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Title:
Thirst, hunger or sweetness? What motivates humans to drink in the modern beverage environment?

Thirst, hunger or sweetness? What motivates humans to drink in the modern beverage environment?

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April 2018

School of Experimental Psychology

A dissertation submitted to the University of Bristol in accordance with the requirements for award for the degree of Doctor of Philosophy in the Faculty of Science

Word count: 59950

Abstract

Physiological fluid balance is strictly regulated, yet much of our drinking occurs irrespective of fluid balance. The addition of palatable beverages to our diet encourages drinking for the enjoyment of taste. The emphasis on hydration in our society, "Drink at least eight glasses of water a day", encourages drinking to prevent future thirst. The custom of consuming a beverage with a meal encourages drinking to wash food down or complement the flavours in the meal. The frequency with which drinking occurs irrespective of fluid balance may have led to the disassociation between thirst and drinking. In turn, individuals may believe they are thirsty (i.e., in physiological need of water) when they are simply responding to habit or reward.

It has been suggested that the low satiety of sugar-sweetened beverages leads to increased intake and consequently weight gain. However, evidence of the satiety of beverages is mixed and points to a range of sensory, cognitive, and physiological factors. Previous research has focused on the properties of liquid calories. Therefore, the subsequent experiments shifted the focus from the static properties of beverages to the dynamic motivations of the individual.

A field-based qualitative study generated theories about thirst, drinking, and beverage choice. Two laboratory-based studies measured intake of water, a reduced-sugar sweetened beverage or a sugar-sweetened beverage when participants (Study 1, N = 32; Study 2, N = 66) were both hungry and thirsty (only Study 1), hungry, thirsty, and neither hungry nor thirsty. Two online-based studies measured beverage choice (N = 166) and intake (N = 98) in the context of a meal. Choice and intake of water, a reduced-sugar sweetened beverage, and a sugar-sweetened beverage were assessed with 100 kcal, 300 kcal, 500 kcal, 700 kcal, and 900 kcal portions of food. These experiments raised questions about how drinking behavior may depend on the nature of thirst, and about reward underlying drinking behavior. Therefore, a final laboratory-based study (N = 26) investigated beverage reward and its ability to predict beverage intake, and if intake of water depended on whether the individual simply feels thirsty or undergoes physiological changes to fluid balance.

The experiments taken together offer a novel contribution to the literature by highlighting how motivational states can lead to poor beverage choices and inadvertently increase energy intake. The findings of this thesis reveal the robust effect of thirst on beverage intake despite satiation cues. When thirsty, beverage intake is increased even when the beverages provide taste and energy and when the individuals have recently eaten or expect to eat soon. Further, the findings of this thesis reveal the robust effect of thirst on beverage intake even when the experience of thirst is psychological and not caused by a physiological need for fluid. Under these conditions, individuals may unknowingly and unnecessarily increase energy intake. Individuals should carefully select their beverages. While low-calorie beverage options might be useful for reducing energy intake, as they provide reward without calories, additional work needs to be done to prevent consumer resistance to such products.

Acknowledgements

Firstly, I would like to thank my parents for their unconditional support and encouragement throughout my life, but especially when I asked to move across the Atlantic Ocean to pursue a PhD in England! Secondly, I could not have asked for a better supervisor during my PhD than Professor Peter Rogers. I would like to thank him for his generosity with his time and support. I am grateful that he offered invaluable wisdom and guidance, but always encouraged me to develop my own research ideas. Most importantly, he made obtaining a PhD a straightforward and enjoyable experience. I would like to thank the NBU, specifically Danielle Ferriday for her meticulousness and mentorship. I would like to thank Dr. Karen Siedlecki, my undergraduate mentor at Fordham University, for helping me to realize my passion for research.

Thank you to my friends in New York who encouraged me to take a chance and move to a foreign country to pursue a PhD (a special thanks to Kristina, Elianny, and Sarah for visiting me in Bristol!). Thank you to Tia for helping me to make the life-changing decision to move to Bristol, and then for moving here too! Thank you to Charlotte, my research partner-in-crime, for always keeping things light, fun, and interesting, and for literally providing blood and sweat to help pilot my study! Thank you to Becci for making me feel less homesick when I first arrived in Bristol, and for providing moral and intellectual support throughout the PhD. I would like to thank the other PhD students, especially Miriam, Eleanor, Meg, Andy, Jim, Jane, Rebecca, Emily, Abi, Robyn, Adele, and Kayleigh, and the NBU Crew (Natalie, Roya, Sophie) for their support at work and making Bristol feel like my home.

I would like to thank Dr. Andrea Waylen for her guidance when I designed the qualitative study and her feedback on the written report presented in Chapter 2. I would like to thank Becci Griggs for helping to generate the ideas tested in the online studies and assisting in the data analysis and written report presented in Part 1 of Chapter 5. I would like to thank Andy Brown for his hard work and patience in programming my online studies exactly how I imagined them despite the many logistical hurdles we faced. I would like to thank the University of Bristol School of

Mathematics statistics clinic and Dr. Bobby Stuijfzand for assisting me with the more complex statistical analyses presented in Chapter 5. A special thanks to Bobby who was generous with his time, taught me a great deal about statistics and programming, and gave me feedback on the written report presented in Part 1 of Chapter 5. I would like to thank Harriet Carroll for sharing her knowledge on hydration and helping me with the study design (including piloting) and data collection and analysis for the study presented in Chapter 6. I am very grateful that Harriet drove me all the way to Loughborough while recovering from major surgery! I would like to thank Dr. Lewis James for allowing me to use the facilities at Loughborough University. Thank you to both Harriet and Lewis for assisting me in analyzing the blood samples.

Thank you to Gabrielle, Aunt Debbie, Uncle Paul, Luke, and Hunter, for continuously reminding me of the loving and supportive family I have.

Author Declaration

I declare that the work in this dissertation was carried out in accordance with the requirements of the University's Regulations and Code of Practice for Research Degree Programmes and that it has not been submitted for any other academic award. Except where indicated by specific reference in the text, the work is the candidate's own work. Work done in collaboration with, or with the assistance of, others, is indicated as such.

Any views expressed in the dissertation are those of the author.

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Chapter 1 Introduction

According to the World Health Organization (World Health Organisation, 2015), in 2014 more than 1.9 billion adults, 18 years and older, were overweight. Of these, over 600 million were obese. While these statistics are alarming, studying human decision-making about food and drink is not only relevant to the fight against obesity. Poor nutrition has been linked to an array of other health issues, such as diabetes, cardiovascular disease, cancer, dental disease, osteoporosis (World Health Organisation, 2002), digestive issues, immunology (Round & Mazmanian, 2009), vitamin deficiencies, and mental illness (Bodnar & Wisner, 2005). Furthermore, individuals in the U.K. spend on average 130 minutes a day eating and drinking (including preparation and washing up) (Warde, Cheng, Olsen, & Southerton, 2007) and the complexities of our eating and drinking behaviours can say a lot about us (Sobal, Bisogni, & Jastran, 2014)). Therefore, it would seem crucial to study ingestive behaviour even if poor health was not a concern.

Researchers have been curious about food choice since at least the 1940's (Lewin, 1943). Numerous studies have investigated factors that individuals consider when making decisions about what to eat. These factors include, but are not limited to, macronutrient composition (Day, McHale, & Francis, 2012; Drewnowski, 2004; Geiselman et al., 1998; Gosby, Conigrave, Raubenheimer, & Simpson, 2014; Levine, Kotz, & Gosnell, 2003; Wurtman & Wurtman, 1995), energy density (Drewnowski, 2004; Prentice & Jebb, 2003), unit size (Geier, Rozin, & Doros, 2013), texture (Hogenkamp, Stafleu, Mars, Brunstrom, & de Graaf, 2011; Yeomans & Chambers, 2011; Zijlstra, Mars, de Wijk, Westerterp-Plantenga, & de Graaf, 2008), flavour (Brunstrom & Fletcher, 2008; Griep, Mets, & Massart, 1997) taste (Glanz, Basil, Maibach, Goldberg, & Snyder, 1998; Krebs, 2009; Raghunathan, Naylor, & Hoyer, 2006), smell (Yeomans, 2006), palatability (Pliner & Mann, 2004; Yeomans, Gray, Mitchell, & True, 1997), familiarity (Brunstrom, Shakeshaft, & Scott-Samuel, 2008), health (Bryant & Dundes, 2008; Raghunathan et al., 2006; Wardle et al., 2004), weight control (Glanz et al., 1998), mood (Oliver, Wardle, & Gibson, 2000; Rogers, 1996), cost (Bryant & Dundes, 2008; Drewnowski, 2004; SA French, 2003; Glanz et al., 1998), convenience (Bryant & Dundes, 2008; Glanz et al., 1998), preference for natural (Rozin et al., 2004; Rozin, Fischler, & Shields-Argelès, 2012), and ethical concerns (Michaelidou & Hassan, 2008). Consulting such a vast list of considerations, with many on the list being in direct conflict with one another, would make frequent decision-making about what to eat time consuming and inefficient. Scheibehenne and colleagues (Scheibehenne, Miesler, & Todd, 2007) proposed a simpler route to choice, specifically that individuals avoid trade-offs when choosing foods by using heuristics focusing on their highest priorities.

Significantly less research has investigated beverage choice. Theoretically, many of the factors that contribute to food choices would also contribute to beverage choices. A search of the literature reveals that much of the research surrounding beverage choice has focused on alcoholic beverages (Callinan, Livingston, Dietze, & Room, 2014; Corcoran, 1995; Gruenewald, Ponicki, Holder, & Romelsjo, 2006; Klatsky, Armstrong, & Kipp, 1990; McCann et al., 2003). The focus on alcohol is most likely due to its well-known negative effects on health (World Health Organisation, 2014). However, non-alcoholic beverages have also been associated with negative health outcomes. For example, research suggests that sugar-sweetened beverages are a significant contributor to increasing rates of weight gain (Malik, Pan, Willett, & Hu, 2013; Malik, Schulze, & Hu, 2006) and metabolic disorders (Malik et al., 2010).

Reasons why non-alcoholic beverages may have been neglected in the research is that compared to more traditional beverages (*i.e.,* beer, wine, spirits, milk, coffee, and tea), sugar-sweetened beverages, in the way in which they are consumed today (*i.e.,* not a cup of tea with a spoonful of sugar), are modern additions to our food system (Bellwood, 2005; Hanson, 1995; Heiss & Heiss, 2011; Standage, 2007; Weinberg & Bealer, 2001). In terms of non-alcoholic beverages, observational studies illuminate what individuals are drinking (Almiron-Roig et al., 2013; Drewnowski, Rehm, & Constant, 2013; Forshee & Storey, 2003; Gibson, Gunn, & Maughan, 2012; Ng, Ni Mhurchu, Jebb, & Popkin, 2012; Nissensohn, Castro-Quezada, & Serra-Majem, 2013), but few studies have investigated why individuals are choosing to consume these beverages (Block, Gillman, Linakis, & Goldman, 2013; Mason, Welch, & Morales, 2014; Mueller Loose & Jaeger, 2012).

By understanding the motivations behind eating and drinking behaviours, researchers can more effectively design experiments which will pick up on factors which encourage the overconsumption of energy. Therefore, the first experiment of this thesis was of an exploratory nature. Qualitative data was collected and analysed using a grounded-theory approach. In brief, a grounded-theory approach is data-driven and thus encourages the researcher to collect data without any prior assumptions (Willig, 2013). Accordingly, an extensive literature review was not conducted prior to data collection. Instead, the results of the first experiment guided the literature review and generated theories which were tested in the studies reported in the remainder of this thesis. Therefore, the aims of this thesis will be outlined after Chapter 2.

Chapter 2 Investigating beliefs about food and beverage choice, and associated hunger and thirst

2.1 Introduction

In order to generate hypotheses for future research, the present study was designed to gain a better understanding of the motivations behind ingestive behaviour. An aim of this study was to explore how many factors are considered and which factors are prioritized when individuals make food decisions (*i.e.,* what and when to eat).

In terms of the rationale underlying food choice, other researchers have asked participants to reflect on their typical ingestive behaviour in artificial settings (*e.g.,* focus groups conducted in a room of a school) (Bisogni, Connors, Devine, & Sobal, 2002; Block et al., 2013; Connors, Bisogni, Sobal, & Devine, 2001; Mason et al., 2014). The present study aimed to collect less hypothetical data in a real-world setting. Specifically, participants were asked to discuss actual food choices in the setting where the foods were selected. To my knowledge, two other studies have conducted interviews on food choice in a real-world setting (Furst, Connors, Bisogni, Sobal, & Falk, 1996; Kemp, Insch, Holdsworth, & Knight, 2010). Both studies recruited and interviewed participants while they were grocery shopping. The data collected in these studies is arguably more representative of consumer buying behaviour than ingestive behaviour. As shopping is an iterative process, product choices are tentative until the time of purchase. Interviewing participants after purchasing the food (*i.e.,* once the food choices are finalised) would be more indicative of ingestive behaviour. Nonetheless, food purchased at the grocery store is often not for immediate consumption, and intentions can change during the period between purchase and consumption. In addition, food purchased at the grocery store might be purchased partly for others (*e.g.,* the family), whose motives for food choices and preferences may not be accessible to the purchaser. In an attempt to capture *finalised* decisions about *immediate* ingestive behaviour, participants were interviewed in the setting where the foods were selected and around the time that they consumed or would be shortly consuming the selected foods.

In terms of the rationale underlying the timing of an eating episode, it was anticipated that many of the participants would allude to hunger. Despite the popular usage of ‘hunger’ in the lexicon, it is a rather non-specific concept(Mattes & Friedman, 1993). According to Blundell (Blundell, 1980), ‘hunger’, ‘appetite’ and ‘satiety’ are not objective experiences, but instead are blanket terms used to represent a number of sensations. Previous research has investigated subjective experiences of hunger and satiety using structured questionnaires (Monello & Mayer, 1967), pictoral scales (Friedman, Ulrich, & Mattes, 1999) and focus groups (Murray & Vickers, 2009) revealing that the concept of hunger and satiety are defined by various physiological (*e.g.,* head, mouth, throat, gastric, and overall body sensations) and psychological (*e.g.,* mood, cognition) aspects.

It is popular belief that hunger occurs as a result of low energy reserves which initiates eating as a means to replenish these reserves (Assanand, Pinel, & Lehman, 1998; McKiernan, Houchins, & Mattes, 2008). However, eating does not necessarily occur out of energy depletion (Rogers & Brunstrom, 2016) but as a means to attain pleasure (Yeomans, Blundell, & Leshem, 2004) referred to as hedonic hunger (Lowe & Butryn, 2007), or out of habit (Mattson et al., 2014). In the present study, the aim was to understand if individuals recognize that many of their eating episodes do not occur out of an immediate biological need for energy. Assanand and colleagues (Assanand et al., 1998) investigated the degree to which individuals agreed with the beliefs that feelings of hunger are caused by the depletion of energy resources and that it is healthier to consume daily caloric intake as three meals than as several snacks. However, in that study participants’ responses were hypothetical as they were independent of an actual eating episode. As stated earlier, the intention of the present study was to collect responses that reflected immediate and concrete decisions about ingestive behaviour.

It would be insufficient to investigate hunger, eating, and food choice, without also considering thirst, drinking, and beverage choice. Research demonstrates that about 70-75% of drinking occurs around the time of meals (Mattes, 2010) and inappropriate ingestive events (*e.g.,* reportedly not thirsty but hungry, and drinking but not eating; reportedly thirsty but not hungry, and not drinking but eating) occur around 62% of the time (McKiernan, Hollis, McCabe, & Mattes, 2009). In addition, as highlighted in Chapter 1, research on motivations behind beverage choice is limited. Therefore, this study also investigated how many factors are considered and which factors are prioritized when deciding what and when to drink.

The visual analogue scale (VAS) is the most commonly used measure of appetite (Murray & Vickers, 2009) despite criticism that the VAS has reliability and validity issues (McKiernan et al., 2008; Rolls, Fedoroff, Guthrie, & Laster, 1990; Rolls, Gnizak, Summerfelt, & Laster, 1988; Rolls, Hetherington, & Burley, 1988b; Sibilia, 2010; Stubbs et al., 2000). Further, the VAS does not provide information on which factors of appetite are being considered when deciding on the degree of hunger or fullness. An alternative method is to ask participants to mark on a human figure the extent and locus of hunger sensations (Friedman et al., 1999; Lowe, Friedman, Mattes, Kopyt, & Gayda, 2000). However, this method still limits appetite ratings to those associated with internal stimuli. Therefore, an additional aim of the current study was to disassemble how individuals conceptualize and utilize the appetite VAS. Again, as eating and drinking are associated concepts, thirst scales were analysed as well.

In summary, the present study investigated the factors that underlie what and when individuals eat and drink. Specifically, the present study aimed to gain insight on (1) the beliefs about hunger and thirst which exist and how those beliefs might affect ingestive behaviour and (2) the factors which are considered when choosing foods and beverages for consumption and how those factors are prioritized.

2.2 Methods

In order to better understand experiences of hunger and thirst and decision making about food and beverages, the current study utilized a mixture of qualitative and quantitative methods. The methods were semi-structured interviewing and quantitative data collection of thirst and hunger ratings and food and beverage choice. As the rationale for the study was to generate hypotheses for future research and because no predictions were made about themes that would emerge, a grounded theory approach was applied to the qualitative data collection and analysis (Willig, 2013). An extensive literature review was not conducted prior to data collection to avoid biasing the data collection and analysis with a priori knowledge. Instead, the results were used to guide the subsequent literature review and generate theories surrounding hunger, thirst, food and beverage choice.

2.2.1 Recruitment Procedure

The study settings were university cafeterias during the hours of 12:00 and 14:00 (Monday-Friday). Research assistants approached individuals who had at least one beverage or one food item in their possession and asked if they were interested in participating in a study which entailed talking to a researcher for 10 minutes about their food and beverage choices and beliefs about hunger, thirst, eating, and drinking. Recruiting participants after their food and beverage choices were finalised, ensured that their decision making was not influenced by the knowledge that they would be partaking in a research study. Participants who consented received £2 as compensation. There was a 50% rejection rate and the most common reason for not participating was lack of time (e.g. needing to work during the lunch break or having to attend class or return to work shortly).

2.2.2 Sampling Procedure

Originally, 33 University of Bristol (UoB) students and staff members were recruited from and interviewed in the UoB Social Sciences Café (Experimental Psychology; Economics, Finance, and Management; Sociology, Politics and International Studies) using convenience and snowball sampling. Preliminary analyses (detailed below) were conducted on the interview data to identify the manifest themes. Before beginning the main analysis, additional UoB students and staff members from cafeterias associated with different academic departments and located elsewhere on campus (UoB Engineering Café and the UoB Computer Science Café) were recruited and interviewed. The analysis of the interview data from 7 participants different to the original sample did not reveal novel themes, suggesting that at this stage, theoretical saturation had been achieved (Willig, 2013). As the data set was extensive enough to begin analyses, data collection ceased with 40 participants.

2.2.3 Testing Procedure

The order of the methods was counterbalanced. There were 4 orders with 10 participants in each (detailed in Table 1). The interviews were conducted in the cafeterias always at tables in secluded areas. Each interview took under 10 minutes and was audio-recorded. The audio-recordings were later transcribed verbatim (retaining slang, incorrect grammar, false sentence starts, and pauses when they occurred; hyphens were used to represent any pause or filler word such as “ugh”, “erm” “um”, etc.), using Dragon NaturallySpeaking software (Nuance Communications, 2015) by the interviewer.

Table 1 Interview schedules (counterbalanced orders)

Order A	Order B	Order C	Order D
Food/Beverage choice Free Association Test	Food/Beverage choice Free Association Test	Food/Beverage choice semi-structured interview	Food/Beverage choice semi-structured interview
Food/Beverage choice semi-structured interview	Food/Beverage choice semi-structured interview	Food/Beverage choice Free Association Test	Food/Beverage choice Free Association Test
Hunger rating & explanation	Thirst rating & explanation	Hunger rating & explanation	Thirst rating & explanation
Thirst rating & explanation	Hunger rating & explanation	Thirst rating & explanation	Hunger rating & explanation

The interviews were semi-structured because generally all participants were asked the same questions with a few exceptions. Due to the nature of qualitative interviewing and conducting a study in a real-world setting, interview questions often had to be tapered to fit the individual and the situation. For example, some questions had to be adapted to reflect the stage of consumption (*i.e.,* if the participant was about to start eating, in the middle of eating, or had just finished eating). Alternatively, some participants were consuming beverages without food, and therefore the questions asked to them focused more on drinking and beverage choice. Additionally, some interviews required more probing from the interviewer if the participants seemed unready to respond.

2.2.4 Interview Content

2.2.4.1 Food and beverage choice

Free Association Test (M. Nielsen & Ingwersen, 1999): Participants were informed that they would have 20 seconds to verbally list all words that came to mind when thinking about a particular item (which would be specified by the interviewer at the start of the task). Before beginning the task, the interviewer assured participants that there were no wrong answers and demonstrated how the task worked by using the example “car” with the example responses “fast”, “dangerous”, “mobile”, “technology”, “transportation”, etc. “Car” was selected for the example as it is an item unrelated to food and beverages. Once a participant confirmed that he or she understood the task, the interviewer identified the main component of the participant’s meal (e.g. a sandwich if the meal consisted of a sandwich, a bag of pretzels, and a juice), and instructed the participant to complete the task while thinking about that item. The interviewer transcribed the verbal responses and then asked participants to look over the list and assign a value (very negative, negative, neutral, positive, or very positive) to each word or phrase.

Semi-structured interview: Participants were asked to identify all food and beverages they had in their possession to the researcher. Participants were then asked about when they had or would consume these items and why they chose to consume the item at the specific time. Participants were also asked to clarify if the items were what participants were having for lunch. Lastly, participants were asked why they chose the specific food and/or beverages over alternatives. In some cases, participants were asked about a food/beverage that was no longer in their possession, but they had very recently consumed.

2.2.4.2 Beliefs about hunger and thirst

Quantitative data collection of hunger and thirst ratings: Participants were presented with a VAS, a double-anchored 100 mm line without visible measurements, on a computer screen and asked to rate their current degree of hunger (Not at all Hungry = 0 / Extremely Hungry = 100) and thirst (Not at all Thirsty = 0 / Extremely Thirsty = 100).

Semi-structured interview: After rating hunger or thirst on the VAS, the corresponding numeric value appeared on the top right-hand corner of the screen. The interviewer drew attention to the corresponding numeric value and enquired about the participant's reasons for the rating. Lastly, the participant was asked to think about personal experiences of extreme hunger and were asked to compare them to the hunger they were experiencing or had recently experienced.

2.2.5 Coding Procedure

The researcher read through the transcribed interviews to familiarise herself with the entire data set. Afterwards, the researcher began analysis, using *NVivo,* a qualitative data analysis software package (QSR International, 2012). Initially, the researcher utilized open coding to broadly identify the manifest themes in the data (see Table 2). As stated earlier, additional data was collected (from interviewing new participants) to ensure that theoretical saturation was achieved at this stage. The researcher then began a more analytical coding of the data. The original themes were aggregated and refined (Willig, 2013) by identifying negative and positive aspects of each theme (e.g. separating health into responses that referred to being healthy and responses that referred to being unhealthy) and documenting when themes emerged (e.g. in response to which questions; after what amount of probing). Two additional researchers independently read the transcripts, coded the data using already established codes or creating novel codes when necessary. Interrater reliability (Cohen's kappa coefficient) was found to be 87% or higher (values of 81-100% are regarded as indicating almost perfect agreement, (Landis &

Koch, 1977)). As the coders agreed that theoretical saturation had been achieved, additional interviews were not conducted. Lastly, matrix coding queries were run to observe (1) the relationship between the hunger and thirst ratings and the themes that emerged in the reasons given for these ratings, and (2) the relationship between the themes that emerged during the free association test and the valence ratings.

Table 2 Open coding – manifest themes

Appetite	Fullness Hunger Thirst	
Psychological experiences	Boredom Cognition Conscious vs. Subconscious Liking Moodiness	Overreaction Pleasure or comfort Stress or guilt Want or craving
Physiological experiences	Body Head Mouth / throat Stomach / intestines	
Characteristics of food/beverage	Appearance Brand Cuisine Familiarity Fillingness Ingredients Odour	Portion Size Production Processed Quality Taste Variety or exoticness
Temporal or situational factors	Accessibility Comparison to past or future meals Convenience Environmental temperature Habits Illness	Location Meal (lunch vs. breakfast or dinner) Monetary cost Social influence Time of day
Internal consequences	Dietary restriction Gain or loss of fat or muscle Health or nutrition	Medicinal Necessity Physical attractiveness
External consequences	Animal welfare Environmental concerns	

2.3 Results

2.3.1 Participants

Of the 40 participants who took part in this study, 19 were male and 21 were female, aged 19-34 years (M = 22.0 ± 3.74). Seventy-three percent of the sample had completed A levels, Scottish Highers, or Equivalent; 18% held a BSc, BA, etc.; and 10% held a Higher Degree. Eighty-five percent of the sample identified as Caucasian, 8% identified as Mixed/Multiple ethnic groups, and 8% identified as Asian/Asian British. Participants originated from Australia, Brazil, Ireland, Israel, Italy, Malaysia, Norway, Russia, Switzerland, and Zambia, with a majority originating from the United Kingdom (73%). While two participants originating from other countries had lived in the U.K. for 10 years or more, the majority had only lived in the U.K. for 2 years or less. Participants' BMI scores, based on self-reported weight and height, ranged from 17-35 (M = 22.34 ± 3.67) kg/m^2. Twenty percent of the sample was currently dieting: 10% to lose weight, 2.5% for medical reasons, 2.5% to be healthy, 2.5% for animal ethics, and 2.5% to build muscle. Twenty-two percent of current non-dieters had dieted in the past year to lose weight.

2.3.2 Hunger

Hunger ratings. Hunger scores ranged from 0 to 86 (M = 40, Mdn = 46, SD = 30). Fifty percent of responses referred to when they last ate. Thirty-four percent of responses included phrases such as I need/do not need to eat, I want/do not want to eat, I can/cannot wait to eat, I could/could not eat, and I should/should not eat. Twenty-six percent of responses referred to physical feelings (*i.e.* experiencing rumbling, emptiness, bloating, or fullness in the stomach).

> "I can - It's a physical feeling - I had a piece of toast at 9:00 so I feel like 'well it's time to be hungry again' and I feel physically empty."

> "Um, because I feel that at the same time as me feeling that I want to eat right now, I could go... For a lot longer without actually eating. I do not really need to eat right now."

Participants who chose ratings close to "Not at all hungry" alluded to nearing the end of a meal or recently finishing a meal. They described physiological experiences, such as feeling the food, or more generally, "fullness", in the stomach. They also referred to psychological experiences, such as stress or disinterest in food leading to a reduction in appetite. They mentioned that although they were full or had no desire to eat, they could continue to eat. Those who chose the lowest possible rating, "0", explained that they did not feel "ready to eat" or able to move due to fullness. There was one exception: someone who believed it was possible to feel fuller despite selecting the minimal rating of hunger.

Participants who chose ratings near the midpoint suggested that they were moderately hungry. They supported this claim by highlighting the time of day, the length of time that elapsed since they late ate, or the amount that they had eaten at their last meal. However, participants also trivialised their experiences of hunger by stating that they did not need to eat and could wait to eat. They supported these claims by comparing their hunger at the time of the interview to experiences when they were too hungry to postpone eating. One participant below the midpoint explained that thinking about and discussing food caused him to feel less hungry. Whereas, participants just above the midpoint referred to how thoughts and discussions about food could intensify their feelings of hunger. Participants who rated their hunger just above the midpoint made references to physiology (*e.g.,* the stomach feeling empty, that the individual felt ready for an energy boost, and that recent exercise increased appetite).

Participants who chose the highest hunger ratings gave reasons such as: low energy levels, poor concentration, time of day, and eating less (referring to amount or frequency) than usual. There were also references made to always feeling hungry or that eating increases appetite.

Hypothetical experience of hunger: Many of the participants with low hunger ratings were asked (independently of the hunger scale) hypothetically about how they recognize when they are hungry. Out of the 14 participants queried, 100% referred to physiological (stomach-ache, stomach rumbling) or psychological (cravings, fatigue, moodiness, inability to concentrate) symptoms.

