for future research on inhibitory control interventions aimed at reducing soft drink consumption. Specifically, the findings suggest that Go/No-Go inhibitory control interventions might prove effective for men. However, as the finding did not reach statistical significance, conclusive evidence is still lacking. Future research might consider focusing on developing and evaluating inhibitory control interventions specifically targeted at men to reduce soft drink consumption. For women, it may be that inhibitory control interventions are not effective in reducing soft drink consumption. Therefore, future research might benefit from focusing on the efficacy of alternative interventions aimed at reducing soft drink consumption in women.

Overall, the present thesis provides important theoretical and practical insights into some cognitive and behavioural mechanisms underlying soft drink and unhealthy food consumption, with wider implications for health interventions. From a theoretical perspective, the findings emphasize the relevance of dual-process models (Strack & Deutsch, 2004) in understanding appetitive behaviours more generally, and extend the application of this model to the context of soft drink consumption. The thesis also provides clear evidence of two key points: (i) a link between inhibitory control and unhealthy food consumption, and (ii) the effectiveness of interventions targeting inhibitory control for reducing such consumption. Finally, the thesis presents the first evidence that cravings for non-alcoholic beverages, particularly those triggered by environmental cues like advertisements and food, are directly linked to their consumption, and thus, expand existing craving models (Berridge & Robinson, 1995; Kavanagh et al., 2005; Tiffany, 1990; Tiffany & Conklin, 2000) to a new appetitive consumption domain. Together, these findings highlight the need to consider both cognitive and environmental factors in understanding soft drink and unhealthy food consumption, thereby informing both theoretical frameworks and intervention strategies.

On a practical level, the findings from the present thesis offer several promising avenues for reducing soft drink and unhealthy food consumption, both of which have become significant global public health concerns (Cecchini et al., 2010; Machado et al., 2020; Pan & Hu, 2011; World Health Organization, 2017). Specifically, the findings overall suggest that interventions that aim to modify evaluative bias, target inhibitory control, and manage cravings could all contribute to reducing soft drink consumption, while also providing clear evidence for a role for inhibitory control in curbing unhealthy food consumption. Importantly, each of these mechanisms is modifiable, either through individual-level interventions or through broader interventions that target environmental triggers. In so doing, the thesis underscores the complex, multi-faceted nature of soft drink and unhealthy food consumption, and importantly, highlights the need for multi- dimensional strategies to reduce such consumption. While the interventions tested in the present thesis, namely evaluative conditioning and inhibitory control training, showed limited success in reducing soft drink consumption, the findings still provide valuable insights and suggest directions for future research. For example,

refining inhibitory control interventions specifically for men or further developing approaches to target craving-induced consumption may enhance their effectiveness. Overall, the thesis highlights the complexity of both soft drink and unhealthy food consumption and, consequently, the challenge of reducing such consumption. Furthermore, it advocates for interventions that address both cognitive and environmental triggers and stresses the need for tailored approaches that consider individual and demographic differences.

Strengths, Limitations, and Future Directions

The studies presented in this thesis have some notable strengths. First, Studies 1, 2, and 5 offer unique and thorough investigations of cognitive biases, inhibitory control, and/or craving in the context of soft drink consumption, an area previously underexplored. In particular, Studies 1 and 2 offer the first investigations of multiple cognitive biases (including attentional and approach biases) and craving in the context of soft drink consumption, respectively. In addition, Study 5 presents the first investigation of a combined intervention that integrates evaluative conditioning and inhibitory control training for reducing soft drink consumption. Notably, Study 2 identifies cravings, a previously unexplored factor in soft drink consumption, as a potential target for managing such consumption. Experimental research has successfully used techniques such as guided imagery or cognitive defusion to reduce cravings for coffee (Kemps & Tiggemann, 2009) and food (Hamilton et al., 2013; Schumacher et al., 2017). Based on the findings of Study 2, future research could investigate the efficacy of these techniques also for reducing soft drink consumption.