Experience of extreme hunger: Each participant was asked to recall a personal experience of *extreme hunger* and compare it to their current experience of *everyday hunger*. There was much consensus among participants about experiences of *extreme hunger*: participants described their experiences as “horrible” and “painful”. More specifically, they struggled with dizziness, headaches, weakness, fatigue, nausea, and abdominal pain, cramping, and emptiness. They were stressed, angry, and frustrated. Their thoughts were consumed by food and they were unable to concentrate. They felt drained of energy and as though they might faint. They felt unable to engage in conversations and easily lost their temper with friends and family members.

Their experiences tended to revolve around themes of accessibility (*e.g.* hiking up a mountain or travelling by train where there was no access to food for a long period of time). Many of these experiences were intensified by the fact that the individuals were physically exerting themselves, like hiking or playing sport, or mentally exerting themselves, like staying up all night to meet a deadline for school or work. Participants explained that they felt fearful or anxious because they did not know where their next meal would come from or when they would be able to eat again. Some individuals explained that the situation was made worse because they had started off with a strong expectancy to eat and then were denied access to food. For example, a few discussed their privilege in having constant access to food. Therefore, they felt frustrated by the fact that they did not live in a deprived area of the world, yet were unable to access food for a period of time. One participant who stated that “it felt like starvation” recognised that his undesirable experience was more likely due to his expectations not being met, rather than his body requiring energy. Others felt frustrated with themselves for not better preparing, such as eating before a hike or stocking up on groceries before staying up all night to meet a deadline.

Many participants discussed the overwhelming desire to “cram food in [their] face[s]” with little concern over what it was they were eating and the immense feelings of happiness and pleasure that set in once they had eaten. One participant described the impulsive behaviour as “the kind of feeling like you get when you are a child and want something to eat.” Conversely, a handful of participants described their experiences of extreme hunger as “satisfying” since they “succeeded in overcoming [the] urges”, were “detox[ing]”, and felt that they could concentrate better. Several participants also explained that as time passes they habituated to the uncomfortable feeling of hunger, reaching a point where they no longer felt hungry or they forget that they were hungry.

When asked to relate their personal experiences of *extreme hunger* to the hunger they felt currently or had felt before lunch, a little over half of the participants declared that these two types of hunger were incomparable. When experiencing *everyday hunger,* some participants did believe that their bodies required energy, but most participants felt "quite comfortable" and were able to postpone eating. They added that they only needed to eat to concentrate on their work or that their experience of *everyday hunger* had more to do with their usual eating habits, time of day, or anticipation of hunger than it did true hunger. Many participants believed that their experience of extreme hunger, although extreme for them, was not an absolute extreme. They described the most extreme experiences of hunger that they could imagine arising from not eating for days or weeks; being stranded in a desert or somewhere with no access to food; living in poverty or being surrounded by food but unable to have it; the after-effects of intense physical labour or being under immense stress; and being close to starvation or death. A handful of participants discussed being thirsty and/or not having access to water as a factor that would exacerbate the situation.

2.3.3 Food choice

A majority of participants (35 out of 40) had just eaten, were in the middle of eating, or were about to eat at the time of the interview. Participants were asked about why they were eating now versus later or vice versa. Fifty-four percent spontaneously reported that the chosen time was most convenient, whereas only 17% spontaneously reported feeling hungry. However, once including responses after participants were probed and prompted by the interviewer in the analysis, 66% reported convenient time and 57% reported hunger. Participants were also asked why they chose to ingest the specific items that they had in their possession. 54% of participants referred to taste, 51% referred to convenience, 47% referred to health or nutrition, 43% referred to cost, and 40% referred to how much they liked the item. 31% referred to the variety or exoticness of their food item(s), 26% of participants referred to how filling an item was and 26% of participants referred to how much energy an item would provide. Each participant listed between 1 and 6 reasons ($M = 3.56 \pm 1.40$) for his/her choice of food (including responses given after being probed or prompted by the interviewer).

2.3.4 Thirst

Thirst ratings. Thirst scores ranged from 5 to 91 (*M* = 51, *Mdn* = 55, *SD* = 25). Sixty-seven percent of participants reported that they based their ratings on when they last drank or how much they had drunk so far that day. Twenty-six percent reported that they based their ratings on eating recently (especially eating something salty).

> "Probably because I had a glass of water not too long ago. I feel quite well hydrated."

> "I think it's probably also just knowing how much I've had today in terms of water and liquids and things. Probably, I kind of feel like I should have a drink as well"

> "I'm a little more thirsty considering I just had some food and I would like to wash it down with some water, but in the grand scheme of things, not thirsty. "

> "Why I'm not completely not at all thirsty, is that these sandwiches are probably quite salty - they have a lot of cheese and ham, so those things kind of make you quite thirsty."

Individuals with low thirst ratings: Participants who chose ratings closer to "Not at all thirsty", discussed recently having a drink or that they had been drinking a lot throughout the day. Additionally, some mentioned not feeling thirsty because they had a drink with them that they knew they could drink whenever needed. Many described their low degree of thirst as not needing nor wanting to drink (clarifying that they would not go out of their way to seek out a drink but that they could drink or would not mind drinking if there was something available).

Participants who chose ratings closer to the midpoint (but still below it): mentioned many of the themes above, but also discussed being somewhat thirsty. They referred to recent eating (usually something salty and/or dry); drinking alcohol the previous night; currently drinking something that was not thirst-quenching; having a dry mouth; and not drinking recently or enough that day.

Individuals with high thirst ratings: Participants who chose ratings just above the midpoint, also discussed recent eating and having a dry mouth or throat. Despite choosing ratings near the higher end of the scale, some participants mentioned that recent drinking or drinking a lot throughout the day had led them to feel as though they did not need a drink at that time. Whereas, others mentioned not drinking recently or much throughout the day had led them to feel like they do not drink enough and need to drink more. Having a drink accessible was mentioned by a participant in this group as well, but in this case the drink had not yet been opened, so it was not immediately accessible. Therefore, the participant's expectations about drinking led to an increased thirst. Others in this group reiterated this theme of thoughts and expectations about drinking leading to increased thirst. Two other themes introduced by this group of participants were: recent exercise leading to increased thirst and feeling the urge to have a drink.

Participants who chose the highest ratings reiterated: recent eating; lack of drinking; dry mouth; thinking about drinking; and feeling the urge to have a drink. New themes introduced by this group were: the dry air of the environment or the physical act of talking leading to a dry mouth. In addition, accessibility was discussed again. For example, a participant explained feeling thirsty, because he had forgotten to fill up his water bottle, and had been walking around with an empty water bottle all day. Another participant who was on break from work stated that she was currently thirsty because this was the only time she had access to a drink.

Hypothetical experience of thirst: The interviewer was a bit surprised that more participants did not refer to physical (e.g. dry mouth, headache) and psychological (e.g. craving for water) factors when explaining their thirst ratings. Therefore, most participants (32 out of 40) were asked (independently of the thirst scale) hypothetically about how they recognize when they are thirsty. In response to this question, 27 participants referred to physiological and psychological factors. Eighty-five percent of those participants reported that they knew based on physical sensations or symptoms (*e.g.,* dry lips/tongue/mouth/throat/eyes, headaches, dizziness/ light-headedness, weakness, fatigue, etc.) and 33.3% discussed an indescribable mental sensation which signals to them that they want or need to drink (usually water).

2.3.5 Beverage choice

Twenty-four out of 40 participants had recently ingested, were ingesting a beverage (or two) at the time of the interview, or would be ingesting a beverage (or two) after the interview. Each of these 24 participants was asked to explain the rationale behind his/her beverage choice. The beverages included were: water (n = 12), coffee & tea (n = 9), and caloric beverages (n = 9) such as fizzy drinks, juices, sports drinks, and smoothies. Forty-six percent reported choosing their beverages to obtain energy (from sugar, calories, caffeine or the refreshing nature of consuming a liquid).

> "Because I didn't really eat that much for breakfast so I feel like I should-- even though I'm not hungry - I should get something in my body."
>
> "I do drink a lot of water, but sometimes if I just need an extra kick to get me through the day, I may just have a bit of sugar as well."
>
> "I went for the coffee because I am really tired and needed a bit of a boost."
>
> "It's just a really simple, cheap way of keeping your mind really active in lectures - just a - whenever you feel yourself drifting off a little bit, just take a sip of water and then it seems to focus you a lot…"

Thirty-eight percent reported choosing their beverages for taste. Thirty-eight percent reported choosing their beverages to hydrate (including to maintain hydration, quench thirst, or cure a hangover). Twenty-five percent of participants referred to health or nutrition and 25% of participants referred to cost. Each participant listed between 1 and 6 reasons (M =2.41 ± 1.50) for his/her choice of beverage (including responses given after being probed or prompted by the interviewer).

2.3.6 Free Association Test

In the free association test, thirty-five food items and five beverage items were discussed. Each participant listed anywhere from one to seventeen words or phrases (M = 7.5 ± 3.21) during the twenty-second time frame to describe his or her item. Each participant revealed one to nine themes (M = 5.4 ± 1.72). Generally, the words or phrases described the item (*e.g.,* filling) but a few responses described something associated with the item (*e.g.,* monkey when the item was a banana). In order to compare the responses from the free association test with the semi-structured interview, only food items were included in the analysis, as only five of the forty items included in the free association test were beverages. The results are summarised in Table 3.

Table 3 Most commonly reported responses during Free Association Test (for food items) separated by valence ratings

FAT results	Very negative	Negative	Neutral	Positive	Very Positive
Health/nutrition (69%)	unhealthy, not that healthy, carbohydrates	pretend-healthy, too much potassium		healthy, wholesome, nutritious, vitamins, minerals, proteins, carbohydrates	healthy, nutritious, proteins, 5 a day
Taste (66%)		too salty	salty, meaty, fishy	sweet, salty, savoury, tasty	tasty
Ingredients (63%)	carbohydrates	carbohydrates condiments sweets	carbohydrates condiments fruit meat sweets vegetables	carbohydrates cheese condiments meat oats proteins smoothies vegetables	carbohydrates cheese condiments eggs fruit meat proteins vegetables
Texture (26%)		dry	soft, creamy, flaky	quite slimy, quite gooey	crunchy, chewy, not dry
Fillingness (29%)		too much of it	filling	filling	
Cost (23%)	expensive, overpriced	expensive		cheap, well-priced, meal deal	good price, freebie
Quality (23%)	overcooked, stodgy	mediocre, leftovers, stodgy		well-made, natural, clean	fresh, natural
Temperature (23%)		cold	warm	warm, hot	warm
Colour (20%)	brown	beige, plain	yellow	yellow, white	green, yellow

2.4 Discussion

2.4.1 Hunger

The meal habits of individuals living under ad-libitum conditions are not likely governed by short-term energy balance (Lowe & Butryn, 2007; Rogers, Ferriday, Jebb, & Brunstrom, 2016; Yeomans et al., 2004). In this study, one sixth of participants spontaneously reported hunger as a reason for eating. In comparison, just over half of participants spontaneously reported that they were eating because it was a convenient time for them. Considering those participants who reported hunger as a reason for eating after prompting from the interviewer, a little more than half of participants did discuss hunger as a reason for eating. However, none of the participants referred to an internal indication of hunger (*e.g.*, experiencing a rumbling stomach or feeling faint).

It is a widely held belief that eating three meals a day is an essential part of maintaining a healthy lifestyle (Assanand et al., 1998; Casazza et al., 2013). However, research demonstrates that there is little evidence to support this claim. Eating three meals a day is only characteristic of modern societies. This meal pattern seems to have evolved because of (1) prolonged hours of illumination due to the invention of artificial light, and (2) altered work schedules that were established after the agricultural revolution. In fact, eating three meals a day may be detrimental to health, as animals normally fed ad-libitum and humans used to eating three meals a day both show remarkable improvements in health when switched to an intermittent energy restriction diet (Mattson et al., 2014). Many of the participants in this study held the belief that we need to eat three meals a day, made evident by statements such as, “Your body knows what time it's supposed to have dinner, what time it's supposed to have lunch, and what time it's supposed to have breakfast and if you miss one of those meals or have one of those meals late then you get really really hungry.” Perhaps, lunch is often consumed at the most convenient time around midday even if hunger levels are low because it allows for three meals to comfortably be consumed in a single day. In other words, refraining from eating the afternoon meal too late in the day safeguards against feeling too full to eat the evening meal.

Eating three meals a day may also be a strategy to stave off hunger. If individuals eat to avoid hunger from occurring in the first place, this then begs the question, “Can we recognize when we are hungry?” All of the participants who were asked hypothetically how they know when they are hungry, referred to physiological and psychological symptoms. However, when participants were asked to explain the rationale behind their ratings on the hunger scales, only one quarter of participants referred to an internal experience. In contrast, one half referred to when they last ate. Similar to the explanations participants gave for why they were eating, their explanations for how they knew whether or not they were hungry relied on a concept of an ideal eating schedule more often than internal cues. For example, one participant stated, “I had a piece of toast at 9:00, so I feel like it’s time to be hungry again” and another stated, “Cause it’s been a while since I had—the last meal I ate was dinner—so I know that I should be hungry at this point in time.” Other researchers have heard similar responses during informal discussions on the rationale behind hunger ratings: participants referred to feeling full or empty, but also frequently mentioned how long ago they last ate, how large their last meal was, and whether or not it was currently close to a time that they would usually expect to eat (Rogers & Hardman, 2015).

Earlier work has largely focused on stomach, head, and body sensations to measure appetite (Friedman et al., 1999; Mattes & Friedman, 1993; Mayer, Monello, & Seltzer, 1965; Monello & Mayer, 1967). More recently, participants evaluated foods and beverages and reflected on their views of hunger and fullness on an empty stomach to prepare for focus group discussions (Murray & Vickers, 2009). In contrast with the results presented in this chapter, participants defined hunger as a composite of physiological and psychological sensation; most agreed that they began eating as a result of these sensations, while fewer participants referred to “time, routine, the options of food available, and the desire to stop and take a break to eat” as reasons to begin eating (Murray & Vickers, 2009). The contrasting results might be due to the hypothetical nature of the questions posed in Murray and Vickers’ study (*e.g.,* “How do you define hunger?” “How do you know when you are hungry?”) compared to the questions posed in the current study (“Why are you eating?” and “Why did you rate your hunger as ‘x’ “?). In fact, in the current study, some participants discussed hypothetical reasons for recognizing when they are hungry or why they eat; similar to Murray and Vickers' results, they too, referred to physical or mental sensations

Not only the initiation of eating, but the cessation of eating seems to be controlled by a culturally defined concept of the meal. Participants who were in the middle of consuming a meal during the interview tended to rate their degree of hunger around the midpoint. They discussed that they knew they were still hungry or that they desired to continue eating even if they were full simply because the meal was not finished. For example, one participant stated "if I was to think about it rationally, I'd have to say, I've only had half, well three quarters of the sandwich, I haven't yet had any fruit, and I've only finished half of my drink," and another stated, "Because I'm halfway through eating my sandwich. And…um…mainly because although I wasn't hungry when I first bought it, now that I've started eating it—and sort-of because I haven't quite finished my meal—I know that I'm still hungry and I'd like to finish it." In fact, research has shown that energy intake in a single meal is governed by the portion size one is served (Diliberti, Bordi, Conklin, Roe, & Rolls, 2004; Rolls, Morris, & Roe, 2002). These findings are consistent with the results of Murray & Vickers' (Murray & Vickers, 2009) focus group discussions. In that study, participants referred to "when all the food was gone, when the time allotted for eating was over, and when a loss of appetite or loss of desire to eat a particular food occurred" or for dieters, when their nutritional needs were met.

While it was not immediately evident whether participants were cognisant that the majority of their eating episodes were unnecessary from an energy standpoint, many of the participants did distinguish between needing to eat and other states such as being able to eat, feeling as though they were supposed to eat, or wanting to eat. Ancestral humans met their energy requirements despite an inconsistent food supply. The ability to eat whenever regardless of hunger and fullness states allowed those individuals to eat enough during periods when food was readily available to compensate during food shortages (Chakravarthy & Booth, 2004; Mela & Rogers, 1998; Neel, 1999). Therefore, modern humans likely share this ability to eat despite their stomach feeling full, or even quite painfully full, and having enough energy reserves for the time-being (Cornell, Rodin, & Weingarten, 1989; Rogers & Brunstrom, 2016).This might explain why many participants discussed not needing to eat, but feeling like they were able to, wanted to, or were supposed to eat. A handful of participants admitted that the urges to eat they feel on an ordinary day had little to do with necessity but more to do with habits and expectations, “I kind of do it by convention by this point” and “You could say, it’s a habitual thing, it’s lunchtime.”

The one exception to always being able to eat would be eating immediately after a large meal when eating more could be highly debilitating to the individual due disruption of bodily homeostasis (Woods, 1991). In this study, none of the participants responded that they felt so full that they could not eat anymore. Instead, participants who chose ratings closest to “Not at all hungry”, stated “I feel really full, but if it came to it I could probably still eat,” “It’s not like I’m stuffed and I couldn’t eat anything else. Like, if you gave me a chocolate bar I could eat it at this point, ha ha. But, I’m not hungry anymore,” “So I'm not that hungry. But I could probably eat a little bit more,” and “I probably could eat some more if I was given food. But you know, I'm not immediately hungry right now.” For modern humans, overeating in a single instance does not pose any immediate risks (Woods, 1991), other than impair later performance (*i.e.,* feeling sluggish), which might help to explain why some individuals are able to continue eating despite feeling full.

Of the participants who referred to needing to eat their lunch that day, some believed that abstaining from food might affect their mood and concentration, but not to the extent of causing incapacity. The only instance in which participants thought skipping their lunch would be detrimental was before or after exercise. According to a sports nutritional guide, exercising on an empty stomach could put an individual at risk of hypoglycaemia and can lead to premature fatigue, fat and muscle loss (Bean, 2009). However, recreational exercise can be compared to the physical activity required to escape predation and hunt-and-gather food in ancestral human populations. During times of famine, ancestral humans needed to continue to expend large amounts of energy (to hunt, forage, and evade predators) in order to survive. Therefore, ancestral humans who were more capable of conserving muscle glycogen, which could provide rapid energy, would have had a survival advantage (Chakravarthy & Booth, 2004). In fact, some research has demonstrated benefits to exercising on empty stomach (De Bock et al., 2005, 2008; Proeyen, Szlufcik, Nielens, Ramaekers, & Hespel, 2010), suggesting that modern humans evolved the ability to exercise while in a fasted state.

Nonetheless, eating immediately before exercise is not ideal either. During digestion, blood flow is concentrated on the stimulation of gastrointestinal motility and transit. If an individual is physically active during digestion and absorption, these processes are affected due to the redirection of blood flow to the skin and muscles and may result in adverse effects such as gastrointestinal discomfort (Brouns & Beckers, 1993). Therefore, sports nutritionists advise eating two to four hours before physical activity to allow the stomach time to settle (Bean, 2009).While eating prior to physical activity provides a ready supply of glycogen (Chakravarthy & Booth, 2004), the timing of the pre-exercise meal matters and the participants in this study did not make this distinction.

In regards to participants' opinions that refraining from eating after exercise would pose a risk to the individual, sports nutritionists do advise eating after exercise in order to replenish depleted stores of glycogen (Bean, 2009). However, eating immediately after exercise is likely to be inhibited as research has demonstrated an anorexigenic effect of exercise (Blundell & King, 1999; Brownell & Stunkard, 1980; Jaworowska, Blackham, Stevenson, & Davies, 2012; King & Blundell, 1995; King, Burley, & Blundell, 1994; King, Lluch, Stubbs, & Blundell, 1997; King, Snell, Smith, & Blundell, 1996; Lluch, King, & Blundell, 1998; Thompson, Wolfe, & Eikelboom, 1988). The disadvantage to eating after exercise is that the exercise is likely to mobilize endogenous fat and carbohydrate fuels into the blood; therefore, eating a meal immediately after exercise would further increase fuels in the blood and stress the metabolic system (Woods, 1991). This suggests that while refueling might be necessary, not only is it not urgent, but it may also be beneficial to delay. Further, the need to refuel after exercise is likely dependent on the intensity of the exercise. Most individuals (with the exception of athletes) are unlikely to regularly participate in vigorous exercise. Therefore, for most individuals the amount of energy expended during moderate exercise is insignificant compared to the amount stored in energy reserves (Rogers & Brunstrom, 2016). As a result, eating after mild to moderate exercise is probably unnecessary and may inadvertently increase energy balance. Participants in this study did not mention the intensity of exercise in their claims, making it unclear whether they were aware that the effect of missing a meal after exercise would depend on the intensity of the exercise and the timing of the meal.

Previous research demonstrates that individuals are more likely to report a greater amount of physical sensations when imagining extreme hunger compared to imagining ordinary hunger occurring 30 minutes before a meal (Monello & Mayer, 1967). Further, ordinary hunger is primarily characterized by physical sensations related to the stomach, whereas extreme hunger was primarily characterized by physical sensations related to the head and sensations related to psychological state (Murray & Vickers, 2009). In the present study, when participants were asked to imagine occasions when they did or could possibly experience extreme hunger or starvation, they recalled or predicted the experience being mentally and physically brutal. Once they considered these brutal scenarios, almost all participants declared that their day-to-day hunger was inconsequential and most likely rooted in habit. For example, a participant stated, “I don't necessarily think that [thinking about true starvation] would change how you feel or how you react to not eating [on a regular day] because you are in that pattern. Um, but I do think that perhaps, sometimes, we do say phrases like, 'Oh, I'm starving’, and you're not actually. So I guess we do, perhaps, overreact a bit to that. But then I do think that's because of the pattern you are accustomed to.” Many participants alluded to the fact that they had never experienced poverty or famine and that they ate regular meals. Therefore, it is unlikely that the hunger sensations they typically experience are due to energy depletion (Rogers & Brunstrom, 2016). Instead, the daily expectation to eat moderate amounts of food regularly spaced over intervals makes the actual or imagined experience of food being inaccessible (even if only for a limited amount of time) extremely frustrating. Therefore, indicators commonly associated with hunger, such as light-headedness, poor concentration, and moodiness, may often be a consequence of not being able to eat when one expected to.

Many participants agreed that hunger can be easily ignored if short lived or the individual is sufficiently distracted. However, as times passes the intensity of hunger, and therefore the impulse to eat, intensifies. For some, this experience can become so unbearable that they are willing to eat anything, even if they are normally food neophobic. They described the experience of eating at last as pure bliss. For others, the increase in hunger and desire to eat, while intense, is tolerable. They described feeling extremely accomplished from fighting the impulse and refraining from eating. Several participants added that the intensity of hunger eventually reaches a peak, weakening or dissipating entirely. They noted that at that point, ignoring hunger is quite an accomplishable feat. One reason why individuals can have such contrasting experiences may depend on whether the food restriction is enforced by another (*e.g.,* on-board a cross-country train that is not serving food) or self-imposed (*e.g.,* working through lunch to meet a deadline). For example, people with anorexia do not report feeling overwhelmingly hungry whereas individuals who have experienced semi-starvation while incarcerated report increased hunger and preoccupation with food (Mela & Rogers, 1998).

Although uncommon, some participants did refer to an internal bodily experience when explaining how they rated their hunger. It is possible that individuals mistake internal bodily cues such as an empty stomach to mean they immediately require energy. In reality, the feeling of an empty stomach may simply signal to the individual that he or she could eat (*i.e.,* because the previous meal has emptied from the stomach and has been largely digested and absorbed) but not that he or she needs to eat (*i.e.,* because the body's energy reserves are low).

2.4.2 Thirst

Primarily, we drink to hydrate our bodies either because we currently feel thirsty or believe we may be dehydrated, or we are attempting to prevent future thirst or dehydration. When asked how they recognize thirst in a hypothetical situation, two thirds of participants referred to a physiological sensation, a psychological sensation, or both. Overall, these physiological and psychological indications of thirst seem to be universally experienced, but are also difficult to describe. Therefore, the experience of thirst seems more primal and innate than everyday hunger. For example participants stated, “You can just kind of feel it in your mouth…I don't know how to describe it more than that,” and “There's a sort of feeling that I don't know how to describe – just a need for something to drink”, “I can't really describe it in any other way than saying I just feel thirsty,” “A sort of sensation which says have a drink," "Because my body tells me that I need to drink something – usually [with] a sensation," and "I feel like I want to drink, consciously I think that".

Participants' explanations of their thirst ratings, however, largely did not support their hypothetical claims that they relied mostly on physiological and psychological sensations to detect thirst. Instead, participants who did not feel thirsty made comments such as, "I've been drinking all day", or "I had a glass of water not too long ago". Similarly, those participants who did feel thirsty gave explanations such as, "I haven't had a drink since about 10:00" or "I've not drunk anything today besides coffee". Participants who felt thirsty also talked about their usual drinking behaviour, "I don't drink enough anyway, so I think I'm probably always quite thirsty", and compared the amount that they drank that day to their usual behaviour, "I probably drink a litre of water a day so I probably feel like I'm quite low [today]". Another common response among participants who felt thirsty involved recent eating. Therefore, as we saw with eating behaviour, it is possible that when deciding when one should or need to drink, individuals may focus less on the body's internal signals and more on how long ago they last drank (or in some cases, ate).

When participants described experiences of extreme hunger, they often referred to situations when they were unable to access food. Some were anxious about where and when they would next eat, while others were irritated because they were used to being able to eat wherever and whenever. Likewise, participants' experiences of thirst were associated with concern over the accessibility of fluid. Participants who did not feel thirsty gained confidence in their claim of low thirst if they were carrying a beverage at the time of the interview, "I know I have a water in my bag" and "Because I carry water around with me. That's one thing I make sure I have every day". Similarly, participants who did feel thirsty blamed not having immediate access to fluids as part of the problem, "Because I have bought a bottle of water, but I haven't opened it yet," and "I forgot to fill up my bottle of water. I thought it was filled already. Yeah, I came to school with an empty bottle and haven't gotten a drink yet."

Others have proposed that living in an environment where food is always so readily available, has made many individuals desensitized to internal cues of hunger (Herman, 1987; Hetherington, 2007; Schachter, 1971). Individuals with ad-libitum access to food rarely go very long without eating. The hunger they experience is more likely to be 'hedonic hunger' than true homeostatic hunger (Lowe & Butryn, 2007). Further, Rogers & Brunstrom (2016) argue that there is no 'hunger' signal related to short term energy depletion. McKiernan and colleagues (McKiernan et al., 2009) have suggested a similar profile of thirst and drinking behaviour. Research has shown that sugar-sweetened beverages, low-energy-sweetened beverages, sports drinks, coffee, tea, etc., effectively hydrate us just as well as water does (Tucker et al., 2015). With the exception of underdeveloped nations and impoverished communities, most individuals have ad-libitum access to an array of these beverages (Gibson et al., 2012), and they drink a beverage with every meal and sometimes between meals as well (Mattes, 2010). In addition, the biological mechanisms that regulate hydration status are exceptionally efficient. When the body's osmoreceptors detect low plasma osmolality, they signal the release of the hormone, vasopressin, which works to restore water balance (e.g. by concentrating the urine or reducing urine secretion) and they initiate thirst, which encourages drinking. However, the threshold for the initiation of thirst is much higher than it is for the secretion of vasopressin, so thirst is only initiated if vasopressin is failing to restore the water balance (Robertson, 1984). Therefore, it is believed that most individuals living under ad-libitum conditions (perhaps with the exception of the elderly, those working strenuous jobs, and those living in extremely warm climates) are almost always adequately hydrated (Tucker et al., 2015; Valtin, 2002). It is even possible that individuals living under these conditions drink more than they actually need to, perhaps in anticipation of thirst (SJ French, Read, Booth, & Arkley, 1994; Phillips, Rolls, Ledingham, & Morton, 1984), but that over-drinking goes largely unnoticed as the body is very efficient at eliminating excess water (Nicolaidis, 1998; Popkin, D'Anci, & Rosenberg, 2010). In parallel with the suggestion for hunger, perhaps we have become somewhat desensitized to detecting thirst because many of us rarely experience true thirst. Researchers have argued that as of now, there are no adequate biomarkers to assess hydration status (Armstrong, 2005, 2007; Popkin et al., 2010; Shirreffs, 2003) and often the measures of subjective thirst do not match up with the biomarkers (Mattes, 2010; Shirreffs, Merson, Fraser, &

Archer, 2004) and ingestive events (McKiernan et al., 2009). Since individuals may not be that sensitive to slight changes in hydration status, measures of subjective thirst might simply be inaccurate, explaining why they do not correlate well with the biomarkers.

2.4.3 Food & Beverage Choice

Responses from the free association test were compared with responses from the semi-structured interview. As stated earlier, only food items were included in this comparison analysis. Both techniques revealed that taste was the highest priority during food choice. Both techniques also demonstrated that health or nutrition, and how filling a food is, are popular considerations during food choice. How the results differed was that the free association test found that participants prioritized the ingredients and texture of the item. Participants are likely to have retrieved highly accessible properties of the food items during the free association test as this task required them to describe the item under time constraints. On the other hand, the semi-structured interview allowed participants to be more reflective about their food choices, and themes such as convenience, cost, liking, variety or exoticness, and how much energy the food would provide, were highlighted. Regardless of technique, no participant considered more than six factors, even when probed or prompted by the interviewer, when describing their food and beverage choices.

The semi-structured part of the interviews revealed that when making choices about food, the most common factors which participants considered were taste, convenience, health or nutrition, cost, liking, variety or exoticness, how filling an item was, and how much energy an item would provide. When making choices about beverages, the most common factors which participants considered were how much energy an item would provide, taste, hydration, health or nutrition, and cost. Similarly, previous research on beverage choice in the United States demonstrated that caregivers of young children prioritize taste, cost, and then health and nutrition (Mason et al., 2014) and that university students prioritize taste followed by cost, with much less of a focus on health and nutrition (Block et al., 2013). The caregivers never referred to hydration, while the university students referred to hydration only when discussing water (Block et al., 2013). Therefore, it appears that many individuals drink, not to hydrate, but to obtain energy, enjoy the taste of, or to benefit their health or nutrition. In this study, while taste was mentioned only when referring to flavourful beverages, it was not necessarily the case that hydration was mentioned only when referring to water and that energy was mentioned only when referring to caloric beverages. Some participants referred to caloric and caffeinated beverages as hydrating and thirst-quenching. Others referred to water being able to energise them, *e.g.,* "whenever you feel yourself drifting off a little bit, just take a sip of water and then it seems to focus you". However, participants did not refer to the degree to which water would energise them (compared to a caloric beverage or food). Several participants in Murrary & Vickers' study (2009) discussed water lacking "the same energized feeling that food provides".

Simply defined, a food is a medium which brings energy into the body and a beverage is a medium for hydration. With these definitions in mind, it became clear that participants in this study were conceptualising and treating many beverages as if they were foods. What was not made clear was whether participants were aware of the distinction between food and beverage. On one hand, some participants were simultaneously consuming more than one beverage, each for a different purpose (*e.g.*, water and coffee). They distinguished between water and flavoured/caloric beverages, *e.g.,* "I don't find drinking coffee that thirst-quenching so I'd possibly have a drink of water now". Some participants may have even recognised that a flavoured/caloric beverage is analogous to a food. For example, a participant who was explaining the rationale behind his hunger rating stated "I find cappuccino actually quite fulfilling as a drink in itself". Another participant was interviewed shortly after finishing her lunch. The beverage she drank with her lunch was a smoothie. When asked for her rationale behind her degree of thirst, she stated "I haven't had a drink in a while". Her comment suggested that she did not consider the smoothie to be a beverage in the traditional sense. A smoothie is unlikely to be considered thirst-quenching due to some of its properties, such as viscosity: products with thick sensory characteristics are anticipated to cause more thirst (McCrickerd, Lensing, & Yeomans, 2015). Therefore, even though the smoothie was chosen as the drink component of the meal and the liquid was physically drunk, its viscosity might have triggered the disassociation from the concept of a beverage.

On the other hand, some participants explained that they were having a flavoured/caloric beverage as a substitute for water, or that a flavoured/caloric beverage was thirst-quenching. A participant who planned to have lunch later in the day was drinking a smoothie at the time of the interview. When asked why she selected it, she answered that she was thirsty and that her friend was having one, too. She clarified that she was not hungry [enough to eat], but then went on to explain why she chose the smoothie over another beverage, water. “I thought [the smoothie] was more substantial…[Both a smoothie and water] are sort of reasonably similar in price and the smoothie is sort of slightly thicker.” Her use of the words, “substantial” and “thicker”, is puzzling. While it is true that by “substantial”, she simply may have been referring to the cost-benefit ratio between the two choices (as she did mention that they were similarly priced); it is also true that the choice of beverage that is “thicker” seems odd if the individual is thirsty, but not hungry. This is because there is a learned effect of viscosity on satiation (Mars, Hogenkamp, Gosses, Stafleu, & De Graaf, 2009).

According to Richard Mattes (Mattes, 2010) drinking is more highly motivated than eating, but drinking to excess is not as consequential as eating to excess. In other words, while we can survive weeks without food, we can survive at most a few days without water, so there is a stronger motivation to seek out water. While overeating tends to lead to a positive-energy balance (and weight gain), drinking in excess of requirements is not usually harmful as the body is very efficient at regulating its hydration status (Mattes, 2010; Robertson, 1984). Of course, this is not taking into consideration the harmful effects of binge eating or electrolyte imbalances, but instead focusing on eating or drinking to excess in more ordinary situations. With these classifications in mind, we can see that the behaviour of individuals, who conceptualize their behaviour as drinking, but are in fact taking in energy (which is the case with the ingestion of caloric beverages), becomes behaviour that is highly motivated *with* potentially problematic consequences.

Systematic reviews indicate that individuals who consume sugar-sweetened beverages are at higher risk for weight gain (Malik et al., 2013, 2006). In addition to sugar-sweetened beverages being a major source of added sugar (Ervin, Kit, Carroll, & Ogden, 2012; Guthrie & Morton, 2000; Langlois & Garriguet, 2011; Lee et al., 2014), some research has demonstrated that liquid calories have a weaker satiety effect than equivalent solid calories (Flood-Obbagy & Rolls, 2009; Mattes, 2005; Mourao, Bressan, Campbell, & Mattes, 2007). Liquid calories require less mechanical processing and spend less time passing through the gastrointestinal tract (Andrade, Greene, & Melanson, 2008; Glasbrenner, Pieramico, Brecht-Krau, Baur, & Malfertheiner, 1993; Hogenkamp, Mars, Stafleu, & de Graaf, 2010; Lavin, French, Ruxton, & Read, 2002) and often lack sensory characteristics that alert the body to prepare for the digestion and absorption of nutrients and calories (Chambers, Ells, & Yeomans, 2013; Mars et al., 2009; Yeomans & Chambers, 2011; Zijlstra et al., 2008). This body of work suggests that individuals who consume sugar-sweetened beverages are at risk for weight gain because liquid calories are not completely compensated for and will therefore lead to increased energy intake. However, several studies also support the notion that liquid calories are at least as satiating as solid calories as evident by a systematic review (Almiron-Roig, Chen, & Drewnowski, 2003) and more recently published studies (Gadah, Kyle, Smith, Brunstrom, & Rogers, 2015; Martin, Hamill, Davies, Rogers, & Brunstrom, 2015).

Several of the studies which concluded that liquid calories can be just as satiating as equivalent solid calories often used soup as the liquid pre-load (Himaya & Louis-sylvestre, 1998; Mattes, 2005; Rolls, Bell, & Thorwart, 1999). It has been suggested that cognitive beliefs about the liquid can impact its satiating properties. For example, a study demonstrated that hunger ratings decreased and fullness ratings increased to a greater degree after consumption of apple soup compared to an energy-matched apple juice. The author suggested that the difference might be due to the fact that a liquid perceived as a beverage is conceptualized as a means to satisfy thirst; whereas a soup is perceived as a food, and therefore as a means to satisfy hunger, which in turn might increase its satiating ability (Mattes, 2005). In another study, participants consumed low-energy and high-energy versions of thin beverages labelled as thirst-quenching, filling snacks, or without any contextual information. While participants in the control and thirst-quenching conditions showed weak satiety responses to the high-energy version of the beverage, those in the filling snack condition responded to the higher-energy version of the beverage by adjusting their intake at a subsequent meal (McCrickerd, Chambers, & Yeomans, 2014). In addition, liquid calories thought of as beverages are usually served in glasses, cups, mugs, etc., with or without a straw, which the individual sips directly from. In contrast, liquid calories thought of foods are typically served in bowls with spoons which the individual needs to slowly bring over to his/her mouth. The way in which individuals consume the liquid not only affects how quickly they consume it, but also their conceptualization of what they are ingesting (Martens & Westerterp-Plantenga, 2012; Mattes, 2010). Furthermore, cognitive beliefs about the liquid appear to affect not only appetite but also postingestive responses. For example, in a study, participants consumed oral liquid and solid preloads which they were told would either be liquid or solid once inside the gastrointestinal tract. The rate of gastric-emptying and orocecal transit was quicker when participants expected the preload to be liquid inside the gastrointestinal tract (Cassady, Considine, & Mattes, 2012).

The results of this study demonstrate that there are not clear distinctions between food and beverages. For example, two participants in this study explained that they were ill and did not have much of an appetite so they selected an item which would get nutrients into their bodies without the fullness they would experience from a typical meal. One participant was having a smoothie (in a cup with a straw) and the other was having a soup (in a bowl with a spoon), but both items were chosen because they were thought to be nutritious, but not filling. A third participant, who was hungry, was consuming a soup (in a bowl with a spoon) because he believed that the soup was filling. He also mentioned that he was not very thirsty due to the hydrating properties of the soup. Therefore, he was having a nutritious and filling item, which was also thirst-quenching. In all three cases, it is unclear whether these liquids should be categorized as foods or beverages. Whether a liquid is nutritious, filling, hydrating, or thirst-quenching or which vessel the liquid is ingested from does not seem to be the defining characteristic.

Smoothies are an informative beverage to consider because they tend to be thought of as more nutritious and have a thicker consistency than most beverages. Therefore, they are arguably more satiating than typical beverages. However, while some individuals apparently consume smoothies to curb their appetites in place of or in between meals, others consume smoothies when they are thirsty and/or not very hungry because they believe smoothies to be thirst-quenching and/or light.

Similarly, soups can be thought of as any combination of nutritious, filling and hydrating. These differences could depend on the temperature, consistency, or content of the smoothie or soup, or the context in which the liquid is being ingested. Furthermore, soups are not always served in bowls with spoons, but sometimes are drunk directly from mugs. Therefore, it is impossible to say that everyone conceptualizes all smoothies as beverages and all soups as foods all of the time.

2.4.4 Rating scales

As thirst and hunger can be very subjective experiences, it is reasonable that two individuals could choose the same value on the scale to represent different degrees, and perhaps different qualities, of these experiences. For example, two participants both rated their degree of thirst at “64” stating that they were a bit thirsty. However their experiences differed, in that one participant mentioned that he was “okay” because he had “been drinking all day”, while the other explained that he had not drunk very much that day and therefore was preoccupied with thoughts of drinking. While these individual differences pose no problems when looking at changes in appetite ratings within individuals, it complicates the comparison of appetite ratings between individuals. In fact, a review of VAS found that the scales are best used in within-subject, repeated-measure designs where the effect of the different treatments can be compared under similar circumstances (Stubbs et al., 2000). In addition, it is important to keep in mind that individuals may conceptualize the questions which the scales represent in incongruent ways. The present study illustrated that although the majority of individuals utilize the scales in appropriate ways, there is confusion for some. While other research has shown that fullness and hunger ratings correlate negatively (Flint, Raben, Blundell, & Astrup, 2000; Rogers & Hardman, 2015), this study demonstrated that fullness can be defined in more than one way (i.e. not needing versus not being able to eat anymore) and that the absence of hunger is not always seen as the equivalent to absolute fullness. While some perceive hunger and fullness as polar opposites, others may perceive them as independent scales. Murray and Vickers (2009) also found that hunger and fullness are not always conceptualised as a continuum. In their study, participants agreed that it is possible to not feel full and not feel hungry at the same time and that it is possible to feel hungry and slightly full at the same time (*e.g.,* sensory specific satiety). In addition, it is important to note that there is no universally accepted term which is equivalent to the opposite of thirst (Mattes, 2010). These distinctions are important as they could affect the validity of the rating scales.

2.4.5 Limitations

In order to comprehensively examine beliefs about ingestive behaviour, only a small group of individuals could be studied. In addition, members of the group were predominantly Caucasian undergraduate students from the United Kingdom. Lastly, it is important to note that the location and timing of the study may have imposed certain constraints. As testing took place during the university/work week at lunch time, many participants were on a designated and limited break. In fact, many individuals declined to participate in the study because they had to attend a class or get back to work shortly. In addition, a few participants mentioned that their food or beverage choice was restricted by the available options in the cafeteria. Therefore, the large number of responses which referred to convenience and time may have been specific to this testing scenario.

Taking these limitations into consideration, one must be cautious about the generalizability of the results to other populations. Nonetheless, the data offers valuable insight into both singular and shared experiences, and while the results of this study cannot be used to explain ingestive behaviour universally, the provocative questions generated by the study will be instrumental in designing future experiments. This study found that individuals seem to appropriately conceptualize and utilize hunger and thirst scales with a few exceptions. The comparison of the techniques used demonstrated that the semi-structured interviewing revealed a more extensive overview of decision making. However, the free association test still detected the most prevalent themes and therefore can be a useful and economical alternative to semi-structured interviewing.

2.4.6 Conclusions

Individuals living under ad-libitum conditions may infrequently feel truly hungry because it is rare that they would be without food for such a prolonged period of time that they would experience the physical consequences of early starvation. If individuals were severely energy depleted whenever they skipped a meal, their hunger should persist and intensify rather than fade later as often occurs. Instead of hunger, orosensory reward and a culturally-defined concept of an ideal eating schedule may dictate the frequency with which individuals eat. The internal experiences many feel and assign to a biological need for food, like a growling stomach, may only signal the capacity to safely eat again, as individuals are (for the most part) always able to eat even if they have recently consumed a meal. Ignoring the urge to eat may cause changes in mood or performance, but these changes may have more to do with frustration arising from unmet expectations, than physiological adversity.

Unlike energy balance, fluid balance is under stringent homeostatic control (Rogers & Brunstrom, 2016). However, the matter is complicated by beverages that are, by definition, foods. Individuals living under ad-libitum conditions drink quite regularly. They possibly drink more than necessary, as they often drink in the absence of internal signals, like headache and dry mouth, because they are motivated to drink for reasons other than quenching a thirst. Individuals are motivated to drink by orosensory rewards and energy boosts. In addition, many individuals seem motivated to drink regularly in order to entirely avoid the sensation of thirst. As with hunger, individuals living under these conditions probably do not experience true thirst that often.

Although there are numerous factors which individuals could consider when deciding what to eat or drink, in this study, individuals seemed to use shortcuts by considering only the few factors most important to them. Although foods and beverages traditionally serve different purposes, this study demonstrated that both categories share many of the same motivating factors for consumption. Therefore, it is not clear whether individuals consider flavourful and/or energy-providing liquids to be beverages or food. A potential problem of this ambiguity is that individuals may not be cognisant that they are taking in calories when ingesting certain liquids because they conceptualize their behaviour as drinking, and individuals may be less inclined to associate drinking with weight gain. While it appears reasonable that individuals consider liquids, thought to be filling and nutritious and eaten from bowls with spoons, to be food, and liquids, thought to be hydrating, drunk from cups, mugs, and glasses, to be beverages, this study illustrated that these distinctions are by no means clear-cut.

Perhaps it has less to do with the static properties of the liquid item and more to do with the individual's momentary motivations for consuming the liquid item. This would explain why it is possible for the same liquid to be consumed from the same vessel by the same individual on two different occasions, in one instance to be thought of as a food and in the other to be thought of as a beverage. For example, someone might decide to have a smoothie today because he does not have much of an appetite and is feeling a bit dehydrated. The following week, he might have the same smoothie because he is running late. He does not have the time to sit down for a proper meal, but wants to quickly ingest something tasty and nutritious that will fill him up for the time being. Therefore, future research should focus more on the motivations behind ingesting liquid calories in order to better understand the complex nature of flavourful and/or energy-providing beverages.

Chapter 3 Literature review and thesis objectives

The qualitative experiment discussed in Chapter 2 discovered important aspects of both food and beverage consumption. While the initial focus of the experiment was on food consumption, the interactive and dynamic analysis of the data led to a revised focus on beverage consumption. Specifically, the results highlighted the complex nature of beverages. A comparison of the results with the relevant literature established that this finding was not novel, and that many relevant theories had been explored (*e.g.,* psychological and physiological influences on the satiating and thirst-quenching capacities of liquid calories). The results taken together suggested that the static properties of liquid calories may be less important than dynamic motivations of the individual when attempting to understand beverage consumption.

The shift in focus from food to beverage consumption is justified for two reasons. Firstly, the shift occurred as a result of utilizing an inductive approach to guide the direction of this thesis. Secondly, the shift has important implications as motivations underlying ingestive behaviour have been less comprehensively researched in the beverage domain than in the food domain (as outlined in Chapter 1). Considering how the complexities of beverages may have modified relationships with thirst and drinking, this thesis was dedicated to understanding how motivations behind beverage consumption might lead to poor beverage choices or inadvertently increase energy intake.

While sugar-sweetened beverages are not a modern invention (Bellwood, 2005; Hanson, 1995; Heiss & Heiss, 2011; Standage, 2007; Weinberg & Bealer, 2001), the way in which sugar-sweetened beverages are consumed today is a relatively recent change to our diets. In the 1950's, Coca-Cola began producing 10- 12- and 26- US fluid ounce bottles in addition to their original 6.5 US fluid ounce bottle (The Coca-Cola Company, n.d.). In 1970, Pepsi Co introduced the first 2 L bottle (67.6 US fluid ounces) (Pepsi Co, n.d.). In 1985, 3 L bottles (101.4 US fluid ounces) were sold (Maidenberg, 1985). From 1977 to 2001, the proportion of daily energy intake obtained from soft drinks in the US increased from 2.8% to 7.0% (S. J. Nielsen & Popkin, 2004).

Today, there is a wide variety of sugar-sweetened beverages: soda, fruit drinks, sports drinks, energy drinks, sweetened waters, and coffee and tea beverages with added sugars, milk, etc. There is also a wide variety of the added sugars used to sweeten the beverages: brown sugar, corn sweetener, corn syrup, dextrose, fructose, glucose, high-fructose corn syrup, honey, lactose, malt syrup, maltose, molasses, raw sugar, and sucrose (U.S. Department of Agriculture & U.S. Department of Health and Human Services, 2015). Sugar-sweetened beverages are marketed as satisfying a wide range of needs (*e.g.,* thirst, pleasure, social interaction, energy, taste, etc.).

<u>1950s</u>

Images of 1950s Coca Cola Adverts removed for copyright reasons

<u>2010s</u>

Images of 2010s Coca Cola Adverts removed for copyright reasons

Consumption of sugar-sweetened beverages is associated with weight gain in both children and adults. It has been suggested that this relationship is due to the low satiety of beverages and consequent lack of full energy compensation at subsequent ingestive events (Malik et al., 2013, 2006). However, evidence of the satiation and satiety of beverages is mixed. While some research supports the view that liquid calories are less satiating than equivalent solid calories (Flood-Obbagy & Rolls, 2009; Mattes, 2005; McCrickerd et al., 2014; Mourao et al., 2007), other research suggests equivalent liquid and solid calories are at least equally satiating

(Almiron-Roig et al., 2003; Gadah et al., 2015; Martin et al., 2015). The inconsistent findings may be partly due to interactions between sensory, cognitive, and physiological factors involved in beverage consumption (Andrade et al., 2008; Cassady et al., 2012; Chambers et al., 2013; Glasbrenner et al., 1993; Hogenkamp et al., 2010; Lavin et al., 2002; Yeomans & Chambers, 2011; Zijlstra et al., 2008).

Foods and beverages share several defining characteristics(Martens & Westerterp-Plantenga, 2012; Martin et al., 2015; Mattes, 2005; McCrickerd et al., 2014) and are sometimes only subtly differentiated by delivery to the mouth (*i.e.,* bowl with a spoon versus cup with a straw)(Martens & Westerterp-Plantenga, 2012) and by cognitive beliefs (*i.e.,* foods are filling and beverages are hydrating)(Mattes, 2005; McCrickerd et al., 2014). Because calorie-containing beverages provide flavour, energy and hydration, they can be thought of as filling, thirst-quenching, or both(Mattes, 2005; McCrickerd et al., 2014). Furthermore, the same beverage can be conceptualized as either filling or thirst-quenching depending on the context (McCrickerd et al., 2014). As suggested in Chapter 2, this ambiguity can pose a problem because if individuals conceptualize consumption of beverages as “drinking”, they may not be as cognisant that they are ingesting energy as they would be if they conceptualised their behaviour as “eating”. This point is exemplified by an experiment which manipulated expectations of the postprandial consequences of liquid ingestion. When participants believed they were ingesting a product that would present a liquid (compared to a solid) gastric challenge, they felt less satiated and had faster oroceal transit times (Cassady et al., 2012). Therefore, conceptualising energy intake as “drinking” might reduce negative physiological feedback on intake. Further, research has demonstrated that increased energy intake from beverages is not fully compensated for by reducing energy intake at a concurrent or subsequent meal, resulting in a significant increase in total energy intake (DellaValle, Roe, & Rolls, 2005; Flood, Roe, & Rolls, 2006; Panahi, El Khoury, Luhovyy, Goff, & Anderson, 2013; Rogers, Hogenkamp, et al., 2016).

Previous research which has investigated the satiety issue of beverages has identified that consuming caloric liquids that are thickened (*e.g.,* Chambers et al., 2013), served in a bowl (*e.g,* Martens & Westerterp-Plantenga, 2012), or labelled as filling (*e.g,* McCrickerd et al., 2014) can reduce energy intake. The results of these studies are informative and could possibly bring about changes in manufacturing (*e.g.,* regulations which prevent caloric beverages from being labeled thirst-quenching). However, while beverages without satiety-relevant cues are still prevalent in our food system, it is impractical to solely focus on the properties of caloric beverages; the context these beverages are consumed in might also need to be considered to prevent the overconsumption of energy.

The context surrounding beverage consumption might prompt consumers to focus on certain features of a liquid (*e.g.,* how hydrating, thirst-quenching, filling, energizing, palatable, nutritious, or healthy it is) and influence whether it's perceived as a food or as a beverage. This difference in perception might influence the amount of liquid, and therefore calories, ingested. The experiments discussed in Chapters 4, 5, and 6 will manipulate motivational factors with the intention to influence the perception of liquids. Collectively, the experiments aim to identify everyday situations that might encourage increased energy intake of caloric beverages. The findings, if conclusive, can be used to identify strategies to reduce energy intake when drinking.

Food and water are two of our most basic needs (Maslow, 1943) and therefore it can be argued that hunger and thirst are two motivational states that are frequently experienced. The qualitative results presented in Chapter 1 support the theory that desire to eat and the desire to drink in the absence of a physiological need for food and water are also conceptualized by many as hunger (Lowe & Butryn, 2007; Mattes, 2010) and thirst (Mattes, 2010; Phillips et al., 1984), which further stresses the frequency with which these motivational states are experienced. While intuitively, thirst should promote drinking, research demonstrates that is not always the case. McKiernan and colleagues (McKiernan et al., 2009) conducted an observational study of hourly appetite ratings and food and beverage intake over a 7-day period. Participants engaged in 'inappropriate' ingestive events (*e.g.,* drinking but not eating when hungry but not thirsty) 62% of the time. The authors' hypothesis that thirst promotes eating and hunger promotes drinking was not supported, but thirst ratings did not even predict drinking and hunger ratings only weakly predicted eating. The authors propose that living in an environment with constant access to food and beverages leads to eating in the absence of a need for food (Lowe &

Butryn, 2007) and drinking in the absence of a need for fluid (Phillips et al., 1984), thereby confounding opportunities to associate eating and drinking with the relief of hunger and thirst. The authors also suggest that the large variety of energy sources (*e.g.,* energy containing liquids, and foods and beverages with diluted energy content) might also weaken the association between appetite and intake, and that similar to hedonic hunger (Lowe & Butryn, 2007), hedonic thirst (*i.e.,* rewarding sensory properties of beverages) may encourage drinking regardless of fluid needs.

The qualitative research described in Chapter 1, complemented by previous research (Block et al., 2013; Mason et al., 2014), expands on this theory that beverages are not only rewarding for their thirst-quenching or hydrating properties, but for their taste and energy properties. The experiment revealed that flavoured beverages are often utilised as if they are foods, rather than beverages. For example, 46% of participants reported choosing beverages to obtain 'energy'. They believed that the sugar, caffeine, nutrients, and/or calorie content, or the refreshing nature of consuming a liquid would energise them and increase their concentration. The same percentage of participants referred to taste (38%) and to hydration (38%) as motive for consumption of beverages. As hunger can be equated to a need or desire for taste or energy, when hungry, whether physiological or hedonic, individuals might be more likely to choose sweetened beverages and/or might consume more of sweetened beverages than if they were not hungry.

The effect of thirst is somewhat more complex. A physiological need for water might lead to a choice of fluid perceived to be more thirst-quenching or hydrating. It also might increase intake of a fluid perceived to be more thirst-quenching or hydrating. Research demonstrates that drinks which are acidic, astringent, fruity and fairly strong in flavour, are perceived as being more thirst-quenching than drinks which are thick, sweet or carbonated (McEwan & Colwill, 1996). However, if hedonic thirst is motivating beverage consumption, then the thirst-quenching or hydrating ability of a beverage may be a less important factor in beverage choice and intake. Instead, a beverage with satiety-relevant cues (*e.g.,* thickness, sweetness, carbonation) may be preferred, selected, and consumed in greater quantities.

Research has shown that hypohydration (compared to an euhydrated control trial) (1) influences subjective feelings of thirst, hunger and fullness (Corney, Sunderland, & James, 2015), (2) increases ad libitum fluid intake (although not enough to fully restore fluid balance) (Corney et al., 2015; Shirreffs et al., 2004), but (3) does not affect ad libitum energy intake (when fluid was readily available with the meal) (Corney et al., 2015; Kelly, P. J., Guelfi, K. J., Wallman, K. E., & Fairchild, 2012). Other studies in humans (Engell, 1988; Shirreffs et al., 2004) and animals (Senn, M., Gross-Lüem, S., Kaufmann, A., & Langhans, 1996; Watts, 1998) found that fluid restriction reduced energy intake. These studies did not provide fluids during the ad libitum meal, which might reduce food intake by altering palatability and/or making the foods difficult to eat (Corney et al., 2015).

Given that most individuals are adequately hydrated (Tucker et al., 2015; Valtin, 2002), it is important to understand how states less severe than hypohydration, such as typical thirst, influences fluid and energy intake. Durlach and colleagues (Durlach, Elliman, & Rogers, 2002) found that repeatedly drinking a flavoured beverage after a high-salt meal (compared to a low-salt meal) led to conditioned increases in consumption of that beverage. Fluid deprivation increases fluid intake of both water and flavoured beverages, but it is not known if the effect is more pronounced in one or the other.

Further, fluid deprivation does not increase energy intake when various low or no-calorie options are available. For example, in Corney and colleagues' study (Corney et al., 2015) an additional 1,000 ml of fluid was consumed from the buffet meal during the hypohydrated trial. As energy intake did not simultaneously increase, it is likely that the additional fluid came from the no and low-calorie options (namely water, coffee, tea) and not the high-calorie options (*i.e.,* semi-skimmed milk, orange juice, and apple juice).

Therefore, an objective of this thesis was to understand how hunger and thirst might affect perception of water, a reduced-sugar-sweetened beverage, and sugar-sweetened beverage. Other research has covertly manipulated hydration status by delivering fluid through a gastric feeding tube (James, Moss, Henry, Papadopoulou, & Mears, 2017). While this method removes expectation biases associated with fluid passing through the oral cavity, it is arguably ecologically invalid. A more feasible and naturalistic method of manipulating hunger and thirst is via the presence or absence of food and fluid. In addition, this method circumvents the limitation of imprecise hunger and thirst signals and recognizes that many conceptualize ‘hunger’ and ‘thirst’ as any deviation from routine ingestive behavior. Instead of relying on participants’ nonspecific belief that they are ‘hungry’ or ‘thirsty’, the experiments in this thesis prompt participants with axioms such as 1) they have not eaten or drank for a period of time longer than usual, and 2) they are eating or drinking more or less than usual.