Furthermore, the meta-analyses (Studies 3 and 4) provide valuable and novel insights into the role of inhibitory control and inhibitory control interventions in food consumption amid conflicting literature. Initially, the meta-analyses aimed to focus on soft drinks. However, as there was only one study each on the role of inhibitory control (Ames et al., 2014) and inhibitory control interventions (Ames et al., 2016) in sugar-sweetened beverage consumption, and no literature specifically on soft drinks, the focus of the meta-analyses shifted to food consumption. By utilizing the greater statistical power and pooled effect estimates provided by meta-analysis, these studies have established statistical significance that might not have been evident in individual studies. They confirm that inhibitory control is indeed related to food consumption and demonstrate that the Go/No-Go Task is an effective method for reducing food intake, with findings of the latter remaining robust across various parameters and demographic variations. However, it remains for future research to see whether these findings apply to soft drink consumption.

Despite its strengths, the present thesis also has some limitations, which provide important directions for future research. The specific limitations of each study are detailed in their respective chapters. This section offers a summary of the main limitations.

First, while Studies 1 and 5 tested specific hypotheses, and Study 2 provided a systematic investigation of cravings for non-alcoholic beverages, these studies were not pre-registered [Studies 3 and 4 were pre-registered]. Thus, replication of the present findings is warranted in future pre-registered studies.

Second, the samples of Studies 1, 2, and 5 were made up of young adults. While young adults are the primary adult consumers of soft drinks (Miller et al., 2019; Roy Morgan Research, 2015), children and older adults also consume these and other non-alcoholic beverages. Therefore, future research could investigate how cognitive biases, inhibitory control, and cravings impact soft drink consumption in other age groups.

Third, in Studies 2 and 5, beverage intake was reported just once at the end of the day. This may have led to incomplete recall or reporting. Future research should consider using a finer-grained measure of beverage consumption, such as Ecological Momentary Analysis, which has the advantage of repeatedly sampling participants' behaviours and experiences in real time, and within their natural environment (Shiffman et al., 2008).

Fourth, although beyond the scope of Study 3, additional within-task moderator variables could be investigated in the relationship between inhibitory control and food consumption. For the Go/No-Go and Stop-Signal tasks, these variables might include the number of trials and the ratio of stop to go trials. For food consumption measures, relevant variables could include, for example, the quantity of food provided in bogus taste tests (Robinson et al., 2017). Future research could examine how such additional variables might influence the relationship between inhibitory control and food consumption.

Fifth, in Study 4, moderator analyses could not be conducted for all variables because some comparison subgroups had an insufficient number of studies (fewer than four studies; (fewer than four; Fu et al., 2011). Further, the conclusion that no tested parameter variations (except number of training sessions), significantly impacted the effect of inhibitory control training for reducing food consumption may have been limited by the moderator analyses' ability to detect differences based on the small number of studies in some subgroups. Thus, future research might re-examine how such variables influence the relationship between inhibitory control and food consumption as more data become available.

Finally, although Study 5 targeted habitual soft drink consumers, most participants did not consume what might be considered a "large" amount on a weekly basis. Interventions might be more effective for individuals who consume larger quantities of soft drinks more frequently, as they are likely to exhibit stronger evaluative biases and poorer inhibitory control. Consequently, future research should aim to recruit participants with higher levels of soft drink consumption. Relatedly, as neither evaluative conditioning nor Go/No-Go inhibitory control interventions successfully

modified the respective underlying mechanisms of evaluative bias and motor responses, future research might explore whether, and under which conditions, such interventions could effectively modify these mechanisms.

Conclusion

In conclusion, the results of this thesis provide evidence for the relationships between underlying mechanisms and soft drink and unhealthy food consumption and identify key targets for potentially reducing such consumption. In particular, this thesis makes a valuable and unique contribution to the research on soft drink consumption by identifying evaluative bias towards soft drink cues and inhibitory control as key targets for decreasing such consumption. It also offers a novel demonstration of cravings for soft drinks and their link to consumption. In addition, it presents the first examination of dual-process models in the context of soft drink consumption and introduces the first combined intervention integrating evaluative conditioning with inhibitory control training to reduce soft drink consumption. Furthermore, the thesis provides comprehensive evidence of the role of underlying mechanisms in unhealthy food consumption. Specifically, it demonstrates that inhibitory control is linked to food consumption and that Go/No-Go inhibitory control interventions effectively and robustly reduce such consumption, in addition to offering guidance on the optimal protocol for such interventions. Thus, this thesis provides a valuable and unique contribution to the understanding and possible remediation of both soft drink and unhealthy food consumption, which are each significant public health concerns.

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