As a beverage is often consumed as an accompaniment to food (Mattes, 2010), it is important to understand beverage consumption not only on its own, but in the context of a meal (which includes both food and beverage). Previous research on meal-centered beverage choice revealed various meal characteristics and personal factors which predict beverage choice among water, hot beverages, milk, carbonated beverages, juice, wine, and beer (Mueller Loose & Jaeger, 2012). One limitation of the study is that diet beverages were not included among the beverage options. Further, beverage characteristics (*e.g.,* hydration, taste, and energy properties) and present appetite for energy and fluid were not considered.

Primarily, a beverage is consumed alongside food to facilitate chewing and swallowing of food (Kissileff, 1973), prevent thirst (Phillips et al., 1984), and rinse the mouth to reduce gustatory habituation (Bellisle & Le Magnen, 1981). However, a beverage, which is palatable and/or filling, may be consumed alongside food because it variegates the flavors in the meal and/or increases satiation. In this context, the beverage acts as a food would act to influence meal satisfaction, which is comprised of the enjoyment of taste experienced during the meal and post-meal fullness (Rogers, Ferriday, et al., 2016).

Reductions in food portion size (*e.g.,* as a strategy to reduce energy intake) can affect expected eating enjoyment and expected satiation, and subsequently meal satisfaction. Reduced meal satisfaction may prompt compensatory behaviour (*e.g.,* snacking after the meal) undermining the goal of energy reduction (Ferrar, Ferriday, Smit, McCaig, & Rogers, *under review*). Meal size was not among the measures of meal characteristics (*e.g.,* meal location and time, meal activity, social context), and only beverage choice (not beverage intake) was assessed in Mueller and Jaeger's study (Mueller Loose & Jaeger, 2012). Therefore, another objective of this thesis is to investigate how changes in food portion size, and their theoretical effect on meal satisfaction, would influence beverage selection and intake of water, a reduced-sugar-sweetened beverage, and a sugar-sweetened beverage.

Research suggests that under ad-libitum conditions, few eating episodes occur as a result of energy depletion. The majority of eating episodes occur as a result of food reward. This is especially true if the gut is empty and the food is liked (Rogers & Hardman, 2015). It can be argued that the reward value of a food depends on the energy it provides, not the degree to which it fills you up. This is because energy is what is biologically valuable, whereas feeling full limits energy intake (Rogers & Brunstrom, 2016) and may even reduce food reward (Sclafani & Ackroff, 2004). This theory offers a plausible explanation for why energy-dense foods are more rewarding than energy-dilute foods (Holt, Miller, Petocz, & Farmakalidis, 1995). While satiety can inhibit energy intake, it is nonetheless rewarding to avoid the unpleasant feeling of an empty gut. This can be achieved by satiety, which helps to explain why energy-dilute foods are sometimes preferred to energy-dense foods (Brunstrom & Rogers, 2009).

As increasing amounts of a food is ingested, the food's reward value (*i.e.,* desire to ingest the food) decreases. This is not because the food is less liked: the food tastes just as pleasant (except in respect of sensory-specific satiety) whether the individual is hungry or full. Instead, as satiety increases, wanting for the food decreases: the individual has less of desire to ingest more of the food. It is difficult to ignore the influence of how much the food is liked when rating how strong the desire is to eat that food. By measuring desire to eat and liking for the food, wanting for the food can be deduced (Rogers & Hardman, 2015). This model of reward has not yet been investigated in relation to fluid ingestion, and therefore is the final objective of the thesis. For example, it is not yet known if the reward value of fluid decreases as thirst is alleviated. Further, it is unclear if this relationship depends on traits of the fluid (*e.g.,* flavor, calories).

Previous research on fluid energy compensation has typically considered the effect of beverage consumption on subsequent food consumption. This often involves using a “preload test-meal” method where, after consuming a fixed portion of a beverage, ad-libitum intake at a subsequent test meal is measured (Rogers, Hogenkamp, et al., 2016). However, the ecological validity of this paradigm is questionable. Research has demonstrated that 75% of drinking occurs peri-prandially (McKiernan et al., 2009) and anecdotal evidence demonstrates that beverages may be consumed regularly throughout the meal, towards the end of the meal or even after all of the food has been eaten. Therefore, outside of the laboratory, beverages are unlikely to be consumed in entirety before food consumption. Furthermore, while meals are often pre-planned (Brunstrom, 2014), they are not necessarily pre-planned in the way suggested by this paradigm (*i.e.,* that beverage choice affects food choice). Instead, the time at which beverage choice occurs during meal planning varies depending on the context. Decisions about what to eat and drink may happen simultaneously. In some situations, a beverage is typically selected, and often partly consumed, before the food has been selected (*e.g.,* in sit-down restaurants). However, in other situations, a beverage is selected after the food has been selected. For example, when ordering at a fast-food style restaurant, it is customary to be asked “What drink would you like with your meal?” after ordering the food components of your meal. In addition, regardless of the situation, food is the primary component of a meal and thus decisions about food should be prioritized over decisions about the beverage. Therefore, the opposite paradigm (*i.e.,* the effect of food consumption on beverage consumption), should be investigated. As pre-meal planning predicts consumption (Fay et al., 2011), whether or not decisions about energy-containing beverages are made in a state of satiety (*i.e.,* before or after eating), has implications for fluid energy compensation. For example, selecting or consuming a beverage before the food has been selected or consumed (when satiety cues are not particularly salient), may disrupt energy compensation and promote overconsumption. In contrast, selecting or consuming a beverage after the food has been selected or consumed may influence individuals to pay more attention to satiety cues and, as a result, their energy intake. To my knowledge, research on fluid energy compensation has not investigated the effect of food consumption on subsequent beverage choice and intake. Therefore, all of the experiments in this thesis were designed so that the outcome variable was beverage choice or intake.

The test beverages selected for this thesis were water, Ribena light, and Ribena. Ribena and Ribena light (Lucozade Ribena Suntory, 2018) were selected as the sugar-sweetened and reduced-sugar-sweetened test beverages, respectively, as they are highly familiar to individuals from the United Kingdom. Pilot data suggested that Ribena light and Ribena are beverages that are well-matched in appearance, taste, and consistency and would be considered appropriate to consume at all mealtimes. In addition, using non-carbonated beverages was an attempt to avoid possible effects of carbonation on appetite (Moorhead, Livingstone, Dunne, & Welch, 2008). Highland Spring Still Water was selected as the brand of water, as it is commercially available in supermarkets where Ribena and Ribena light are sold and the bottle has a similar shape to Ribena and Ribena light bottles.

In summary, Chapter 4 will explore the effect of current hunger and thirst on beverages consumed in isolation, while Chapter 5 will explore the effect of anticipated hunger and thirst on beverages consumed as part of a meal. Finally, Chapter 6 will explore how varying degrees of thirst influence beverage reward.

Chapter 4 Food or fluid? The effect of motivational states (hunger and thirst) on how beverages are conceptualized and consumed

4.1 Introduction

Previous research suggests that the current food and beverage environment encourages eating irrespective of acute energy balance (Lowe & Butryn, 2007) and drinking in the absence of acute fluid balance (Phillips et al., 1984), thereby weakening the association between homeostatic needs and ingestive behaviour. Continual access to food and beverages with varied flavour and energy properties (e.g. high and low energy versions of flavoured liquids; processed foods with diluted energy content) confounds satiation and hydration cues and intensifies the reward associated with ingestion (McKiernan et al., 2009).

As summarised in Chapter 3, being thirsty does not increase ad libitum energy intake of foods (Corney et al., 2015; Kelly, P. J., Guelfi, K. J., Wallman, K. E., & Fairchild, 2012), but increases ad libitum fluid intake of beverages, including flavoured varieties (Corney et al., 2015; Shirreffs et al., 2004; Zellner & Durlach, 2002a). If the flavoured beverage is low-calorie, energy intake is unlikely to increase (Corney et al., 2015). However, if the flavoured beverage is high-calorie, and is the only source of fluid, then energy intake will increase as fluid intake increases. The degree to which energy intake will increase might depend on both the properties of the fluid and the state of the individual. Intake of an energizing and flavoured beverage might be increased when hungry, and intake of a beverage perceived to be more hydrating and less like food might be greater when thirsty. More specifically, if drinking is motivated by thirst or to facilitate swallowing of food, the motivation to drink should dissipate quickly, after the meal is finished or once fluid balance is met. The time required to quench a thirst is only a couple of minutes (Poothullil, 2005). However, if the beverage is flavoured or caloric, and therefore more rewarding, then motivation to drink may persist after the need for fluid has dissipated (Passe, Horn, & Murray, 2000).This might be particularly true if the individual was also hungry. On the other hand, if the drinking is occurring while the individual is full, the taste or calories provided by the beverage may be unpleasant, and therefore reduce intake. If drinking occurs while fluid balance is stable but when hungry, a flavoured higher-calorie beverage might be perceived as the most appealing due to its satiating and hedonic properties, followed by a flavoured low-calorie beverage, and then water (with intake adjusted accordingly).

These predictions assume that drinking behaviour is only influenced by hedonics and physiological mechanisms. However, research has demonstrated that appetite and intake can be influenced by the cognitive beliefs about the beverages even when the test and control groups receive identical beverages (Cassady et al., 2012; McCrickerd et al., 2014). Cognitive beliefs may moderate drinking behaviour due to variability in how caloric beverages could be perceived. The qualitative work in Chapter 1 illustrated that the same beverage can be seen as either thirst-quenching or appetite-satisfying or both. For example, participants who recently consumed a caloric beverage differed in whether they acknowledged its satiating properties when justifying their hunger ratings and its hydrating properties when justifying thirst ratings. Although sugar-sweetened beverages are equally effective in maintaining euhydration during everyday conditions (Ganio & Tucker, 2014), they are perceived as being less refreshing than water (Zellner & Durlach, 2002b), especially if they are also perceived as being thick, carbonated or sweet (McEwan & Colwill, 1996).

The satiating properties of fluids are currently debated. While some research has demonstrated that fluids are less satiating (Flood-Obbagy & Rolls, 2009; Mattes, 2005; Mourao et al., 2007), an earlier review found that liquids are equally or more satiating than solids (Almiron-Roig et al., 2003). Other research has shown that individuals ingest more energy from a fluid (compared to a semi-solid) (Hogenkamp, Stafleu, Mars, & de Graaf, 2012), but that the difference in energy is not fully compensated for regardless of food form (Akhavan, Luhovyy, & Anderson, 2011; Gadah et al., 2015; Hogenkamp et al., 2012). Water (calorie-free and largely tasteless) appears to be transiently satiating (Corney, Sunderland, & James, 2016; Lappalainen, Mennen, van Weert, & Mykkänen, 1993; Van Walleghen, Orr, Gentile, & Davy, 2007). However, other research suggests that this has little to do with its volume, but is, instead, a cognitive effect. For example, the same amount of water consumed as a beverage alongside food was found to be less satiating than water consumed when incorporated into the food (Rolls et al., 1999).

Several physical and psychological factors have been identified as influencing the satiation of fluids (*e.g.,* viscosity, mode of consumption, and contextual cues) (Mattes, 2005; McCrickerd et al., 2014; Mourao et al., 2007), and it is possible that in everyday life a combination of these factors affects an individual's perception of the fluid and consequently his/her motivations for consuming the fluid. The studies presented in this chapter will explore whether being thirsty or hungry (which logically should increase motivation, respectively, for fluid and energy) leads participants to view different beverages as more beverage-like or more food-like and whether this would influence beverage intake. The beverages were water, and a low-calorie and high-calorie version of a sweet beverage. To my knowledge, these questions have not been investigated previously. In particular, I was interested in the possible consequences of the availability of calorie-containing beverages. Mattes (Mattes, 2010) highlights that there is greater motivation to drink than there is to eat (living things can only survive a few days without water). It is possible that individuals living under ad-libitum conditions (with the exception of the elderly, those working strenuous jobs, and those living in hot climates) drink more than required, perhaps in anticipation of thirst (SJ French et al., 1994; Phillips et al., 1984), but that this over-drinking goes rather unnoticed as the body is very efficient at removing excess water (Nicolaidis, 1998; Popkin et al., 2010). It was reasoned therefore that 'liquid calories' may be particularly liable to contribute to positive energy balance because (1) there is little negative feedback to inhibit the overconsumption of liquids, (2) calorie-containing beverages may be relatively unsatiating calorie-for calorie, and (3) conceptualising consumption of calorie-containing beverages as drinking rather than eating may cause the calories they contain to be discounted in the conscious, cognitive control of energy intake.

The current research comprised two studies, with some methodological differences: the sample size, the pre-loads, time spent in the lab after ad-libitum intake, and the cover story for the study. The most feasible and naturalistic way to manipulate hunger and thirst is via the presence or absence of food and fluid. Therefore, hunger and thirst was manipulated by restricting food and fluid intake, causing participants to recognize that it had been longer than usual since they last ate and/or drank (*i.e.,* that they had missed a meal). As detailed in Chapter 3, due to the nature of the research question, a paradigm which consisted of food and/or fluid as the ‘pre-load’ and fluid as the ‘test-meal’ was utilized.

Part 1. The effect of hunger and thirst on intake of a sugar-sweetened beverage, a reduced-sugar-sweetened beverage, and water.

4.2 Methods

4.2.1 Participants

Participants were recruited from the Bristol area (U.K.) via an online database belonging to the Nutrition and Behaviour Unit at the University of Bristol and via social media. Ethical approval was granted by the University of Bristol Faculty of Science Human Research Ethics Committee. Written consent was obtained from all participants. Participants who were: (1) not fluent in English, (2) unable or unwilling to consume the study foods and beverages, (3) unable or unwilling to fast for 11 hours, or (4) unwilling to provide urine samples at the start of each session were not eligible to take part. In order to hide the true aims of the study from participants, it was advertised as a study investigating the effects of fasting on mood. Therefore, participants took part in a distractor task (a free-writing exercise on current thoughts, feelings, and mood) during the test sessions.

4.2.2 Study design

This study utilised a mixed measures design (3 groups x 4 repeated measures). Participants were assigned to one of three test beverage conditions: water (0 kcal/ml), Ribena light (0.04 kcal/ml), or Ribena (0.41 kcal/ml) and always received that beverage (in the labelled bottle) during the ad-libitum intake. Each participant took part in four appetite conditions: (1) hungry but not thirsty, (2) thirsty but not hungry, (3) both hungry and thirsty, and (4) neither hungry nor thirsty (control).

4.2.3 Hypotheses

An interaction between appetite condition and beverage type was expected. The hypotheses are represented by Figure 1.

When hungry, but not thirsty, it is expected that fluid needs will be irrelevant, and intake will be driven by an increased desire for the stomach to feel full, for orosensory reward in the oral cavity, and to provide the body with energy. While all three liquids will physically fill the stomach, only the sweetened beverages will provide orosensory reward, and only the sugar-sweetened beverage will provide a considerable amount of energy to the body. Therefore, it is expected that intake of Ribena will be the greatest, followed by Ribena light, and then water.

When thirsty, but not hungry, it is expected that intake will be driven by fluid requirements. As all three beverages similarly contribute to a positive fluid balance (Ganio & Tucker, 2014), it is expected that intake will be similar among the three beverages. However, the orosensory and energy properties of the beverages need to be considered. The orosensory reward provided by the sweetened beverages might increase consumption (Engell & Hirsch, 1991), while the energy (or at the very least knowledge of the energy) of the sugar-sweetened beverage might simultaneously decrease consumption.

Due to combined effects of hunger and thirst, it is expected that the greatest fluid intake will occur when participants are hungry and thirsty simultaneously and that intake will be similar for all three beverages.

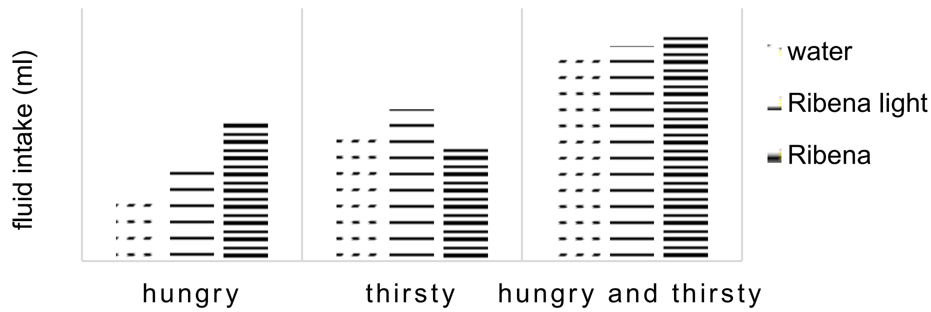


Figure 1 Hypotheses for influence of appetite condition and beverage type on fluid intake

4.2.4 Power calculations

As the study design for this research question was novel, preliminary power calculations were conducted using data on similar topics to determine the sample size. Using the results from a previous study which found a within-subjects effect of a low salt versus high salt meal on water intake ($\eta p^2 = .25$) (Durlach et al., 2002), power calculations (80% power) indicated that at least 8 participants were required to detect the within-subject effect of thirst on intake of a flavoured calorie-free beverage. It was assumed that thirst would have a similar effect on intake of other beverages. As evidence is mixed on the satiating properties of liquids, it was unclear whether this sample size would be large enough to detect an effect of hunger on fluid intake. However, the results from a previous study which found a within-subjects effect of carbohydrate form on fullness (Mattes, 2005) also detected a similar effect size ($\eta p^2 = .25$).

Results from a previous study found an interaction effect of the cognitive manipulation of sensory context (between-subjects factor) on the satiating ability of a high energy beverage (within-subjects factor) ($\eta p^2 = .12$) (McCrickerd et al., 2014). Assuming that the effect size for the physiological manipulation of hunger and thirst on intake of beverages with differing flavour and energy properties would be similar, power calculations (80% power) estimated that at least 30 participants were required to detect the effect.

Taking all the power calculations into account, and to allow for a fully balanced Latin-square design and attrition, it was decided that 12 participants per group (36 participants in total) would be recruited.

4.2.5 Study foods and beverages

Preloads consisted of either 500 ml of water, two Sainsbury's Farmhouse Cheese scones (496 kcal), 10 g of Sainsbury's English Butter, salted, (74 kcal) with 500 ml of water or with 50 ml of water, or nothing. Test beverages (water, Ribena light, and Ribena) were served in their original bottles (*i.e.,* the name of the beverage, nutritional information, and any advertised information was visible to participants). Participants received two 500ml bottles alongside a glass. Participants were instructed that they could choose whether or not to drink directly from the bottle or to use the glass. The scones were served warm, the butter was served at room temperature and water was served between chilled and room temperature (M =13.11 ± 2.48 °C). As the test beverages were served in sealed bottles, the temperature could not be directly assessed before serving. A systematic review determined palatability was greatest with cool drinks (< 22°C) (Burdon, Johnson, Chapman, & O 'connor, 2012), but some studies have found that cold beverages (0–10 °C) were ingested in smaller volumes (Boulze, Montastruc, & Cabanac, 1983; Hubbard et al., 1984). Thus, beverages were removed from a refrigerator (maintained between 1 and 4 °C) and were left out at room temperature for 10 minutes before being served.

4.2.6 Measures

Beverage ratings: Participants were asked to rate their study beverage on various characteristics, regardless of whether or not they had ever consumed them. If they had never consumed the beverage, they were instructed to make the ratings based on a very similar beverage that they had consumed before. To assess familiarity, participants reported how frequently they consumed the beverage (e.g., several times a day, once a day, several times a week, etc.). They also estimated how many calories they thought the beverage contained. The following ratings were rated on 100 mm VAS (anchored from "Not at all" to "Extremely"). Participants reported how much they liked the preload and test beverage. For the beverage, they reported how much they enjoyed its taste, and how filling, energising, nutritious, hydrating, and thirst-quenching they perceived it to be.

Appetite ratings: Participants reported levels of hunger, thirst and fullness using 100 mm VAS (anchored from “Not at all” to “Extremely”).

Habitual behaviour: Participants reported which beverages they usually consumed from the following choices: a) mostly diet (“zero-calorie / sugar-free”), b) mostly regular (“sugar-containing”), c) a mix of both, or d) neither.

Demographics: Participants reported their age (years), gender, ethnicity, and highest level of education.

Weight status and dietary information: Participants had their height and weight measured. Participants also reported if they were currently dieting. If participants were not currently dieting, they were asked if they had dieted in the past. If participants had dieted in the past, they were asked to record the number of times they had dieted in the past 12 months. Participants also completed the cognitive restraint subscale of the Three Factor Eating Questionnaire R21 (Tholin et al., 2005).

Demand awareness: Participants were asked to describe what they thought the study was investigating.

4.2.7 Procedures

Multiple participants were tested at a time. In order to conceal the study aims, participants were always tested at the same time as other participants assigned to the same beverage group. To prevent order effects of the four appetite conditions, a counterbalanced design was used. Therefore, participants were tested with other participants completing different appetite conditions.

Participants were instructed to abstain from all beverages (including water) and foods starting 10 hours before each session to ensure that participants were similarly fluid and food deprived. At the beginning of each session, participants were provided with one of three possible preloads to manipulate their hunger and thirst:

(a) 500 ml of water (hungry but not thirsty condition)

(b) Scones and 50 ml of water (thirsty but not hungry condition)

(c) Nothing (both hungry and thirsty)

(d) Scones and 500 ml of water (control / neither hungry nor thirsty condition)

Test sessions began at 10:00 h. Participants were seated at tables between dividers so that they could not see one another. At the beginning of each session, participants completed appetite ratings (hunger, thirst, and fullness on a 100-mm VAS with anchor points ‘not at all’ and ‘extremely’), and reported what time they had last eaten and last drank. Participants were then required to provide a urine sample. The data on time since last meal and drink and the urine samples were not analysed, but were included in the study to encourage participants to comply with the overnight abstinence requirements.

Participants were given 15 minutes to consume the entire preload (or sit quietly during the control condition). Music was played in the background so that participants were unable to hear one another eating and drinking. After the pre-load, participants filled out appetite ratings and then spent 5 minutes completing a distractor task (a free-writing exercise on their current thoughts and mood). For the next 15 minutes, participants were told there was a break in the experiment and that they could relax, read, or do work. Participants then filled out appetite ratings and the experimenter stated “As some of you still have not had anything to eat or drink yet, I am going to hand out beverages while we wait for the next task. Please drink as little or as much as you would like”. The assigned beverages were then served to each participant. After 5 minutes, the beverages were collected and put aside out of the participants' view, and participants completed appetite ratings.

At the end of the final session, participants filled out a questionnaire about demographics, diet history, the Three Factor Eating Questionnaire-R21 (TFEQ-R21) (Tholin, Rasmussen, Tynelius, & Karlsson, 2005), and rated the study foods and the beverage that they had consumed during the study. They then completed demand awareness and had their height and weight measured. One participant correctly guessed the study aims, but analyses did not differ when this participant's data was removed, so the data was retained.

4.2.8 Data analysis

All analyses were performed using SPSS. The mean and standard deviation for participant characteristics was calculated. The mean and standard deviation of liking for the preload was calculated. One-way analysis of variance (ANOVA) tests were conducted to assess if the beverage groups differed in their assessment of perceived calorie content of their test beverage, how much they liked their test beverage, how much they enjoyed the taste of their test beverage, and how hydrating, thirst-quenching, nutritious, filling, energising, they perceived the test beverage to be. Where overall differences were found, post-hoc pairwise comparisons were conducted to determine which beverage group pairs differed (Bonferroni adjustments were applied to correct for multiple comparisons). Non-parametric tests were conducted to assess if the beverage groups differed in how familiar they were with their test beverage. A Kruskal-Wallis test was conducted to assess if the three groups differed overall. Where overall differences were found, a Mann-Whitney test was conducted to determine which beverage group pairs differed.

When conducting repeated measures or mixed-model analysis of variance (ANOVA) tests, Greenhouse-Geisser corrections were used when any of the within-subject factors violated the assumption of sphericity. To interpret any overall differences that were found, post-hoc pairwise comparisons were conducted (Bonferroni adjustments were applied to correct for multiple comparisons).

To verify if the experimental manipulation of providing food and/or beverage to fasted participants affected feelings of hunger, thirst, and fullness appropriate to the appetite condition (i.e., hungry, but not thirsty; thirsty, but not hungry; both hungry and thirsty; neither hungry nor thirsty), a two-way repeated-measures analysis of variance (ANOVA) test was conducted. The within-subjects factors were appetite rating (i.e., hunger, thirst, fullness) and appetite condition (i.e., hungry, but not thirsty; thirsty, but not hungry; both hungry and thirsty; neither hungry nor thirsty).

Change scores were calculated to control for individual differences in the outcome measure, fluid intake: specifically, fluid intake in each condition (hungry, but not thirsty; thirsty, but not hungry; both hungry and thirsty) was subtracted from fluid intake in the control condition (neither hungry nor thirsty). A mixed-model analysis of variance test was conducted to assess if fluid intake was affected by the within-subjects factor: appetite condition (i.e., hungry, but not thirsty; thirsty, but not hungry; both hungry and thirsty) and the between-subjects factor: beverage group (Ribena, Ribena light, water).

4.3 Results

4.3.1 Participants

Out of the 36 participants recruited to take part in this study, only 33 participants completed all four sessions and one participant had to be excluded due to non-compliance. All analyses were performed on the remaining 32 participants (17 females; 15 males), aged 18-62 years ($M = 25.5 \pm 10.0$) who had been randomly assigned into one of the three following groups: Water (N = 10), Ribena light (N = 12), and Ribena (N = 10). Groups were well-matched on various characteristics: gender, age, education level, ethnicity, BMI, cognitive restraint, emotional eating, uncontrolled eating scores (results can be found in Table 4), diet history and familiarity with diet and regular products (data not shown).

Table 4 Participant characteristics

		Water	Ribena light	Ribena
	Gender (% male)	50%	50%	40%
	Age (means ± SD)	25(7)	25(10)	27(13)
	Ethnicity (% Caucasian)	90%	67%	80%
	Education level (% university graduates)	50%	58%	40%
	BMI (means ± SD)	25.0(7.8)	21.9(3.0)	23.8(4.7)
TFEQ	Cognitive Restraint (means ± SD)	12.2(3.9)	13.2(4.2)	11.5(2.6)
TFEQ	Uncontrolled Eating (means ± SD)	15.1(3.9	13.0(3.9)	13.2(4.5)
TFEQ	Emotional Eating (means ± SD)	19.8(8.8)	18.8(9.6)	18.9(10.6)

4.3.2 Preloads and test beverages

Liking ratings (scored on a scale from 1 to 10) for the preload (scones) was *M* = 5.5 ± 2.9. A series of one-way analysis of variance (ANOVA) tests and post-hoc pairwise comparisons evaluated how each group perceived their test beverage. Ribena (*M* = 204.0 ± 140.0) was correctly perceived as containing more calories than Ribena light (*M* = 18.0 ± 26.0) and water (*M* = 1.0 ± 2.0) ($p < .001$). Participants in the water group liked their test beverage more than participants in the Ribena light group ($p = .04$). Table 5 reports additional beverage ratings. A Kruskal-Wallis test demonstrated that the groups differed in how familiar they were with their test beverages $\chi 2(2)=21.2$, $p <.001$. A Mann-Whitney test revealed that the water group consumed their test beverage more frequently than the Ribena light group, z = -4.1, $p <.001$ and the Ribena group, z = -4.0, $p <.001$.

Table 5 Study beverage ratings

100 mm VAS	water	Ribena light means (± SD)	Ribena	statistics
Hydrating	91(11)^{a}	63(20)^{b}	57(20)^{b}	$F(2,29) = 12.4$, p < 001
Thirst-quenching	87(11)^{a}	67(18)^{b}	68(18)^{b}	$F(2,29) = 5.2$, $p = .01$
Nutritious	41(21)^{a}	36(24)^{a}	31(22)^{a}	$F(2,29) = 0.5$, $p = .61$
Filling	55(18)^{a}	58(20)^{a}	65(18)^{a}	$F(2,29) = 0.8$, $p = .47$
Energising	59(17)^{a}	53(28)^{a}	59(15)^{a}	$F(2,29) = 0.4$, $p = .71$
Taste	74(13)^{a}	64(25)^{a}	73(18)^{a}	$F(2,29) = 0.9$, $p = .44$

Each superscript value denotes comparisons that do not differ significantly at the .05 level.
Adjustment for pairwise comparisons: Bonferroni

4.3.3 The effect of hunger and thirst on beverage intake

Two-way repeated-measures analysis of variance (ANOVA) tests confirmed that the pre-loads appropriately manipulated hunger, thirst and fullness ratings immediately before ad-libitum intake across conditions, Greenhouse-Geisser corrected $F(3.29,82.16)=39.03$, p <.001, $\eta_p^2=.61$ (Figure 2).

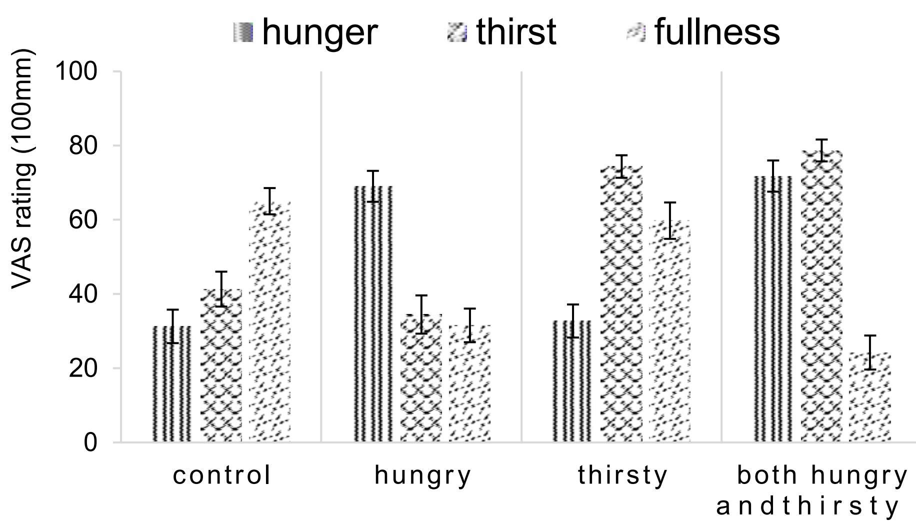


Figure 2 Average VAS appetite ratings immediately before ad-libitum intake in the neither hungry nor thirsty (control) condition, hungry condition, thirsty condition, and both hungry and thirsty condition.

To determine if fluid intake of Ribena, Ribena light, and water was affected by hunger and thirst, a 3 (beverage group) x 3 (appetite condition) mixed-model analysis of variance (ANOVA) was conducted. Fluid intake scores were calculated by subtracting fluid intake in each condition from fluid intake in the control condition (water, M = 201.7 ± 76.1 ml; Ribena light, M = 297.6 ± 193.3 ml; Ribena, M = 215.0 ± 100.4 ml). There was a main effect of appetite condition on fluid intake, $F(2,58)=5.42$, p =.007, ηp^2 = .16 (Figure 3). Post-hoc pairwise comparisons revealed that more fluid was consumed when participants were thirsty (regardless of hunger or fullness).

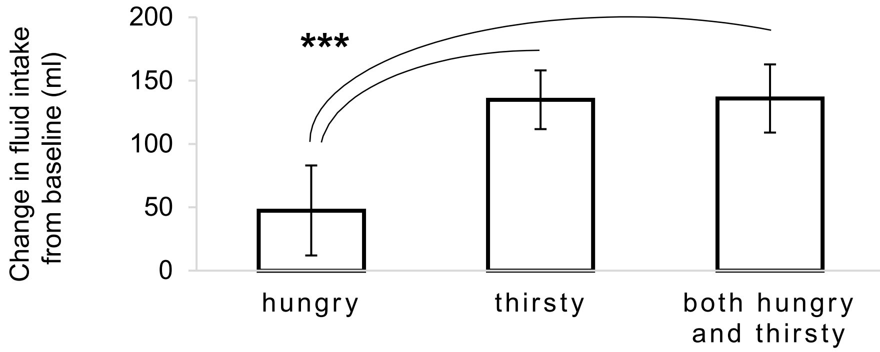


Figure 3 Average fluid intake (change from baseline) when hungry, thirsty, both hungry and thirsty, for all three beverages combined
*Asterisks denote comparisons that differ significantly at the .001 level****
Adjustment for pairwise comparisons: Bonferroni.

Contrary to the hypothesis, there was not an interaction between appetite condition and beverage type, $F(4,58)=1.45$, $p=.230$, $\eta p^2 =.09$ (see Fig 4). Post-hoc pairwise comparisons revealed that more fluid was consumed when participants were thirsty (regardless of hunger or fullness). Exploratory analyses were conducted on each beverage group independently. Only the water group revealed a significant main effect of appetite condition, $F(2,18) = 11.60$, $p=.001$, $\eta^2 =.98$. Intake of water was lower when participants were hungry compared to when thirsty ($p = .002$), and when both hungry and thirsty ($p = .002$). A series of one-way analysis of variance (ANOVA) tests revealed that there were no differences between the three beverage groups within any of the three appetite conditions (hungry, $p = .236$; thirsty, $p = .255$, and both hungry and thirsty, $p = .994$). Additional exploratory analyses (mixed-model analysis of variance (ANOVA) test) revealed that hunger, thirst, and fullness ratings after beverage intake did not differ based on the type of beverage consumed, Greenhouse-Geisser corrected, $F(6.6, 95.9) = .973$, $p = .453$, $\eta^2 = .063$.

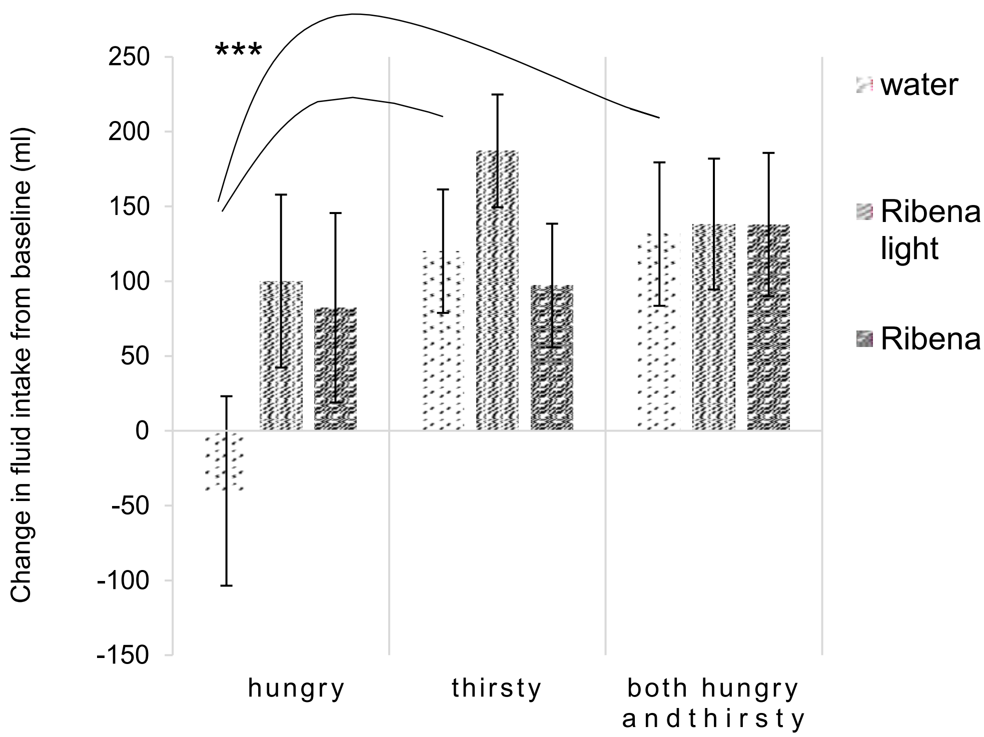


*Figure 4 Average fluid intake (change from baseline) of water, Ribena light, and Ribena when hungry, when thirsty, and when both hungry and thirsty. Asterisks denote comparisons that differ significantly at the .001 level***, .01 level**, and .05 level**

4.4 Discussion

It was expected that the greatest fluid intake would occur when participants were simultaneously food and fluid deprived due to the additive effects of hunger and thirst. However, participants in this study consumed more liquid when they were thirsty, and this relationship was affected by neither their hunger nor their fullness. As predicted, overall fluid intake of each beverage was comparable. However, the prediction that fluid intake among the three beverages would differ when hungry versus when thirsty (as some of the beverages possessed food-like properties) was not supported by the results of this study. In addition, the beverage type consumed did not affect feelings of hunger, thirst, and fullness differently, reinforcing the notion that participants did not recognize the food-like properties of the sweetened beverages.

The results of this study suggest that when fluid deprived, individuals essentially ignore whether they are hungry and whether the beverage possesses food like properties – intake is solely determined by the desire for fluid. That is, in the thirsty and hungry condition, participants who were given the opportunity to consume sweetened beverages did not consume more fluid compared to those with water. In the thirsty, but full (of food) condition, participants who were given the opportunity to consume sweetened beverages did not consume less fluid compared to those with water.

Power analyses calculated that 99.9% power had been achieved in Study 1. However, there were limitations that needed to be addressed. Specifically, post-hoc analyses performed within each of the three beverage groups suggest that the effect of thirst and hunger on fluid intake might be driven by the differences seen within the group who consumed water as the test beverage. On reflection, it is possible that having participants consume water for both the pre-load and the test beverage may have led to sensory-specific satiety for water, and therefore decreased its intake. In addition, allowing participants to leave shortly after the ad-libitum intake may have decreased intake in some participants as the knowledge that they could shortly resume their normal and eating and drinking behaviours may have influenced their behaviour during the test session. Therefore, Study 2 utilized a preload other than water to manipulate thirst, and the time in the lab after the ad-libitum intake was increased in order to mitigate possible effects of anticipation of eating and drinking outside the test session.

Part 2. Replication-extension: the effect of hunger and thirst on intake of a sugar-containing, a reduced-sugar, and an unsweetened beverage.

4.5 Methods

4.5.1 Participants

For Study 2, psychology undergraduate students and members from an online database belonging to the Nutrition and Behaviour Unit at the University of Bristol were recruited. Ethical approval was granted by the University of Bristol Faculty of Science Human Research Ethics Committee. Written consent was obtained from all participants. Participants who were: (1) not fluent in English, (2) unable or unwilling to consume the study foods and beverages, (3) unable or unwilling to fast for 11 hours, or (4) unwilling to provide urine samples at the start of each session were not eligible to take part. In order to conceal the true aims of the study from participants, it was advertised as investigating the effects of fasting on cognitive performance. Therefore, participants completed two distractor tasks (word recall and recognition tests) during the test sessions.

4.5.2 Study design

This study utilised a mixed measures design (3 groups x 3 repeated measures). Participants were assigned to a test beverage condition: water (0 kcal/ml), Ribena light (0.04 kcal/ml), or Ribena (0.41 kcal/ml) and always received that beverage (in the labelled bottle) during the ad libitum intake. Each participant took part in three appetite conditions: (1) hungry but not thirsty, (2) thirsty but not hungry, (3) neither hungry nor thirsty (control).

4.5.3 Hypotheses

Considering the results of Study 1, it was predicted that fluid intake when thirsty would be higher (compared to when hungry) regardless of beverage type. In addition, it was predicted that feelings of hunger, thirst, and fullness after beverage intake would not differ by beverage type.

4.5.4 Power calculations

Using the results from Study 1 which found a within-subjects effect of hunger and thirst on fluid intake ($\eta_p^2 = .16$), power calculations (95% power) indicated that at least 21 participants per group were required to detect a within-subjects effect of thirst and hunger on fluid intake. Although Study 1 did not find that beverage intake was affected by an interaction between beverage group (between-subjects factor) and appetite condition (within-subjects factor), the effect size, $\eta_p^2 = .09$, was used to ensure that the sample size in Study 2 would be large enough to detect an effect of this size. Power calculations (95% power) indicated that at least 45 participants (in total) were required. It was decided that 81 participants would be recruited (27 participants per group) to safeguard against attrition, to attempt to achieve a fully balanced Latin-square design, and to increase the likelihood that any exploratory analyses would properly powered.

4.5.5 Measures

The measures used in Study 2 were identical to those used in Study 1 (for details, please refer to section 4.2.6) with two exceptions: (1) Participants rated all three test beverages (instead of only their own test beverages); (2) An additional measure not included in Study 1, but was used in Study 2, was a measure of the "Time elapsed between the end of the test sessions and first eating and drinking episodes". At the end of each test session, participants were provided with the link to a survey and told that they should complete the survey by inputting the first food and beverage items that they consumed after leaving the test session and the timing of each ingestive event.

4.5.6 Study foods and beverages

Since the scones used in Study 1 were not well-liked by participants, they were replaced in Study 2. Pilot work selected Birds Eye Ham & cheese pastry wraps as the replacement as they were perceived as palatable, filling, and thirst-causing. A limitation identified in Study 1 was that using water as both the preload and the test beverage for some participants may have led to sensory specific satiety for water during the ad-libitum intake. Pilot work selected Twinnings camomile & honey infusion (a low-calorie beverage that is lightly flavoured and perceived as thirst-quenching) as the replacement. As differences in intake seen in the Study 1 were as little as 80 calories, it was important that the preload beverage provided very few calories. Similarly, a sweet or overly palatable beverage could not be used as it may have decreased hunger or desire to consume something providing sweetness and/or energy. However, at the same time, the beverage could not be unpleasant to drink as participants needed to drink 500 ml of the beverage and not feel nauseated afterwards. Additionally, it was important that the beverage was flavoured enough to distinguish it from water, but remained dissimilar to the taste profile of the sweetened blackcurrant beverages.

The preloads consisted of either Ham & cheese pastry wraps (462 kcal), 500 ml of Camomile tea & honey infusion (10 kcal), or both. Test beverages (water, Ribena light, and Ribena) were served in two appropriately labelled 500 ml bottles alongside a glass. Participants were instructed that they could choose whether to drink directly from the bottle or to use the glass. The pastries were served hot from the oven (190 °C) as per package instructions. All beverages were served chilled (but not directly from the fridge), as a systematic review determined palatability was greatest with cold drinks (0–10°C) and slowly decreased as beverage temperature rose (Burdon et al., 2012). The Camomile tea & honey infusion was brewed and chilled overnight. The average temperature measured immediately before serving was 9.5 ±1.5 °C. As the test beverages were served in sealed bottles, the temperature could not be directly assessed before serving. Using the guidelines detailed in Study 1, beverages were removed from a refrigerator (maintained between 1 and 4°C) (*SD* = 1.1), and were left out at room temperature for 10 minutes before being served.

4.5.7 Procedures

Multiple participants were tested at a time. In order to conceal the study aims, participants were always tested at the same time as other participants assigned to the same beverage group. To prevent order effects of the three appetite conditions, a counterbalanced design was used. Therefore, participants were tested with other participants completing different appetite conditions.

Participants were instructed to abstain from all beverages (including water) and foods starting 10 hours before each session to ensure that participants were similarly fluid and food deprived. At the beginning of each session, participants were provided with one of three possible preloads to manipulate their hunger and thirst:

a) Camomile tea & honey infusion (hungry but not thirsty condition)

b) Pastry wraps (thirsty but not hungry condition)

c) Pastry wraps and Camomile tea & honey infusion (control/neither hungry nor thirsty condition)

Test sessions began at either 9:00h or 11:00h. Participants were seated at desks between dividers so that they could not see one another. At the beginning of each session, participants completed appetite ratings (hunger, thirst, and fullness on a 100-mm VAS with anchor points ‘not at all’ and ‘extremely’), and reported what time they had last eaten and last drank. Participants were then required to provide a urine sample. The data on time since last meal and drink and the urine samples were not analysed, but were included in the study to encourage participants to comply with the overnight abstinence requirements.

Participants were given 10 minutes to consume all of the pre-load (or sit quietly during the control condition). Music was played in the background so that participants were unable to hear one another eating and drinking. After the pre-load, participants filled out appetite ratings and then spent 10 minutes completing a distractor task (cognitive measures). For the next 10 minutes, participants were told there was a break in the experiment and that they could relax, read, or do work. Participants then filled out appetite ratings and the experimenter stated “As some of you still have not had anything to eat or drink yet, I am going to hand out beverages while we wait for the next task. Please drink as little or as much as you would like”. Participants were then served with their assigned beverage. After 5 minutes, beverages were collected and put aside out of the participants’ view, and participants completed appetite ratings, followed by another distractor task (cognitive measures).

At the end of the final session, participants filled out a questionnaire about demographics, diet history, and the Three Factor Eating Questionnaire-R21 (TFEQ-R21) (Tholin et al., 2005). They also completed questionnaires on the study foods and all three beverages, completed a measure of demand awareness, and had their height and weight measured. The amount of time spent in the lab after the test of ad-libitum fluid intake was 10 minutes. Before leaving the session, participants were provided with the website address fir a survey and instructed to complete the measure of “Time elapsed between the end of the test session and the first eating and drinking episode.”

4.5.8 Data analysis

All analyses were performed using SPSS. The mean and standard deviation for participant characteristics was calculated. The mean and standard deviation of liking for the preload was calculated. Mixed-model analysis of variance (ANOVA) tests were conducted to assess if the beverage groups differed in their assessment of perceived calorie content of the three test beverages, how much they liked the three test beverages, how much enjoyed the taste of the three test beverage, and how hydrating, thirst-quenching, nutritious, filling, energising, they perceived the test beverages to be. Where overall differences were found, post-hoc pairwise comparisons were conducted to determine which beverage group pairs differed (Bonferroni adjustments were applied to correct for multiple comparisons). Non-parametric tests were conducted to assess if participants were equally familiar with all of the test beverages. Due to the repeated-measures nature of the data (all participants rated all test beverages), a Friedman test was conducted. Where overall differences were found, a Wilcoxon Signed Ranks test was conducted to determine which beverage group pairs differed.

When conducting repeated measures or mixed-model analysis of variance (ANOVA) tests, Greenhouse-Geisser corrections were used when any of the within-subject factors violated the assumption of sphericity. To interpret any overall differences that were found, post-hoc pairwise comparisons were conducted (Bonferroni adjustments were applied to correct for multiple comparisons).

To verify if the experimental manipulation of providing food and/or beverage to fasted participants affected feelings of hunger, thirst, and fullness appropriate to the appetite condition (i.e., hungry, but not thirsty; thirsty, but not hungry; neither hungry nor thirsty), a two-way repeated-measures analysis of variance (ANOVA) test was conducted. The within-subjects factors were appetite rating (i.e., hunger, thirst, fullness) and appetite condition (i.e., hungry, but not thirsty; thirsty, but not hungry; neither hungry nor thirsty).

To assess how long participants from each beverage group waited before eating and drinking after completing each of the three appetite conditions, a mixed-model analysis of variance test was conducted. There were two within-subjects factors: appetite condition (i.e., hungry, but not thirsty; thirsty, but not hungry; neither hungry nor thirsty) and ingestive behaviour (i.e., eating; drinking) and the between-subjects factor was beverage group (Ribena, Ribena light, water).

Change scores were calculated to control for individual differences in the outcome measure, fluid intake: specifically, fluid intake in both conditions (hungry, but not thirsty; thirsty, but not hungry) was subtracted from fluid intake in the control condition (neither hungry nor thirsty). A mixed-model analysis of variance test was conducted to assess if fluid intake was affected by the within-subjects factor: appetite condition (i.e., hungry, but not thirsty; thirsty, but not hungry) and the between-subjects factor: beverage group (Ribena, Ribena light, water). A secondary outcome measure was hunger, thirst, and fullness ratings at the end of the session: a mixed-model analysis of variance test was conducted. The within-subjects factor was appetite condition (i.e., hungry, but not thirsty; thirsty, but not hungry) and the between-subjects factor was beverage group (Ribena, Ribena light, water).

To mimic exploratory analysis conducted in Ch 4 Part 1, paired samples t-tests were conducted to assess if intake when hungry differed from intake when thirsty separately for participants who consumed water, for participants who consumed Ribena light, and for participants who consumed Ribena.

4.6 Results

4.6.1 Participants

Due to feasibility issues, 78 of the intended 81 participants were recruited for this study, 5 participants were removed from the analyses due to attrition and 7 because they correctly guessed the study aims. Analyses were performed on the remaining 66 participants (38 females; 28 males), aged 18-37 years (M = 21.5 ± 4.2), who comprised the following groups: Water (N = 22), Ribena light (N = 24), and Ribena (N = 20). These three groups were well-matched on gender, age, ethnicity, education level, BMI, cognitive restraint, uncontrolled eating, and emotional eating (data displayed in Table 6), diet history and familiarity of diet and regular products (data not shown).

Table 6. Participant characteristics

		Water	Ribena light	Ribena
	Gender (% male)	41%	42%	45%
	Age (means ± SD)	22 (1)	21 (1)	21(1)
	Ethnicity (% Caucasian)	64%	83%	55%
	Education level (% university graduates)	23%	21%	25%
	BMI (means ± SD)	24.9 (1.0)	22.3 (1.0)	23.2 (1.0)
TFEQ	Cognitive Restraint (means ± SD)	18.0 (4.9)	17.5 (5.4)	16.5 (4.6)
	Uncontrolled Eating (means ± SD)	13.9 (4.5)	10.4 (3.3)	11.9 (4.7)
	Emotional Eating (means ± SD)	21.9 (5.2)	22.8 (5.1)	20.3 (4.5)

4.6.2 Preloads and test beverages

Liking ratings (scored on a scale from 1 to 10) for the preloads were *M* = 7.43 ± .23 (pastries) and *M* = 2.90 ± .32 (tea infusion). A series of mixed model analysis of variance (ANOVA) tests and post-hoc pairwise comparisons revealed how participants perceived the three study beverages. The groups similarly and correctly perceived the absence of calorie content of water, but only the Ribena light group correctly perceived the calorie content of Ribena light and Ribena, $F(4,126)=4.2$, $p = .003$. This group difference may be due to the fact that the Ribena light bottle advertises its calorie content on the front label providing the participants in this group with additional information which they may have considered when making their caloric estimations. All other beverage ratings did not significantly differ among the beverage groups. Liking was highest for water, followed by Ribena, and then Ribena light ($p < .001$). Familiarity of the beverages differed by beverage type, (Friedman test, $\chi2(2)=117.5$, $p < .001$). Participants consumed water most frequently, followed by Ribena, then Ribena light, (Wilcoxon Signed Ranks test, $p < .001$). Table 7 reports additional ratings.

Table 7 Study beverage ratings

100 mm VAS	water	Ribena light means (± SD)	Ribena	statistics
Hydrating	92(14)^{a}	58(27)^{b}	40(27)^{c}	$F(2,130)=147.5$, $p < .001$
Thirst-quenching	88(19)^{a}	60(26)^{b}	59(26)^{b}	$F(1.5,95.8)=79.3$, $p < .001$*
Nutritious	63(36)^{a}	42(26)^{b}	40(27)^{b}	$F(1.2,80.0)=22.2$, $p < .001$*
Healthy	95(11)^{a}	47(25)^{b}	37(23)^{c}	$F(1.6,103.6)=296.3$, $p < .001$*
Filling	56 (29)^{a}	49(26)^{b}	53(29)^{a}	$F(1.3,85.5)=4.4$, $p = .03$*
Energising	48 (26)^{a}	48 (23)^{a}	58 (24)^{b}	$F(1.4,88.0)=9.5$, $p = .001$*
Taste	72(23)^{a}	57(22)^{b}	65 (22)^{a}	$F(1.6,104.3)=8.0$, $p = .001$*

Each superscript value denotes comparisons that do not differ significantly at the .05 level.
Adjustment for multiple comparisons: Bonferroni
**Greenhouse-Geisser corrected*

4.6.3 Hunger and thirst manipulation

Repeated-measures analysis of variance (ANOVA) tests confirmed that the pre-loads appropriately manipulated hunger, thirst and fullness immediately before ad-libitum intake across conditions, $F(4,252)=142.5$, $p <.001$, $\eta_p^2 = .69$ (Figure 5).

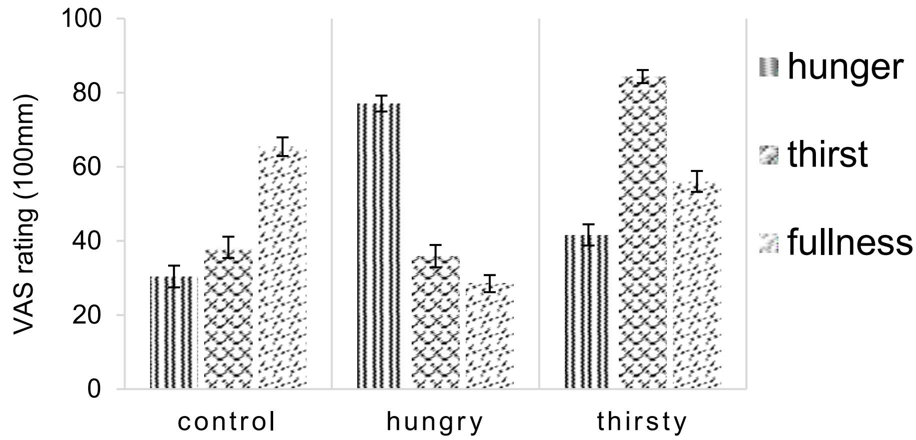


Figure 5 Average VAS appetite ratings immediately before ad-libitum beverage intake in the control (neither hungry nor thirsty) condition, hungry condition, and thirsty condition

4.6.4 Time elapsed between the end of the test session and first eating and drinking episode

The amount of time that elapsed between the end of the test session and before the first food or drink was consumed was self-reported by participants. Due to non-compliance, there was only complete data for 45 participants. A mixed model analysis of variance (ANOVA) revealed that participants ate and drank sooner after completing the hungry condition ($p < .001$) compared to the other two conditions, $F(2,84) = 19.3$, $p <.001$, $\eta p^2 = .31$, (see Figure 6). In addition, participants drank before they ate after completing the thirsty ($p < .001$) and control conditions ($p = .019$), but ate and drank concomitantly after the completing the hungry condition, $F(2,84)=10.2$, $p <.001$, $\eta p^2 = .20$, (see Figure 6). Finally, participants who drank Ribena light (as opposed to water) during the test sessions ate and drank sooner after the test sessions ($p < .008$), $F(2,42) = 4.2$, $p = .023$, $\eta p^2 =.17$) (results listed in Table 8).

Table 8 Elapsed time between the end of the test session and before the first food or drink was consumed separated by test beverage type (Means ± SD)

Test beverage type	minutes (means ± SD)
Water	125.16 (88.89)
Ribena light	84.25 (78.98)
Ribena	112.48 (103.80)

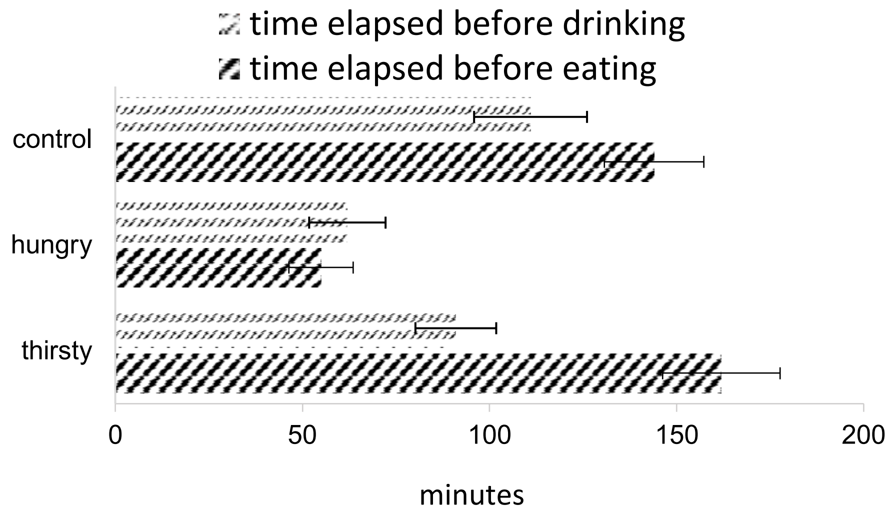


Figure 6 Time elapsed before eating and drinking after completing the test sessions.

4.6.5 Effect of hunger and thirst on beverage intake

To determine if fluid intake of Ribena, Ribena light, and water was affected by hunger and thirst, a 3 (beverage group) x 2 (appetite condition) mixed-model analysis of variance (ANOVA) was conducted. Fluid intake scores were calculated by subtracting fluid intake in both conditions from fluid intake in the control condition (water, *M* = 180.2 ± 163.0 ml; Ribena light, *M* = 325.8 ± 242.3 ml; Ribena, *M* = 231.6 ± 232.6 ml). The main effect of appetite condition on fluid intake, $F(1,63) = 18.2$, $p < .001$, $\eta_p^2 = .22$, revealed that intake was greater when thirsty (*M* = 127.7 ± 20.8 ml) compared to when hungry (*M* = 24.5 ± 22.8 ml). A power calculation suggests this finding reached over 99% power. The interaction between appetite condition and beverage type was not significant, $F(2,63) = .06$, $p = .947$, $\eta_p^2 = .002$ (Figure 7).

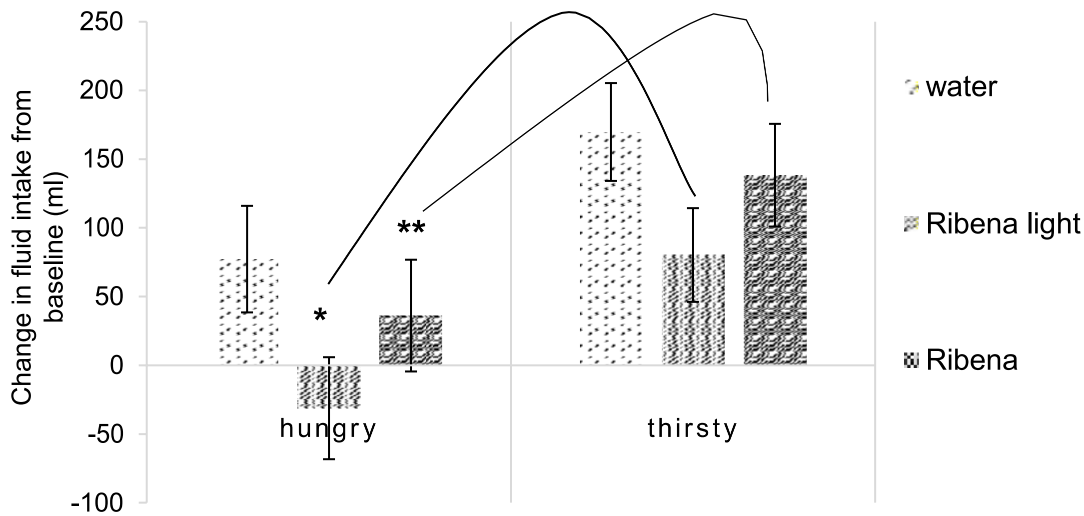


Figure 7 Average fluid intake (change from baseline) of water, Ribena light, and Ribena when hungry and when thirsty.
*Asterisks denote comparisons that differ significantly at the .001 level***, .01 level**, and .05 level**

4.6.6 Effect of beverage intake on hunger, thirst, and fullness

A mixed-model analysis of variance (ANOVA) test confirmed that hunger, thirst, and fullness ratings after beverage intake did not differ based on the type of beverage consumed, Greenhouse-Geisser corrected, $F(5.4,168.5) = 1.2$, $p = .316$, $\eta p^2 = .04$).

4.7 Discussion

Both Study 1 and Study 2 were adequately powered and revealed participants consumed more fluid when they were thirsty compared to when they were hungry irrespective of the beverages' food-like properties. Similarly, fluid intake relieved thirst regardless of beverage type. Since the sweetened beverages were generally perceived as less hydrating and thirst-quenching than water was, if given a choice, participants may have avoided the sweetened beverages in the thirsty condition. However, in this study participants could not choose the type of fluid. Therefore, any fluid was better than no fluid, which helps explain why intake and subsequently reported thirst were similar for all three beverages despite differing perceived properties.

Although the beverages were rated as possessing varied food-like qualities (*e.g.* Ribena as energising, Ribena light as less filling, water as more nutritious), their intake was not motivated by hunger, nor was it inhibited by fullness (from food). In addition, hunger, thirst, and fullness after intake were not affected by beverage type. Further, the finding that eating episodes after the test sessions occurred more urgently after participants took part in hungry condition supports the main finding that participants did not perceive the flavoured and/or calorie-containing beverages as substitutes for food. Nonetheless, these results may be dependent on food accessibility of the environment. That is, there is no need to consume a caloric beverage for energy when food is so easily accessible.

From a biological perspective, this robust effect of thirst (and not hunger) on fluid intake is not surprising as thirst is a more precarious state for survival than hunger is (Mattes, 2010) and therefore should be more urgently attended to. These results are in line with the current body of literature on fluid restriction on fluid intake (Corney et al., 2015; Kelly, P. J., Guelfi, K. J., Wallman, K. E., & Fairchild, 2012; Shirreffs et al., 2004), but is unique in its finding of fluid restriction on increased energy intake (when the energy is in the form of fluid and being consumed in isolation). Offering sweetened beverages (without satiation cues) to hungry participants did not motivate them to consume the beverages for their flavour and energy. However, satiation cues, such as texture, might be particularly important when the beverage is consumed on its own, and less relevant when ingesting several items at once (*e.g.,* from a buffet) (Hogenkamp et al., 2012). For example, Chapter 5 will discuss a virtual study in which participants selected water, a reduced-sugar-sweetened beverage, or a sugar-sweetened beverage, based on the portion size of the food that they were expecting to eat (Ferrar, Griggs, Stuijfzand, & Rogers, *in preparation*). On their own, beverages might not be an effective substitute for a food, but might be a suitable addition to a relative lack of food (*i.e.,* adding a beverage to a meal to compensate for a reduced portion size of food).

In Study 1, post-hoc analyses suggested that the effect of thirst (versus hunger) on fluid intake was driven by the differences in water intake. There was concern that those differences could be attributed to the methodology used in the study (*i.e.,* that the 500 ml water preload used during the *hungry, but not thirsty* *condition* may have caused sensory specific satiety for water and accordingly, low water intake). Therefore, in Study 2, the water preload was replaced with a flavoured fluid. Post-hoc analyses revealed that water intake did not differ between appetite conditions, partially supporting the above interpretation. When hungry, water intake may have been reduced to a greater degree in Study 1 (compared to Study 2) due to differences in study methodology. However, this discrepancy is trivial as in spite of it, the overall effect of thirst (versus hunger) on fluid intake demonstrated in Study 1 was replicated by Study 2.

In Study 1, there was also concern that allowing participants to leave shortly after the ad-libitum intake may have decreased the amount they consumed because of the knowledge that they would soon be free to eat or drink whatever they would like. In Study 2, time spent in the lab after the ad-libitum intake was increased by five to ten minutes and participants self-reported the time of their first eating and drinking episodes. It does not seem to be the case that participants drank immediately after the sessions. The data illustrated that after the thirsty and control conditions, drinking episodes were likely to occur independently of eating episodes; and participants waited on average at least an hour and a half before drinking. In contrast, after the hungry condition, drinking and eating episodes were likely to occur concomitantly; and participants waited on average at least an hour before drinking. In addition, the half hour difference in timing is probably because participants were more motivated to eat after the hungry condition, and most drinking occurs around the mealtimes to wash the food down or mitigate thirst caused by eating (de Castro, 1988; Phillips et al., 1984).

Substituting sugar-sweetened beverages with lower energy options (*e.g.,* low-energy-sweetened beverages or water) can help to reduce energy intake (Bellisle & Drewnowski, 2007; Mattes & Popkin, 2009; Miller & Perez, 2014; Rogers, Hogenkamp, et al., 2016). Whether the option used as a substitute affects weight loss outcomes is a point of contention. Some research indicates that individuals who substitute with low-energy-sweetened beverages, compared to individuals who substitute with water, will experience similar (Tate et al., 2012) or greater weight loss (Peters et al., 2014, 2016). It has been suggested that exposure to sweetness without energy (i.e., low-energy sweeteners) decreases subsequent desire for the same or other sweet items, which indicates a helpful effect of low-energy-sweetened beverages compared to water (Rogers, Hogenkamp, et al., 2016). However, other research has demonstrated that replacing low-energy-sweetened beverages with water helped individuals to lose weight (Madjd et al., 2015) and maintain that weight loss over a year (Madjd et al., 2018). In this study, participants who drank Ribena light ate and drank sooner than participants who drank water. Ribena light was liked less and perceived as having less of an enjoyable taste, as being less filling, less nutritious, less healthy, less hydrating, and less thirst-quenching than water. It is possible that the relative unpleasantness of Ribena light left participants at the end of the test session more motivated to seek compensatory reward from food and fluid. Similar to Madjd and colleagues' results (2015; 2018), this finding suggests an unhelpful effect of consuming low-energy sweeteners in place of water and needs to be investigated further.

The extent to which the effects found in these studies have a primarily 'biological' or primarily 'psychological' basis is a moot point. While a biological manipulation (restriction of fluid and food) was utilized, its purpose was to prime participants to believe that they were thirsty or hungry by highlighting to them that they had deviated from their usual schedule of ingestive events. This manipulation was utilized as instances of a physiological need for fluid and energy are rather rare in ad-libitum environments (Rogers, Ferriday, et al., 2016) and as suggested by the qualitative results described in Chapter 2, eating and drinking occur when individuals believe that they are hungry and thirsty regardless of their current physiological state. The ad-libitum intake occurred for only five minutes, and appetite ratings were recorded immediately after. Fluid balance is restored rather quickly (Poothullil, 2005), and therefore the decrease in thirst ratings could have been the result of physiological mechanisms. However, belief and expectations (*e.g.,* knowledge of consuming a beverage after being fluid restricted for hours) might have also influenced participants to believe that they felt less thirsty. The mechanisms which led to changes in perceived hunger and fullness could have also been partly physiological (*e.g.,* taste of fluid in the mouth or feeling fluid in the stomach), but mainly psychological. The time frame was too short for post-ingestive feedback responses to occur, but the pleasurable taste of the fluid in the mouth, momentary feelings of stomach fullness, and the knowledge that calories had been consumed, might have increased expectations to feel less hungry and fuller. Future research might want to disentangle the physiological and psychological mechanisms involved. For example, appetite ratings and fluid intake could be assessed when fluid balance is covertly manipulated (*e.g.,* hypohydrated participants who believe they are euhydrated versus euhydrated participants who believe they are hypohydrated) but using a more ecologically valid method than gastric feeding tubes (James et al., 2017). Appetite ratings and fluid intake could be assessed when the beverages are unlabelled, so that participants are unaware of whether or not they are ingesting calories. Awareness of the caloric content of the beverages may have both influenced how much was consumed and subsequent feelings of thirst, hunger, and fullness.

A disadvantage to the efficient behavioural response to thirst is that in the context of the complex assortment of energy-containing beverages constantly available in our environment, there is a high likelihood of inadvertently increasing energy intake while trying to relieve thirst. In this study, participants who drank Ribena while thirsty consumed on average between 41 and 57 additional kcals (compared to when hungry and when neither hungry nor thirsty, respectively). Evidence suggests that this increase in energy intake would not be fully compensated for in the next or subsequent eating and/or drinking occasions (Rogers, Hogenkamp, et al., 2016). In the qualitative study described in Chapter 2, participants often reported consuming beverages for reasons other than to quench thirst (e.g. for an energy boost; for the taste; to take a break or refresh). Considering the results of the present study, consuming an energy-containing beverage in a context other than being thirsty could be helpful for maintaining body weight. Whereas consuming one or two sugar-sweetened beverages a day in order to quench thirst may be problematic for healthy weight management.

Chapter 5 The contribution of beverages to meal reward

Part 1. Does (expected) beverage choice compensate for the size of a meal?

5.1 Introduction

The results of chapter 4 suggest that intake of beverages which possess food like qualities (*e.g.,* flavour and energy) is not motivated by hunger, nor is it inhibited by fullness (from food). Further, the intake does not alleviate hunger nor increase fullness. Thus, liquid calories without obvious satiety-relevant cues (*e.g.,* viscosity) are at risk of overconsumption (Flood-Obbagy & Rolls, 2009; Malik et al., 2013, 2006; Mattes, 2005; McCrickerd et al., 2014; Mourao et al., 2007). However, satiety-relevant cues (*e.g.,* viscosity) might be particularly important when the beverage is consumed on its own, and less relevant when ingesting several items at once (*e.g.,* from a buffet) (Hogenkamp et al., 2011).

A theme discussed in Chapter 2 was that feeling "hungry" and "thirsty" are often caused by frustration experienced when food or beverages are inaccessible (even if for only a limited period of time). Participants in the qualitative study explained that the frustration arose because they were accustomed to instant gratification in relation to eating and drinking (*e.g.,* 24-hour grocery stores). Privileged individuals with ad-libitum access to food have little need to rely on liquid calories as a significant source of energy. Therefore, participants in the experiments of Chapter 4 may not have felt enough urgency to identify and use the beverages as sources of flavour and energy. Conversely, beverages may be identified and used as significant sources of taste, energy and satiation when consumed as supplementation to more obvious sources of taste, energy, and satiation (*i.e.,* food items).

Meals are, of course, examples of beverages being consumed alongside food items (McKiernan et al., 2009). As illustrated in Chapter 3, the combination of food and beverage as part of a meal might occur because the beverage facilitates the process of mastication (Bellisle & Le Magnen, 1981; Kissileff, 1973) and reduces negative consequences of eating, like thirst (Phillips et al., 1984). The combination of food and beverage as part of a meal may also occur because both components contribute to meal satisfaction. Meal satisfaction is comprised of the enjoyment of taste experienced during the meal and post-meal fullness (Rogers, Ferriday, et al., 2016). Adding a beverage which is palatable and/or filling can therefore be expected to increase meal satisfaction. This is particularly relevant when trying to maintain meal satisfaction despite changes to hedonic and satiating aspects of a meal (*e.g.,* reducing the portion size or energy-density of food). For example, focus groups on consumer's attitudes and feelings about portion size reduction revealed that participants, who expected to feel dissatisfied by a reduced portion size, predicted that they would compensate for the "missing food". Specifically, they believed that they would consume a second serving, adding a side dish or beverage, or having a snack later on (Ferrar, Ferriday, et al., *under review*). It is possible that individuals who utilize these compensatory techniques would negate the original efforts to reduce energy intake.

While research has demonstrated that both energy dense foods (*e.g.,* crisps or cake) and beverages (*e.g.,* juice or soda) have relatively weak calorie-for-calorie satiety effects (Brunstrom, Rogers, Pothos, Calitri, & Tapper, 2008; Brunstrom & Rogers, 2009; Martin et al., 2015) and increase energy intake (Malik et al., 2013, 2006; Nederkoorn, Houben, Hofmann, Roefs, & Jansen, 2010; Prentice & Jebb, 2003), the addition of a beverage to a meal might occur at a more implicit level. Anecdotally, the addition of a beverage to a meal is more routine (most meals are consumed with beverages) than the addition of a side dish or snack (only some meals are consumed with accompaniments). When attempting to reduce meal portion size, the addition of an energy dense snack or side dish seems explicitly counterproductive to the original goal of reducing energy intake. However, the addition of a beverage might or might not be considered counterproductive depending on the perceived properties of the beverage (*i.e.,* hydrating vs. filling). Therefore, someone who is actively trying to reduce their intake might be more likely to use beverages than food to sustain meal satisfaction, unaware that they may be undermining their original goal. Therefore, the current study investigated if changes in food portion size, and thus changes in meal satisfaction, influence choice of beverages based on their flavour and energy properties.

Although the majority of drinking occurs around the time of meals (McKiernan et al., 2009), anecdotal evidence suggests that the timing of beverage selection and consumption varies. For example, beverages can be chosen before or after the food is decided on. Beverages may be consumed regularly throughout the meal, towards the end of the meal or even after all the food has been eaten. There is variability in the timing of the selection and the consumption of foods and beverages, within a single meal. However, individuals are likely to prioritize decisions about the food (as it is the main component of the meal), and subsequently choose a drink as an accompaniment (as it is a secondary component). Therefore, methodology was designed which assumes that the beverage can be consumed at any point during the meal. However, the key factor is that the food component of the meal is decided on before selecting a beverage, which is consistent with expected effects of meal pre-planning and subsequent plate-cleaning (Fay et al., 2011), as mentioned in Chapter 3.

An online study was conducted to investigate whether providing individuals with meals smaller or larger than their "ideal" portion sizes would influence their choice of beverage to accompany those meals. It was predicted that an individual presented with a larger than ideal food portion size may feel overwhelmed by the imagined orosensory properties or the degree of expected satiety from the food, and to compensate would choose a lower-calorie beverage. Similarly, an individual presented with a smaller than ideal food portion size may feel underwhelmed (*i.e.,* they might predict that consuming the food would not fully satiate them or they would be left wanting additional orosensory reward) and would therefore choose a higher-calorie beverage. If changes in beverage choice were in line with the predictions, it would suggest that individuals recognised and took into account the varying qualities of different beverages (*i.e.,* water provides hydration, reduced-sugar-sweetened beverages provide hydration and flavour, and sugar-sweetened-beverages provide hydration, flavour and energy), and to a degree, were using them as foods.

5.2 Methods

5.2.1 Participants

Participants (*N* = 170) were recruited through an online platform, Prolific Academic (Isis Software Incubator Isis Innovation Ltd, 2017). In order to be eligible for the study, participants had to be aged 18 years or older, fluent in English, be a U.K. national, and currently reside in the U.K. Participants could not be vegan, vegetarian, have a history of eating disorders, have any allergies or intolerances to food, or eat or drink while taking part in the study. The eligibility criteria were listed before participants gave informed consent. Additionally, questions checking the eligibility criteria were embedded in a questionnaire at the end of the study to verify eligibility. Data collected from ineligible participants was deleted prior to analysis. Each participant was reimbursed £0.90 for successful completion of the study, which was credited to their Prolific Academic account. Ethical approval was granted by the University of Bristol Faculty of Science Human Research Ethics Committee.

5.2.2 Software

The task was a single-page webapp, built using TypeScript and Angular(Google, 2016). Participants could only complete the study from a desktop computer (not a tablet or mobile phone) due to the need for keyboard input to select portion sizes. The task was tested on the most recent versions of Chrome, Firefox, and Internet Explorer, and CSS (style sheet language) was used to ensure the on-screen size of salient task elements (e.g. VAS being 100 mm) was kept constant across devices. The data was stored in a University of Bristol supported database (MySQL) which was hosted on a University of Bristol managed server.

5.2.3 Virtual test foods and beverages

Test foods: Spaghetti Bolognese (Beef), Chicken Chow Mein, and Chicken and Prawn Paella were selected as the food "preloads" as they are foods commonly served in the U.K., represented three different cuisines, and each included different main-ingredients (*i.e.,* beef, chicken or prawns) to increase the likelihood of participants liking and being familiar with at least one of the three foods. Nutritional information for the three foods is listed in Table 1. Each food was photographed, with the use of a high-resolution digital camera, on the same white plate (255 mm diameter). Particular care was taken to maintain constant lighting conditions and plate position in each photograph. Photograph sets consisted of 50 photos, ranging from 20 kcal to 1000 kcal in equicaloric steps (preserving the same overall macronutrient composition within each set of images). The name of the food was included in the top left-hand corner of every image (Brunstrom et al., 2016; Hinton et al., 2013; Wilkinson et al., 2012).

Test beverages: Ribena and Ribena light (Lucozade Ribena Suntory Ltd.) were selected as the reduced-sugar-sweetened beverage and the sugar-sweetened beverage, respectively, as they are highly familiar to individuals from the United Kingdom. Non-carbonated beverages were selected to avoid possible effects of carbonation on appetite (Moorhead et al., 2008) in this study. Highland Spring Still Water was selected as the brand of water, as it is commercially available in supermarkets where Ribena and Ribena light are sold and the bottle has a similar shape to Ribena and Ribena light bottles. Nutritional information for the three beverages is listed in Table 8. Each beverage was photographed with the use of a high-resolution digital camera. The photographs were of each beverage in its 500 ml bottle. The front of the label, with the name of the beverage and any advertised information, was visible.

Table 9 Nutritional information for test beverages and foods (values per 100 ml for beverages and per 100 g for foods).

	Energy (kJ)	Energy (kcal)	Protein (g)	Fat (g)	Carbohydrates (g)	Salt (g)
Beverages						
Water	0	0	0	0	0	<0.01
Ribena light	20	5	0	0	0.6	<0.01
Ribena	175	41	0	0	10.0	<0.01
Foods						
Spaghetti Bolognese	593	141	7.2	5.3	16.2	0.28
Chicken and Prawn Paella	553	132	7.7	4.2	14.8	0.60
Chicken Chow Mein	343	81	6.6	2.1	8.9	0.72

5.2.4 Measures

Beverage choice task: The task consisted of fifteen trials presented in a random order. In each trial, one of the three test foods (Spaghetti Bolognese, Chicken Chow Mein, and Chicken and Prawn Paella) in one of five portion sizes (100 kcal, 300 kcal, 500 kcal, 700 kcal, and 900 kcal) was displayed. The instructions were to choose between the three beverage options (water, Ribena light, or Ribena) to accompany the meal. Although the photographs were of the 500 ml bottles, participants were informed that they should imagine consuming half of the bottle (250 ml) as that is the recommended serving on the label. Specifically, participants were presented with the following instructions: “Imagine that you are having the following meal for lunch. Imagine that you must eat everything on the plate and that no other foods will be available until dinnertime! Please click on the beverage that you would have with this meal, knowing that you must consume 250 ml of the beverage.”

Ideal portion size task: The task consisted of four trials. In each trial, one of the fifty portion sizes (20-1000 kcal) was randomly selected as the starting portion size. The photographs were loaded with sufficient speed that continuous key depression gave the appearance that the change in portion size was animated. Depressing the left or right keyboard arrow key caused the portion size to decrease or increase, respectively(Brunstrom et al., 2016; Hinton et al., 2013; Wilkinson et al., 2012). The first trial allowed participants to practice the task by changing the portion size of a plate of peanuts (a food that would not appear elsewhere during the experiment). The following three trials, which were presented in a random order, consisted of selecting ideal portion sizes for the three test foods (Spaghetti Bolognese, Chicken Chow Mein, and Chicken and Prawn Paella). Specifically, participants were instructed to “Imagine that you have just sat down to have the following meal for lunch. No other foods are available during lunch and you will not be able to eat anything else until dinnertime,” and to “Select the amount that you would eat”(Brunstrom et al., 2016).

Beverage and Food ratings: Participants were asked to rate each of the three foods (500 kcal) and each of the three beverages (250 ml) on various characteristics, regardless of whether or not they had ever consumed them. If they had never consumed the beverage or food, they were instructed to make the ratings based on a very similar beverage or food that they had consumed before. To assess familiarity, participants reported how frequently they consumed each beverage and food (*e.g.,* several times a day, once a day, several times a week, etc.). They also reported how many calories they thought the food and beverages contained. The following ratings were rated on 100 mm VAS (anchored from “Not at all” to “Extremely”). Participants reported how much they liked the food and beverages. For each food, they reported how filling and thirst-causing they perceived it to be. For each beverage, they reported how much they enjoyed its taste, and how filling, energising, nutritious, hydrating, and thirst-quenching they perceived it to be.

Appetite ratings: Participants reported levels of hunger, thirst and fullness using 100 mm VAS (anchored from “Not at all” to “Extremely”).

Habitual behaviour: Participants reported which beverages they usually consumed from the following choices: a) mostly diet (“zero-calorie / sugar-free”), b) mostly regular (“sugar-containing”), c) a mix of both, or d) neither.

Demographics: Participants reported their age (years), gender, ethnicity, and highest level of education.

Weight status and dietary information: Participants reported their height and weight (metric or imperial units), whether they considered themselves to be overweight, and if they were currently dieting. If participants were not currently dieting, they were asked if they had dieted in the past. If participants had dieted in the past, they were asked to record the number of times they had dieted in the past 12 months. Participants also completed the cognitive restraint subscale of the Three Factor Eating Questionnaire R21 (Tholin et al., 2005).

Demand awareness: Participants were asked to describe what they thought the study was investigating.

5.2.5 Procedure

The study took approximately 10 minutes to complete. Participants were instructed to read information about the study and the inclusion/exclusion criteria. After giving informed consent, they completed appetite ratings, the “Ideal food portion size” task (including the practice trial), and the “Beverage choice” task. Participants then rated the study foods and beverages, and filled out the questionnaire on demographics and dietary behaviour. Before debriefing participants, demand awareness was measured. As the study was hosted online, an “attention check” question was included to ensure that valid data was collected (Oppenheimer, Meyvis, & Davidenko, 2009). Embedded among the appetite ratings, a VAS for “tiredness” with unique instructions to refrain from making a rating on the scale, but to instead click on the word “tired” was included. In addition, at the end of the study, exclusion criteria questions (history of eating disorders, vegetarian or vegan, food allergies or intolerances, last eating episode, and last drinking episode) were included to ensure the dataset did not include participants who violated the exclusion criteria.

5.2.6 Data Analysis

Data selection: It was predetermined that analyses would focus on the food that was most liked by and most familiar to participants, and that follow-up analyses would be performed on the other two foods to ensure that any effects could be replicated with other types of foods (even ones that were less liked). It was expected that participants who disliked or were unfamiliar with any of the beverage options presented in this study might continually select the same beverage despite changes in food portion size. These potential confounders, *i.e.,* liking for and familiarity with the three beverages, might influence beverage choice, inaccurately depicting participants' sensitivity to changes in taste and calories provided by the meals. Therefore, it was decided that these variables would be controlled for in the statistical models. Since liking and familiarity ratings of the beverages will likely be correlated, only liking will be included.

Analysis strategy: The data were analysed using SPSS Statistics (IBM Corp, 2015) and STATA (StataCorp, 2015). As the three beverages selected for this study could be defined as ordered categorical outcome variables: Ribena = (+) energy (+) taste; Ribena light = (-) energy (+) taste, and water = (-) taste (-) energy, ordinal logistic regression was used for all analyses investigating relationships between this variable and its predictors (*i.e.,* food portion size, ideal food portion size, and liking for the beverages). It should be noted here that due to the repeated measures nature of the study (*i.e.,* there are multiple observations for each participant), the assumption of independency of observations is violated and a conventional ordinal logistic regression analysis is therefore inappropriate. To address this, all models were specified as multilevel ordinal logistic regression models, where observations (level 1) were nested within participants (level 2). The multilevel model approach is described by Field and Wright (Field & Wright, 2011) and Hayes (Hayes, 2006). The Akaike Information Criterion (AIC) and the Bayesian Information Criterion (BIC) were used for model selection, predicted probabilities and confidence intervals were used for model prediction, and likelihood ratio tests were used for significance testing.

5.3 Results

5.3.1 Participants

Four participants were removed from the analyses because they had never consumed any of the three foods. The remaining sample consisted of 166 participants, 103 women and 63 men, of White, Black, Asian, mixed, and other descent, aged 18 to 81 (M = 34.2 ± 12.8) years. 50.6% of the sample had an undergraduate degree and 17.5% had a postgraduate degree. BMI ranged from 15 to 45 (*M* = 25.5 ± 5.3) kg/m2, and dietary restraint scores ranging 9 to 21 (*M* = 14.5 ± 2.3). 29.0% of the sample was currently dieting. Participants rated their hunger (*M* = 38.0 ± 26.0), thirst (*M* = 50.0 ± 24.0), and fullness (*M* = 51.0 ± 25.0). Three participants correctly guessed the study aims, but were retained in the analyses as removing their data did not affect the results.

5.3.2 Beverage characteristics

34.3% of the sample normally consumed diet beverages, 34.9% normally consumed regular beverages, 16.9% normally consumed a mix of both diet and regular beverages, and 13.9% normally consumed neither. 45.7% of the sample had never tasted Ribena light and 19.9% of the sample had never tasted Ribena. Table 9 lists participants' caloric estimations for a 250 ml serving of water, Ribena light, and Ribena. A Friedman test revealed that familiarity with the test beverages differed (p <.001). A Wilcoxon signed ranks test specified that water was consumed more frequently than both Ribena light ($p < .001$) and Ribena ($p < .001$). Repeated measures analysis of variance (ANOVA) tests were conducted to determine how the three beverages may have differed in their perceived properties. The following results have had Greenhouse-Geisser corrections applied. Water was the most liked beverage, followed by Ribena, and then Ribena light ($p < .001$). Participants enjoyed the taste of water, followed by Ribena, and then Ribena light. Water was perceived as more hydrating ($p < .001$), thirst-quenching ($p < .001$), and nutritious ($p < .001$) than both Ribena light and Ribena. Ribena was perceived as more filling ($p < .001$) and more energizing ($p < .001$) than both water and Ribena light ($p < .001$).

5.3.3 Data selection

Ideal food portion size (kcal) for all three foods was as follows: Spaghetti Bolognese (*M* = 468.0 ± 191.0), Chicken and Prawn Paella (*M* = 449.0 ± 209.0), and Chicken Chow Mein (*M* = 357.0 ± 210.0). Table 9 lists participants' caloric estimations for a 500 kcal serving of Spaghetti Bolognese, Chicken and Prawn Paella, and Chicken Chow Mein. The three foods were rated as equally filling (p = .220). Chicken Chow Mein and Chicken and Prawn Paella were believed to increase thirst to a greater degree than Spaghetti Bolognese ($p < .001$). Participants liked

Spaghetti Bolognese the most, followed by Chicken Chow Mein, and then Chicken and Prawn Paella (p < .001). A Friedman test revealed that there was a significance difference in familiarity with the three foods, p < .001. A Wilcoxon Signed Ranks tests revealed that participants were more familiar with Spaghetti Bolognese than Chicken Chow Mein (p < .001) and Chicken and Prawn Paella (p < .001). As Spaghetti Bolognese was most liked and most familiar to participants, it was selected for the main data analysis.

Table 10 Participant caloric estimations of study foods and beverages

	Estimated kcal	*Actual kcal*
Spaghetti Bolognese (500 kcal)	883.8 (502.0)	*500*
Chicken and Prawn Paella (500 kcal)	880.8 (457.4)	*500*
Chicken Chow Mein (500 kcal)	918.8 (490.9)	*500*
Water (250ml)	16.2 (88.7)	*0*
Ribena light (250ml)	207.9 (419.3)	*10*
Ribena (250ml)	455.4 (482.3)	*103*

5.3.4 Effects of portion size on beverage choice

As predicted, liking and familiarity ratings for each beverage were correlated (water: r = .52, p < .001; Ribena light: r = .63, p < .001; Ribena: r = .69, p < .001). Liking ratings among the three beverages were also correlated (water and Ribena light, r = -.26, p = .001; water and Ribena, r = -.23, p = .003; Ribena light and Ribena, r = .58, p < .001), so liking for a single beverage (Ribena) was entered as a covariate for the models.

Model 1 was produced using a multilevel ordinal regression analysis to predict beverage choice using grand mean centered (*i.e.,* zero represents the average portion size) food portion size, grand mean centered ideal food portion size, and the interaction between the two as the predictors. Grand mean centered liking for Ribena was included as a covariate (Table 9 displays the full results). The AIC and BIC of Model 1 (AIC = 1000.0, BIC = 1033.1) was compared to those of the constant only model (AIC = 1220.2, BIC = 1234.3) indicating that the predictors as a set reliably distinguished between the three beverage choices. Food portion size was a significant predictor of beverage choice (p < .001). The likelihood of choosing water increased as portion size of the food increased, the likelihood of choosing Ribena and Ribena light decreased as portion size of the food increased (see Figure

8). However, there was not an interaction effect between food portion size and ideal food portion size. Additionally, beverage choice was affected by how much Ribena was liked ($p < .001$).

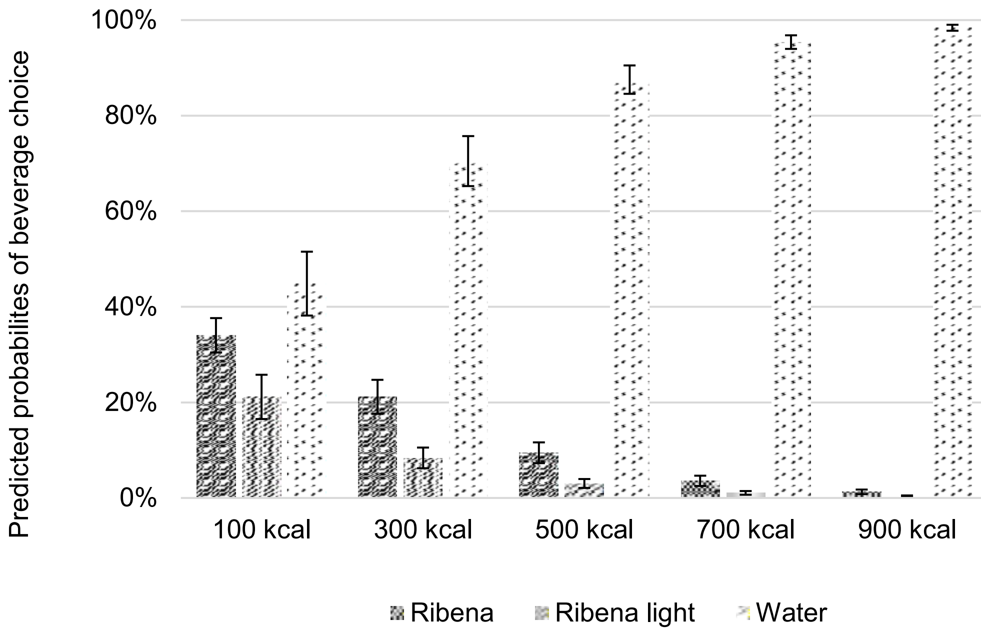


Figure 8 Predicted probabilities of Model 1 for selecting Ribena, Ribena light and water when presented with a 100kcal, 300kcal, 500kcal, 700kcal, and 900kcal of Spaghetti Bolognese.

5.3.5 Exploratory analyses

Since ideal food portion size did not interact with food portion size to best predict beverage choice, other factors believed to influence beverage choice and food portion size were explored. Men on average have a higher energy intake requirement than women (Owen et al., 1986, 1987) and tend to choose larger portion sizes than women (Brunstrom, Rogers, et al., 2008). Studies have also found gender differences in energy compensation for liquid and semi-solid preloads (Davy, Van Walleghen, & Orr, 2007; Gadah et al., 2015; Ranawana & Henry, 2010) and attribute these differences to differences in cognitive control (*i.e.,* that women had a greater tendency to restrict intake) (Gadah et al., 2015). Highly restrained individuals may consistently make “healthier” or more restrictive choices (*e.g.,* err towards selecting low-calorie beverages), but when presented with portions larger than their ideal they may demonstrate counter-regulatory eating (Herman & Polivy, 1983). That is, since the meal has already pushed them past a cognitive “diet boundary” they may choose the caloric beverage (“what the hell effect”). Less clear is the influence that BMI may have. Burger and colleagues (Burger et al., 2007) found that BMI positively predicted portion size, however Brunstrom and colleagues (Brunstrom, Rogers, et al., 2008) found that dieting, dietary restraint and current hunger, but not BMI, predicted portion size. Food liking predicts portion size and food reward (Brunstrom & Shakeshaft, 2009), and therefore the extent to which a participant likes the food might influence their ideal food portion size and in turn their beverage choice; that is, if they dislike the test food they may be dissatisfied regardless of portion size and seek satisfaction from the beverage.

Gender: Male and female participants did not differ in their ideal food portion size selections $t(164) = 1.74$, $p = .08$. Model 2 used a multilevel ordinal regression analysis to predict beverage choice using grand mean centered food portion size, grand mean centered ideal food portion size, and the interaction between the two as the predictors. Grand mean centered liking for Ribena and gender were included as covariates (see Table 10 for complete results). The AIC and BIC of Model 2 (AIC = 1000.3, BIC = 1038.0) was compared to those of the constant only model (AIC = 1220.2, BIC = 1234.3) and Model 1 (AIC = 1000.0, BIC = 1033.1) indicating that the predictors as a set reliably distinguished between the three beverage choices, but that the addition of gender as a covariate was not an improvement over Model 1. Additionally, gender did not have a significant effect on beverage choice.

Dietary behaviour: In this study, dietary behaviour was measured by three variables: BMI, diet status (currently dieting: yes or no), and dietary restraint scores. As these three variables are related (BMI & diet status, $r = .25$, $p = .003$; restraint & diet status $r = .33$, $p < .001$), only dietary restraint was included in the final model to avoid collinearity. Dietary restraint was selected as the covariate for several reasons. Firstly, BMI does not differentiate very well between body fat, muscle mass, and bone density (Shah, Braverman, Cerhan, Flint, & Hannan, 2012). Secondly, using BMI as a covariate would diminish the sample size used as there was missing data for BMI. Thirdly, while dietary restraint and diet status measure similar constructs, using a continuous variable (dietary restraint) would potentially provide more information than using a categorical value (diet status). Participants' level of dietary restraint was correlated with their ideal portion sizes (r = -.17, p < .001).

Model 3 used a multilevel ordinal regression analysis to predict beverage choice using grand mean centered food portion size, grand mean centered ideal food portion size, and the interaction between the two as the predictors. Grand mean centered liking for Ribena and grand mean centered dietary restraint were included as covariates (Table 10 displays the full results). The AIC and BIC of Model 3 (AIC = 998.1, BIC = 1035.8) was compared to those of the constant only model (AIC = 1220.2, BIC = 1234.3) and Model 1 (AIC = 1000.0, BIC = 1033.1) indicating that the predictors as a set reliably distinguished between the three beverage choices, and that the addition of dietary restraint as a covariate was an improvement over Model 1. Additionally, dietary restraint had a significant effect on beverage choice, in that the participants highest in dietary restraint were least likely to select the sweet beverages (p = .01) (Figure 9). Dietary restraint also interacted with food portion size when predicting beverage choice (p = .01). The effect of food portion size on beverage choice was plotted in three separate groups based on their level of dietary restraint (high=upper quartile; medium=middle; low=lower quartile). Participants highest in dietary restraint were more likely to select Ribena with the 100 kcal portion of food than the two other groups (Figure 10).

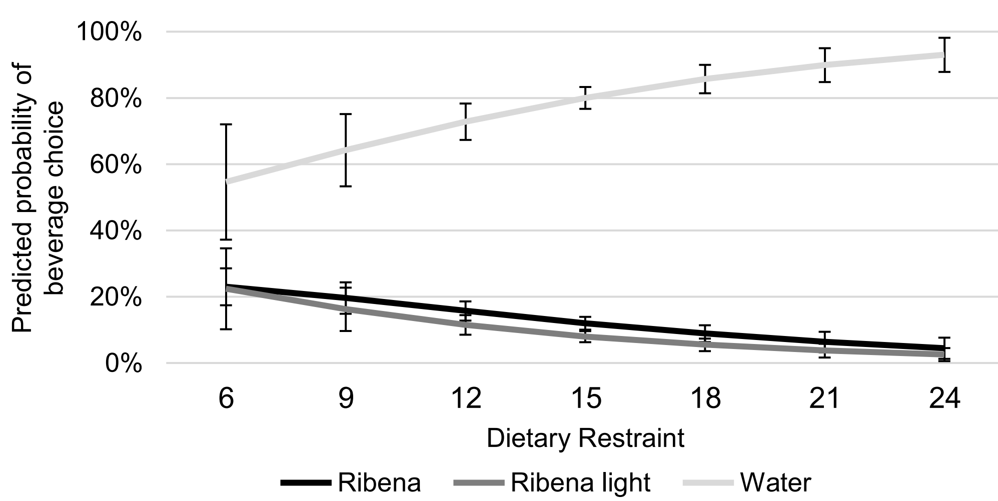


Figure 9 Predicted probabilities of Model 3 for selecting Ribena, Ribena light and water based on participant dietary restraint.

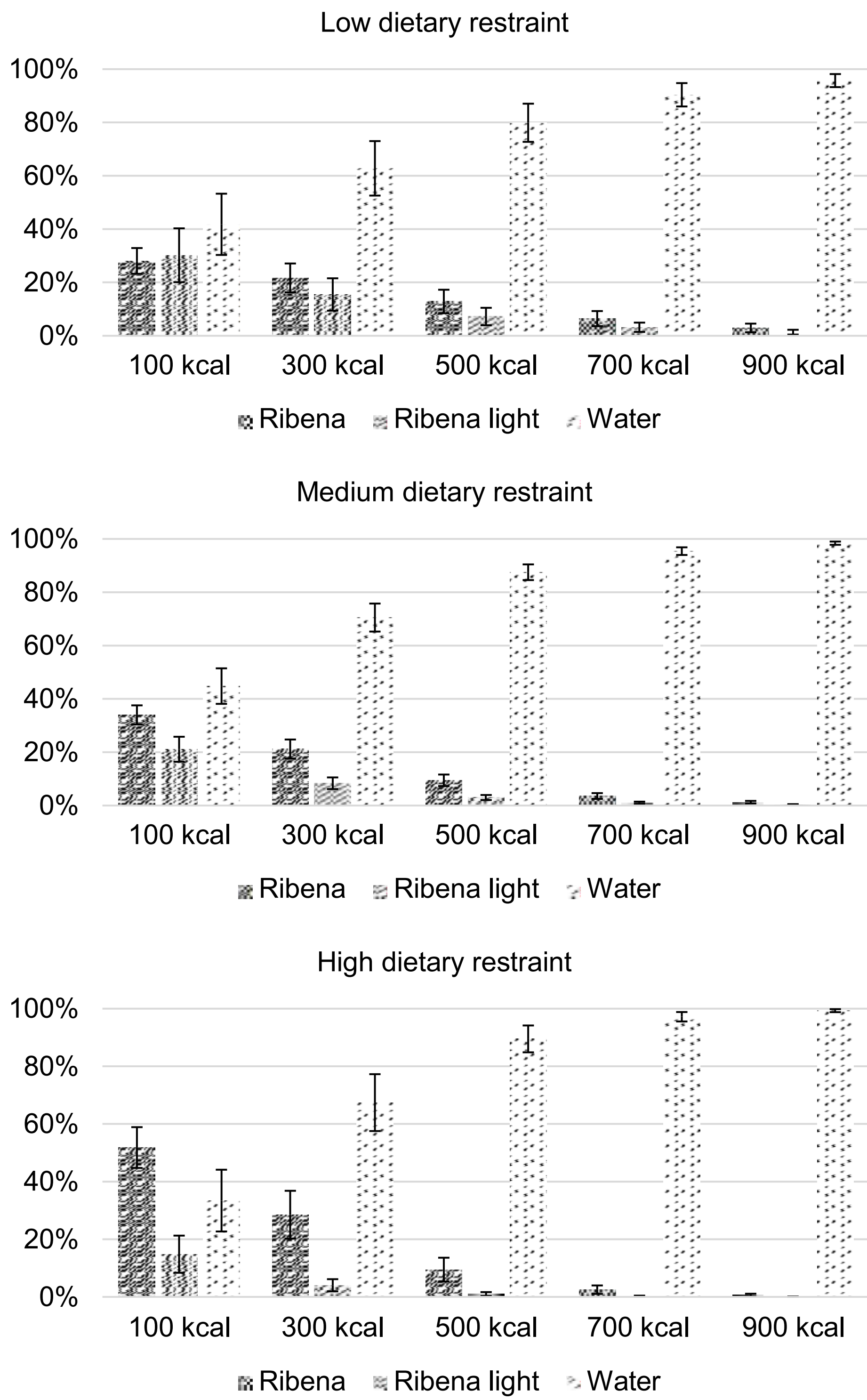


Figure 10 Predicted probabilities of Model 3 for selecting Ribena, Ribena light and water in participants with low, medium, and high cognitive restraint.

Liking for the food: Participants' liking for the food was correlated with their ideal portion sizes (r = -29, p < .001). Model 4 used a multilevel ordinal regression analysis to predict beverage choice using grand mean centered food portion size, grand mean centered ideal food portion size, and the interaction between the two as the predictors. Grand and mean centered liking for Ribena and grand mean centered liking for the food were included as covariates (Table 10 displays the full results). The AIC and BIC of Model 4 (AIC = 990.8, BIC = 1028.5) was compared to those of the constant only model (AIC = 1220.2, BIC = 1234.3) and Model 1 (AIC = 1000.0, BIC = 1033.1) indicating that the predictors as a set reliably distinguished between the three beverage choices, and that the addition of liking for the food as a covariate was an improvement over Model 1. Additionally, liking for the food had a significant effect on beverage choice (p = .001). A test of the model 4 against a constant only model was statistically significant (chi square = 239.4, p < .001, df = 5).

One explanation of why liking for the food would independently affect beverage choice is that liking for the food contributes to its reward value (Rogers & Hardman, 2015). Liking for the food, in particular, should be associated with enjoyment of the meal(Rogers, Ferriday, et al., 2016). If an individual dislikes the food, and therefore expects to enjoy the meal to a lesser degree, they may be tempted to add something to the meal (like a sweetened beverage) to preserve its reward value. Plotting predicted probabilities of choosing Ribena, Ribena light, and water against how much the food was liked confirmed that the likelihood of choosing water increased and the likelihood of choosing Ribena decreased as liking for the food increased (Figure 11).

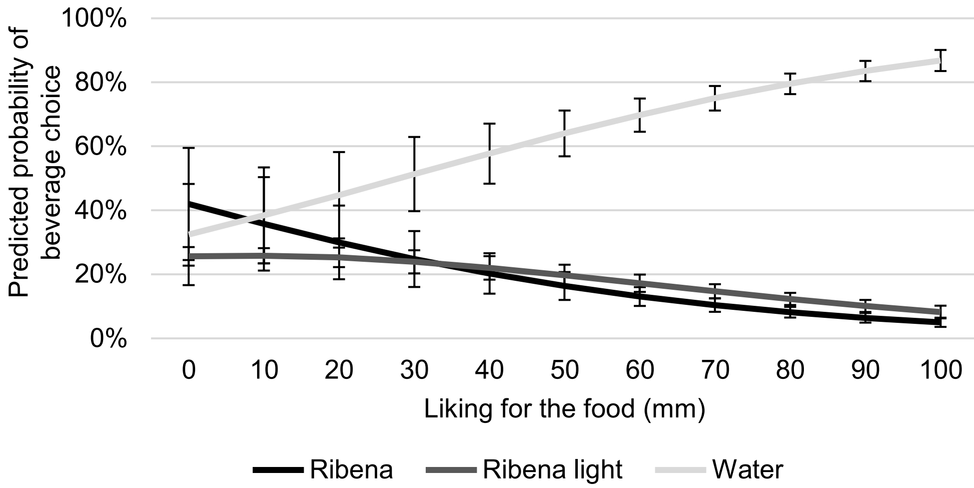


Figure 11 Predicted probabilities of Model 4 for selecting Ribena, Ribena light and water based on how much the food (Spaghetti Bolognese) was liked. Error bars indicate 95% confidence intervals.

Table 11 Multilevel Ordinal Regression Results (Spaghetti Bolognese). [1]Reference category: Ribena

	Model 1				Model 2				Model 3				Model 4			
	Coefficient		95% C.I.		Coefficient		95% C.I.		Coefficient		95% C.I.		Coefficient		95% C.I.	
Cut-off water[1]	-3.47	***	-4.10	-2.85	-3.70	***	-4.44	-2.97	-3.47	***	-4.08	-2.86	-3.44	***	-4.04	-2.83
Cut-off Ribena light[1]	-1.95	***	-2.48	-1.42	-2.18	***	-2.83	-1.53	-1.94	***	-2.45	-1.42	-1.91	***	-2.42	-1.40
Food portion size	0.11	***	0.09	0.13	0.11	***	0.09	0.13	0.11	***	0.09	0.13	0.11	***	0.09	0.13
Ideal food portion size	-0.02		-0.06	0.03	-0.01		-0.06	0.04	-0.01		-0.05	0.04	-0.04		-0.09	0.01
Food portion size*Ideal food portion size	-0.01		-0.01	0.01	0.01		-0.01	0.01	0.01		-0.01	0.01	-0.01		-0.01	0.01
Liking for Ribena	-0.52	***	-0.68	-0.36	-0.52	***	-0.67	-0.36	-0.51	***	-0.67	-0.36	-0.51	***	-0.66	-0.35
Gender					-0.63		-1.55	0.29								
Restraint									0.25	*	0.05	0.45				
Food portion size*Restraint									0.01	*	0.01	0.02				
Liking for the food													0.45	**	0.17	0.62
Participant Variance	6.15				6.02				5.62				5.39			

5.3.6 Replication of effects in additional test foods

The same analysis procedures were used to investigate the effects of portion size of Chicken and Prawn Paella and Chicken Chow Mein on beverage choice. The results for Chicken and Prawn Paella are described first, followed by the results for Chicken Chow Mein.

For Chicken and Prawn Paella, the AIC and BIC of Models 1 (AIC = 881.6, BIC = 914.6), 2 (AIC = 883.1, BIC = 920.8), 3 (AIC = 883.0, BIC = 925.5) and 4 (AIC = 869.7, BIC = 912.2) were compared to those of the constant only model (AIC = 1014.4, BIC = 1028.5), indicating that the predictors as a set reliably distinguished between the three beverage choices, and that the fourth model (which included liking for the food as a covariate) was the best fit for the data (Table 11 displays the full results). Food portion size ($p < .001$), liking for Ribena ($p < .001$) and liking for the food ($p = .001$) had significant effects on beverage choice. Predicted probabilities of choosing Ribena, Ribena light, and water were plotted against food portion size and liking for the food separately (data not shown). The data resembled the data using Spaghetti Bolognese. Specifically, the likelihood of choosing water increased as portion size of the food increased, and the likelihood of choosing Ribena and Ribena light decreased as portion size of the food increased. The likelihood of choosing water increased and the likelihood of choosing Ribena and Ribena light decreased as liking for the food increased. In addition, there was a significant interaction between liking for the food and food portion size ($p = .01$). The effect of portion size on beverage choice in participants who had low (lower quartile), medium (middle), and high (upper quartile) liking for the food was plotted separately. Selecting Ribena with the smaller food portion sizes occurred to a larger degree in participants who liked the food less (Figure 12). Unlike Spaghetti Bolognese, controlling for dietary restraint did not better predict the effect of the portion size of Chicken and Prawn Paella on beverage choice.

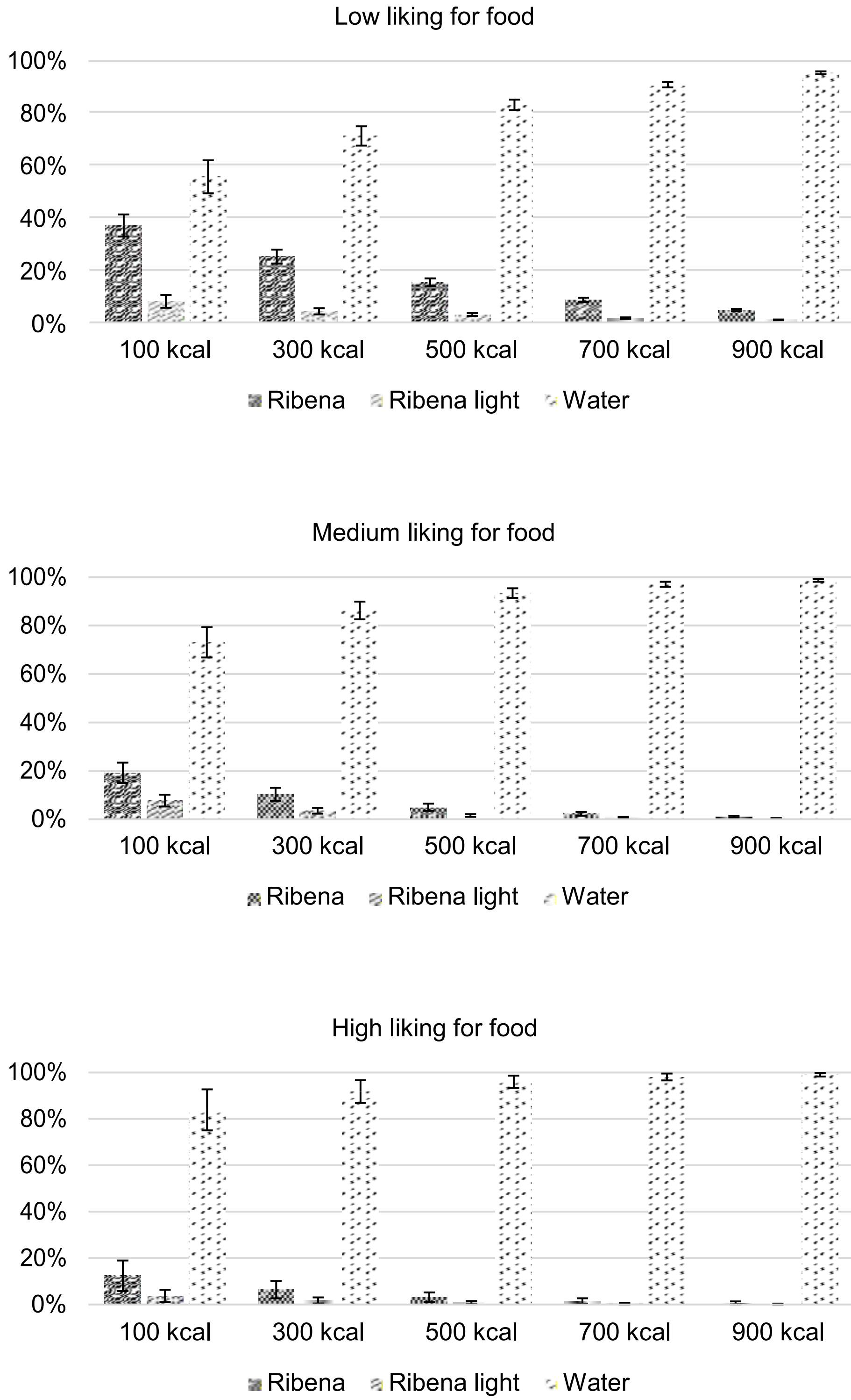


Figure 12 Predicted probability of selecting Ribena, Ribena light and water when presented with 100kcal, 300kcal, 500kcal, 700kcal, and 900kcal portions of the food (Chicken and Prawn Paella) in participants who had low, medium, and high liking for the food (Chicken and Prawn Paella).

For Chicken Chow Mein, the AIC and BIC of Models 1 (AIC = 986.4, BIC = 1019.4), 2 (AIC = 987.4, BIC = 1025.1), 3 (AIC = 986.2, BIC = 1028.7), and 4 (AIC = 988.3, BIC = 1026.1) were compared to those of the constant only model (AIC = 1182.3, BIC = 1196.5), indicating that the predictors as a set reliably distinguished between the three beverage choices and that the models which included covariates were not improvements over Model 1. Table 11 displays the full results. While liking for the food and dietary restraint did not directly or indirectly influence beverage choice (as seen in the other foods), the main effects of food portion size ($p < .001$) and liking for Ribena ($p < .001$) on beverage choice persisted. Predicted probabilities of choosing Ribena, Ribena light, and water were plotted against food portion size and liking for the food separately (data not shown). The data resembled the data using Spaghetti Bolognese and Chicken and Prawn Paella. Specifically, the likelihood of choosing water increased as portion size of the food increased, and the likelihood of choosing Ribena and Ribena light decreased as portion size of the food increased.

Table 12 Multilevel Ordinal Regression Results (Chicken and Prawn Paella). [1]Reference category: Ribena

	Model 1				Model 4			
	Coefficient		95% C.I.		Coefficient		95% C.I.	
Cut-off water[1]	-4.16	***	-4.91	-3.40	-4.24	***	-5.00	-3.49
Cut-off Ribena light[1]	-2.67	***	-3.32	-2.03	-2.75	***	-3.40	-2.10
Food portion size	0.08	***	0.07	0.10	0.09	***	0.07	0.11
Ideal food portion size	-0.01		-0.06	0.04	-0.04		-0.09	0.01
Food portion size*Ideal food portion size	-0.01		-0.01	0.01	-0.01		-0.01	0.01
Liking for Ribena	-0.55	***	-0.73	-0.37	-0.53	***	-0.71	-0.36
Liking for the food					0.33	**	0.14	0.52
Food portion size*Liking for the food	______				0.01	*	0.01	0.01
Participant Variance	7.68				7.09			

Table 13 Multilevel Ordinal Regression Results (Chicken Chow Mein). [1]Reference category: Ribena

	Model 1				Model 4			
	Coefficient		95% C.I.		Coefficient		95% C.I.	
Cut-off water[1]	-3.70	***	-4.39	-3.01	-3.70	***	-4.38	-3.01
Cut-off Ribena light[1]	-2.10	***	-2.69	-1.51	-2.10	***	-2.69	-1.51
Food portion size	0.10	***	0.08	0.12	0.10	***	0.08	0.12
Ideal food portion size	-0.04		-0.08	0.01	-0.04		-0.09	0.01
Food portion size*Ideal food portion size	-0.01		-0.01	0.01	-0.01		-0.01	0.01
Liking for Ribena	-0.56	***	-0.74	-0.39	-0.56	***	-0.74	-0.39
Liking for the food	______				0.06		-0.10	0.21
Participant Variance	7.63				7.63			

5.4 Discussion

This study assessed the influence of food portion size on subsequent beverage choice. The rationale behind the study was that two components of the meal, food and drink, modulate meal satisfaction (a combination of enjoyment of taste and post-meal fullness) (Rogers, Ferriday, et al., 2016). Therefore, reducing food portion size would reduce meal satisfaction, and participants would be more likely to add a flavoured beverage to the meal to sustain satisfaction (Ferrar, Ferriday, et al., *under review*). The results confirm this hypothesis: participants were more likely to choose Ribena and Ribena light as the food portion size decreased in size. This pattern of results was first observed in the most familiar and well-liked test food and then replicated in the two remaining test foods. To my knowledge, this is the first demonstration that food portion size can influence subsequent beverage choice.

When food portion size was too small or too large, it was predicted that recognising the food-like properties of beverages would lead participants to use the beverages to maintain an ideal level of energy and taste provided by the meal (*i.e.,* their satisfaction with the meal). Participants tended to choose water with large food portion sizes suggesting that they maintained meal satisfaction by attempting to avoid a) feeling too full and/or b) consuming too many calories. Participants tended to choose the sweetened beverages with small food portion sizes. Those who chose the high-calorie sweet option may have maintained meal satisfaction by attempting to a) prolong the enjoyment of taste and b) ensure that they would reach fullness. Whereas, participants who chose the low-calorie sweet option might have been maintaining meal satisfaction through taste alone. Indeed, this is one of the reasons why consumption of low-energy sweetened beverages might help individuals to reduce energy intake and lose weight (Rogers, Hogenkamp, et al., 2016).

The pattern of beverage choices with varying portions of food can be interpreted as compensation for anticipated changes in eating enjoyment, satiation, and energy intake. Overall, the results suggest that participants recognised the food-like properties (*e.g.,* energy and flavour) of the caloric beverage which is in line with the Martin and colleagues' finding that snacks paired with caloric beverages were rated as being more filling than the same snacks paired with low caloric beverages or water (Martin et al., 2015). In this study, Ribena was perceived as the most energising, filling, and calorie-containing beverage. Therefore, it is possible that Ribena was less likely to be selected with larger food portion sizes because participants were avoiding a beverage which would further enhance the calorie content of the meal, satiation or both. Theoretically, how enjoyable a beverage tastes can increase its ability to enhance meal enjoyment. Comparing the frequency with which Ribena light (which tastes sweet but contains little calories) and Ribena (which tastes sweet and provides significant calories) were chosen can give some indication about whether participants prioritized the enjoyment of taste or post-meal fullness when putting together their meals. While it should be noted that Ribena light was an unpopular choice (perhaps due to stigma surrounding low-energy sweeteners and diet products), there was little difference in the likelihood of Ribena and Ribena light being selected when the food portion size was 500 kcal or more. Below 500 kcal, as food portion size decreased, participants were more likely to choose Ribena over Ribena light, suggesting that beverage selected was motivated by concerns about satiation and energy intake.

An alternative explanation to the pattern of beverage choice is that changes in food portion size did not provoke concerns over hunger, but over thirst. Participants might have expected that a greater amount of food would require a thirst-quenching beverage to alleviate thirst caused by the food. Water was perceived as the most thirst-quenching, which may have increased the likelihood of it being selected with larger food portion sizes, and consequently reduced the likelihood of the sweet beverages being selected. To assess the likelihood of this explanation, further analyses were conducted which revealed that (a) how thirsty participants expected to be after consuming the food, and (b) the perceived thirst-quenching and hydrating abilities of the beverages, did not predict beverage choice nor interact with food portion size to predict beverage choice. Therefore, the former explanation is more probable.

It was also predicted that an individual's ideal food portion size would determine which food portion sizes were perceived as too small or too large for each participant, and therefore would interact with food portion size to predict beverage choice. It is unclear why his relationship was not found. Part of the rationale for investigating the influence of ideal food portion size was to identify a threshold below ideal food portion size, but before compensatory behaviour occurs. This might, in turn, identify the optimal range for successful caloric restriction and ultimately weight loss. Future research should continue to attempt to identify this threshold.

For Spaghetti Bolognese and Chicken and Prawn Paella, controlling for liking for the food predicted beverage choice. That is, the less the food was liked the more likely participants were to select the sugar-sweetened beverage. Although this was not hypothesized, it is perhaps not a surprising result and aligns with the proposal of meal satisfaction. Liking through enjoyment contributes to meal satisfaction of the food (Rogers, Ferriday, et al., 2016). Therefore, if liking for the food is low, pleasant additions (*i.e.,* energy and taste) to the food that would increase meal satisfaction might be sought out. It is unclear why liking for Chicken Chow Mein did not affect beverage choice. For Chicken and Prawn Paella, there was also an interaction between liking for the food and food portion size on beverage choice. That is, participants who liked the food less were more likely to select the sweetened beverages with large food portion sizes than participants who liked the food more. This interaction effect may have been unique to Chicken and Prawn Paella as it was the least liked food. The group who liked this food less may have strongly disliked this food. Therefore, they may have been more motivated to seek out compensatory reward from the beverages (whether to increase enjoyment of taste or mask the taste of the food), even if caloric intake or fullness would be increased as a result.

For Spaghetti Bolognese, controlling for dietary restraint predicted beverage choice. That is, participants higher in dietary restraint were more likely to choose water and less likely to choose the sweet beverages compared to participants lower in dietary restraint. However, there was also an interaction between dietary restraint and food portion size on beverage choice. When the food portion size was small, participants high in dietary restraint were more likely to choose the sugar-sweetened beverage and less likely to choose the low-calorie options than participants low in dietary restraint. From the present data, it is unclear why the effects of dietary restraint differed by food and this warrants further investigation. Perhaps, differences in how much the three foods were liked by participants might explain the differing results. For example, Spaghetti Bolognese was the most liked food. Exposing restrained eaters to palatable food stimuli primes goals about eating enjoyment, resulting in an inhibition of weight control thoughts, and causes them to experience goal conflict (Stroebe, Mensink, Aarts, Schut, & Kruglanski, 2008). In this study, when restrained eaters were exposed to a palatable food, namely Spaghetti Bolognese, they might have experienced goal conflict and opted for water as an attempt to resolve the conflict. This might explain why the findings did not support the Boundary Model of Eating Behavior (Herman & Polivy, 1983) (*i.e.,* when participants high in dietary restraint imagined eating large portion sizes, they did not disinhibit and select the sugar-sweetened beverage). However, this goal conflict may have been resolved when the portion of the palatable food was small, allowing for the sweetened beverages to be selected. It is possible that the prospect of eating the small portion led those participants to feel less guilty and as though they had calories to spare or to feel accomplished and worthy of a reward.

This experimental evidence complements recent qualitative work which revealed consumers' expectations of using beverages to compensate if they were dissatisfied by the size of a meal (Ferrar, Ferriday, et al., *under review*). While decreasing food portion size encourages the selection of beverages that provide flavour and/or energy, without knowing how much is consumed of these beverages, it cannot be concluded that the energy reduction in the food is negated by the energy increase from the beverage. Therefore, future research should investigate how food portion size affects intake of water, reduced-sugar-sweetened beverages, and sugar-sweetened beverages. Further, this tendency for consumers to compensate in order to preserve meal satisfaction should be considered when encouraging portion reduction as a strategy for reducing intake. It would be counterproductive for an individual who is trying to lose weight to compensate for a reduced portion size with a high-calorie beverage, but not so for an individual who has no reason to reduce energy intake (e.g. healthy-weight). While this study did not distinguish between individuals trying to reduce their energy intake from those trying to maintain their energy intake, reducing the food portion size increased the likelihood of selecting the sugar-sweetened beverage in a sample which consisted of underweight, healthy-weight, and overweight individuals, dieters, past-dieters, and non-dieters, and restrained and unrestrained eaters. Further, participants with high dietary restraint (compared to participants with low dietary restraint) were overall less likely to choose the sugar-sweetened beverage, but they were more likely to select the sugar-sweetened beverage when the portion size was small.

The results of this study suggest that reducing food portion size would be compensated for with caloric beverages even in individuals actively trying to reduce energy intake. One might expect that dieters especially would be "calorie-conscious" and therefore would not be influenced by the portion reduction manipulation to select the sugar-sweetened beverage. It is possible that participants (including dieters) exercised less restraint because the caloric addition was in the form of a beverage, and not a food, and therefore was less apparently associated with weight gain. Alternatively, depending on how participants selected their ideal portion (*i.e.,* how much they actually eat or what they strive to eat) could play a role. For example, a dieter who selected their "diet" portion as their ideal portion, might have felt that they could afford the additional calories with the smaller portion sizes. As this is speculative, future research is needed to draw firm conclusions.

While virtual measures of ideal food portion size have shown to be significantly related to intake (Wilkinson et al., 2012), laboratory studies should be conducted to confirm the effect. The methodology utilized in this study could be replicated in the laboratory. It could also be modified to measure not only choice, but intake and investigate these effects not only within a single meal, but after the food has been consumed in its entirety. Nonetheless, the results of this study suggest that beverages might be used to compensate for the reduction in food during a meal. Further work needs to investigate the significance of this compensation. In this study, a reduction of 200 kcal increased the chances of selecting a calorie-containing beverage. Consuming 250 ml of Ribena (103 kcal) would reduce the degree of caloric reduction, but not completely negate it. Therefore, future work should allow ad-libitum access to the beverages and measure the calories that would be consumed from the beverage to determine if partial or full compensation, or even overcompensation, would occur. An important implication of this work is that research on portion reduction suggests that a 25% reduction in food portion size is sufficient to reduce body weight (Rolls, Roe, & Meengs, 2006b). If the original portion size is 500 kcal, a reduction of 125 kcal would be mostly offset by a 250ml serving of Ribena which provides 103 kcal.

Part 2. Does (expected) beverage intake compensate for the size of a meal?

5.5 Introduction

A subsequent online study was designed to investigate whether the amount individuals expect to drink (of water, a reduced-sugar-sweetened beverage, or a sugar-sweetened beverage) with food depends on the portion size of the food. To better predict beverage intake using a measure of food portion size, individual ideal portion size will be controlled for. Controlling for individual ideal food portion size should define which food portion sizes individuals perceive as too small or too large, and therefore should interact with food portion size to predict beverage choice. In the choice experiment, accounting for ideal food portion size did not improve the predictive ability of the regression model. It is unclear why this relationship was not found. Ideal food portion size will be included in the intake experiment as such a relationship might help to identify a threshold below ideal food portion size to which food portion size can be reduced before compensatory behaviour occurs.

The nature of the choice experiment meant participants could avoid disliked beverages. Disliked beverages were unlikely to be selected, but food portion size still led to changes in beverage choice. In the intake experiment, participants will be unable to avoid disliked beverages. Therefore, they might serve themselves less of beverages that they dislike, ignoring changes in food portion size. In the choice experiment, as liking ratings for the three beverages were correlated, only liking ratings for the sugar-containing beverage were entered into the model to avoid violating the multicollinearity assumption of a regression model. Because liking ratings for the three beverages were not perfectly correlated, a limitation of this method is that some of the information about the other two beverages is discounted.

The intake experiment will include a less impartial method by measuring an additional variable (of an ordinal nature) to capture liking (theoretically, the selected beverage should be one that is liked). Specifically, participants will be asked to select which of the three beverages they would prefer to consume with their ideal portion of food.

As in the choice experiment, it was anticipated that expected eating enjoyment, expected satiation, and expected caloric intake, would play a role in decisions about how much to drink based on the drink type and food portion size. An additional variable of interest was expected thirst. As the portion size of a food increases, individuals may anticipate that they will feel thirstier and/or require more liquid to wash the food down. In the first study, expected thirst was a less relevant variable as participants could only select a fixed amount of the three beverages. In the current study, allowing participants the flexibility of choosing the amount they consume might increase the relevance of expected thirst in the effect of food portion size on beverage consumption. When deciding on the amount to drink of the sweetened beverages, goals to manage expected meal enjoyment, expected satiation, and expected caloric intake, might be in direct conflict with the goal to manage expected thirst. This goal conflict might create a more complex relationship between food portion size and beverage consumption than depicted in the previous study.

5.6 Methods

5.6.1 Participants

Participants (N = 100) were recruited through an online platform, Prolific Academic (Isis Software Incubator Isis Innovation Ltd, 2017). In order to be eligible for the study, participants had to be aged 18 years or older, fluent in English, be a U.K. national, and currently reside in the U.K. Participants could not be vegan, vegetarian, have a history of eating disorders, have any allergies or intolerances to food, or eat or drink while taking part in the study. The eligibility criteria were listed before participants gave informed consent. Additionally, questions checking the eligibility criteria were embedded in a questionnaire at the end of the study to verify eligibility. Data collected from ineligible participants was deleted prior to analysis. Each participant was reimbursed £1.50 for successful completion of the study, which was credited to their Prolific Academic account. Ethical approval was granted by the University of Bristol Faculty of Science Human Research Ethics Committee.

5.6.2 Software

The task was a single-page webapp, built using TypeScript and Angular (Google, 2016). Participants could only complete the study from a desktop computer (not a tablet or mobile phone) due to the need for keyboard input to select portion sizes. The task was tested on the most recent versions of Chrome, Firefox, and Internet Explorer, and CSS (style sheet language) was used to ensure the on-screen size of salient task elements (*e.g.,* VAS being 100 mm) was kept constant across devices. The data was stored in a University of Bristol supported database (MySQL) which was hosted on a University of Bristol managed server.

5.6.3 Virtual test foods and beverages

Test foods: In the first study, Spaghetti Bolognese (Beef), was the most liked and most familiar food. Therefore, it was selected as the food 'preload' for this study. Nutritional information is listed in Table 8. Details about how the photographs were generated can be found in Section 5.2.3. In this study, only the photographs displaying 100 kcal, 300 kcal, 500kcal, 700 kcal, and 900 kcal portions were used.

Test beverages: As in the first study, water, a reduced-sugar-sweetened beverage, Ribena light and a sugar-sweetened beverage, Ribena (Lucozade Ribena Suntory, 2018), were selected as the best beverages. Nutritional information for the three beverages is listed in Table 8. Each beverage was photographed, with the use of a high-resolution digital camera, in two transparent glasses (500 ml each). Particular care was taken to maintain constant lighting conditions and glass position in each photograph. Photograph sets consisted of 50 photos, ranging from 10ml to 1000ml in equivoluminal steps (preserving the same overall macronutrient composition within each set of images). A photograph of each beverage in its 500ml bottle (the front of the label, with the name of the beverage and any advertised information, was visible) was included in the bottom right-hand corner of every image (Brunstrom et al., 2016; Hinton et al., 2013; Wilkinson et al., 2012).

5.6.4 Measures

Ideal portion size task and beverage choice: The ideal portion size task used in Study 1 was used in Study 2 (details can be found in Section 5.2.4) with a few modifications. Firstly, it consisted of two trials (instead of four) as only a single test food, Spaghetti Bolognese, was included in Study 2: the first trial allowed participants to practice the task by changing the portion size of a plate of peanuts (a food that would not appear elsewhere during the experiment) and the following trial consisted of selecting ideal portion sizes for spaghetti Bolognese. Secondly, after the ideal portion size had been selected, the image remained on the screen. A dialog box appeared which instructed participants to choose between three beverage options (250 ml of water, Ribena light, or Ribena) to accompany the meal. Although the photographs were of the 500 ml bottles, participants were informed that they should imagine consuming half of the bottle (250 ml) as that is the recommended serving on the label. Specifically, participants were instructed, “Now that you have selected the amount of food that you would eat for lunch, select which beverage you would like to drink with your meal. Each bottle contains 250ml. You must drink everything in the bottle.” Participants were reminded that, “no other foods or beverages are available during lunch and that you will not be able to eat or drink anything else (besides water) until dinnertime.”

Beverage intake task: The task consisted of fifteen trials presented in a random order. In each trial, one of five portion sizes of Spaghetti Bolognese (100 kcal, 300 kcal, 500 kcal, 700 kcal, or 900 kcal) was displayed. Participants were asked to select the amount they would drink of water, Ribena light, and Ribena with the food portion on display. Each food portion was presented on three separate occasions allowing it to be paired with water, Ribena light, and Ribena (also, presented in a random order). The beverage photographs were loaded with sufficient speed that continuous key depression gave the appearance that the change in beverage portion size was animated. Depressing the left or right keyboard arrow key caused the beverage portion size to decrease or increase, respectively.

This is the first study to use the computer-based assessment of portion size selection (Brunstrom, Rogers, et al., 2008; Hinton et al., 2013; Wilkinson et al., 2012) with beverages, instead of food. During the task, participants were instructed, “Imagine that you are having the following meal for lunch. Remember you must eat everything on the plate and that no other foods will be available until dinnertime! Select the amount of this beverage that you would like to drink with this meal.”

Beverage and Food ratings: Participants were asked to rate the food (500 kcal) and each of the three beverages (250 ml) on various characteristics, regardless of whether or not they had ever consumed them. If they had never consumed the beverage or food, they were instructed to make the ratings based on a very similar beverage or food that they had consumed before. To assess familiarity, participants reported how frequently they consumed each beverage and food (*e.g.,* several times a day, once a day, several times a week, etc.). They also reported how many calories they thought the food and beverages contained. The following ratings were rated on 100 mm VAS (anchored from “Not at all” to “Extremely”). Participants reported how much they liked the food and beverages. For the food, they reported how filling and thirst-causing they perceived it to be. For each beverage, they reported how much they enjoyed its taste, and how filling, energising, nutritious, hydrating, and thirst-quenching they perceived it to be.

Appetite ratings: Participants reported levels of hunger, thirst and fullness using 100 mm VAS (anchored from “Not at all” to “Extremely”).

Habitual behaviour: Participants reported which beverages they usually consumed from the following choices: i) mostly diet (“zero-calorie / sugar-free”), ii) mostly regular (“sugar-containing”), iii) a mix of both, or iv) neither.

Demographics: Participants reported their age (years), gender, ethnicity, and highest level of education.

Weight status and dietary information: Participants reported their height and weight (metric or imperial units), whether they considered themselves to be overweight, and if they were currently dieting. If participants were not currently dieting, they were asked if they had dieted in the past. If participants had dieted in the past, they were asked to record the number of times they had dieted in the past 12 months. Participants also completed the Three Factor Eating Questionnaire R21(Tholin et al., 2005).

5.6.5 Procedure

The study took approximately 15 minutes to complete. Participants were instructed to read information about the study and the inclusion/exclusion criteria. After giving informed consent, they completed appetite ratings, the “Ideal portion size and beverage choice” task (including the practice trial), and the “Beverage intake” task. Participants then rated the study foods and beverages, and filled out a questionnaire on demographics and dietary behaviour. Before debriefing participants, demand awareness was measured. As the study was hosted online, an “attention check” question was included to ensure that valid data was collected (Oppenheimer et al., 2009). Participants were presented with various supermarket logos and instructed to choose which supermarket they shopped at most frequently. However, embedded in the instructions, there was a line of text which stated, “To ensure that we are collecting valid data, we need to make sure that you are paying attention during the study and reading all instructions carefully. If you are reading this, please ignore the question above and choose the logo in the bottom right corner. If you do not pass this attention check, you will not be able to continue with the study.” In addition, at the end of the study, exclusion criteria questions (history of eating disorders, vegetarian or vegan, food allergies or intolerances, last eating episode, and last drinking episode) were included to ensure the dataset did not include participants who violated the exclusion criteria.

5.6.6 Data analysis

The data were analysed using SPSS Statistics (IBM Corp, 2015) and R (R Core Team, 2017). As beverage intake is a continuous outcome variable, a regression was used for all analyses investigating relationships between it and its predictors. The predictors would be the manipulated food portion size and manipulated beverage type, and the measured ideal food portion size and measured ideal beverage type. Due to the repeated measures nature of the study (*i.e.,* there are multiple observations for each participant), the assumption of independency of observations is violated and a conventional regression analysis is therefore inappropriate. To address this, all models were specified as multilevel regression models, where observations (level 1) were nested within participants (level 2). For a primer on multilevel modelling, see Field and Wright (Field & Wright, 2011; Hayes, 2006). Exploratory analyses would include variables such as gender, cognitive restraint, perceived properties of the foods and beverages related to eating enjoyment, satiety, calories, and thirst. The Akaike Information Criterion (AIC) and Bayesian Information Criterion (BIC) were used for model selection and linear regressions and confidence intervals were used for model prediction. Tukey's tests were used for post-hoc comparisons and likelihood ratio tests were used for significance testing.

5.7 Results

5.7.1 Participants

Two participants were removed from the analyses due to a violation of the eligibility criteria. The sample consisted of 98 participants, 49 women and 49 men, of White, Black, Asian, mixed, and other descent, aged 18 to 67 (M = 35.5 ± 13.6) years. 33.7% of the sample had an undergraduate degree and 16.3% had a postgraduate degree. BMI ranged from 16.1 to 43.3 (M = 25.7 ± 5.2) kg/m^2. Nineteen participants were currently dieting and 18 had dieted in the past. Participants rated their hunger (M = 43.7 ± 27.2), thirst (M = 51.8 ± 21.3), and fullness (M = 45.8 ± 24.9). Mean scores from the Three Factor Eating Questionnaire were as follows: cognitive restraint (M = 13.9 ± 3.2), uncontrolled eating (M = 22.4 ± 4.2), and emotional eating (M = 13.1 ± 4.0). Eighteen participants correctly guessed the study aims, but were retained in the analyses as removing their data did significantly alter the results reported below.

5.7.2 Test food and beverages

The average ideal portion size of the food was 496 kcal (*SD* = 209 kcal), accompanied by Ribena (N = 15), Ribena light (N = 15) and water (N = 68). Participants who selected Ribena with their ideal portion size had a larger ideal portion size (*M* = 602.6 ± 192.7 kcal) than participants who selected Ribena light with their ideal portion size (*M* = 422.6 ± 184.4 kcal), t(28) = -2.6, *p* = .014, d = .99. Spaghetti Bolognese was rated on average as 72.1 out of 100 (± 21.4) on the liking scale and 64.1 out of 100 (± 19.9) on the thirst-causing scale. Table 12 lists participants' caloric estimations for a serving Spaghetti Bolognese, water, Ribena light, and Ribena. A Friedman test revealed that familiarity with the test beverages differed (*p* <.001). A Wilcoxon signed ranks test specified that water was consumed more frequently than both Ribena light (*p* < .001) and Ribena (*p* < .001). Repeated measures analysis of variance (ANOVA) tests were conducted to determine how the three beverages may have differed in their perceived properties. The following results have had Greenhouse-Geisser corrections applied. Water was the most liked (*p* < .001) and rated as more hydrating (*p* < .001) and thirst-quenching (*p* < .001) than both Ribena light and Ribena. Water was also rated as the most nutritious, followed by Ribena light, and then Ribena (*p* < .001). Ribena light was rated as tasting worse (*p* =.013) and being less filling (*p* = .002) than both water and Ribena. Ribena was rated as more energising (*p* = .03) than both water and Ribena light.

Table 14 Participant caloric estimations of study food and beverages

	Estimated kcal	*Actual kcal*
Spaghetti Bolognese (500 kcal)	694.6 (451.6)	*500*
Water (250ml)	3.9 (13.3)	*0*
Ribena light (250ml)	116.0 (182.4)	*10*
Ribena (250ml)	305.3 (400.3)	*103*

5.7.3 Effects of food portion size on beverage intake

Model 1 was a multilevel mixed effects linear model, using the 'nlme' package (Version 3.1-131; Pinheiro et al., 2017) in R (R Development Core Team, 2006), that investigated the effect of the following predictors: grand mean centered food portion size (*i.e.,* zero represents the average portion size) and beverage type on beverage intake. Covariates included in the model were grand mean centered ideal food portion size (and the interaction between it and food portion size) and ideal beverage type (and the interaction between it and food portion size. Participant was specified as a random factor to control for the repeated measures design. Complete results for the model are presented in Table 14. The AIC and BIC of Model 1 (AIC = 20196.13, BIC = 20249.06) was an improvement over the AIC and BIC of the constant model (AIC = 20332.35, BIC = 20348.23). To interpret the effect of food portion size on beverage intake (*p* = .042), Table 15 lists beverage intake (*M* ± *SD*) for each food portion size. Post-hoc Tukey's tests revealed that expected beverage intake with the 100 kcal portion of food differed from intake with the 500 kcal (*p* = .025), 700 kcal (*p* = .003), and 900 kcal portions of food (*p* = .002). To interpret the effect of beverage type on beverage intake (*p* < .001), post-hoc Tukey's tests were conducted. Collapsing across beverage types, participants selected larger amounts of water (*M* = 623.7 ± 252.9 ml) compared to Ribena light (*M* = 498.5 ± 270.6 ml) (*p* < .001) and Ribena (*M* = 487.6 ± 265.9 ml) (*p* < .001). Model 2 was identical to Model, except it also included the interaction between beverage type and food portion size. The AIC/BIC criterion (AIC = 20199.57, BIC = 20263.08) revealed Model 2 was not an improvement over Model 1. Further, the interaction was not a significant predictor of beverage intake.

Table 15 Multilevel mixed effects linear regression results. [1]Reference category: water

	β	t	*p*	*95% CI*	
Intercept	608.5	30.72	<.001	569.7	647.2
Beverage type (Ribena light)[1]	**-- 125.2**	**-9.03**	**<.001**	**-- 152.3**	**-98.1**
Beverage type (Ribena)[1]	**-136.1**	**-9.82**	**<.001**	**-163.2**	**-109.0**
Food portion size	**13.6**	**2.03**	**.042**	**0.51**	**-26.6**
Ideal food portion size	24.1	-1.55	.124	-6.7	54.9
Ideal beverage type	33.2	1.59	.115	-8.1	74.5
Food portion size x Ideal food portion size	**29.4**	**5.14**	**<.001**	**18.2**	**40.6**
Food portion size x Ideal beverage type	-0.15	-0.02	.984	-15.2	14.9
Participant variance	20943				
Residual variance	52025				

Table 16 Anticipated fluid intake with 100, 300, 500, 700, and 900 kcal portions of food

Food portion size	Fluid intake *M*	Fluid intake *SD*
900 kcal	570.4 ml	296.7 ml
700 kcal	547.9 ml	270.8 ml
500 kcal	515.2 ml	235.4 ml
300 kcal	505.8 ml	238.7 ml
100 kcal	543.8 ml	299.4 ml

The interaction between the portion size of the food presented to participants during the trial and individuals' ideal food portion sizes on beverage intake (mean of water, Ribena light, and Ribena) is depicted in Figure 13. Participants were separated into two groups based on their ideal portion size of the food using a median split (*Mdn* = 460 kcal). While the depicted data suggests that participants with a large ideal portion size were more susceptible to the effect of food portion size on beverage intake, none of the pairwise comparisons were statistically significant.

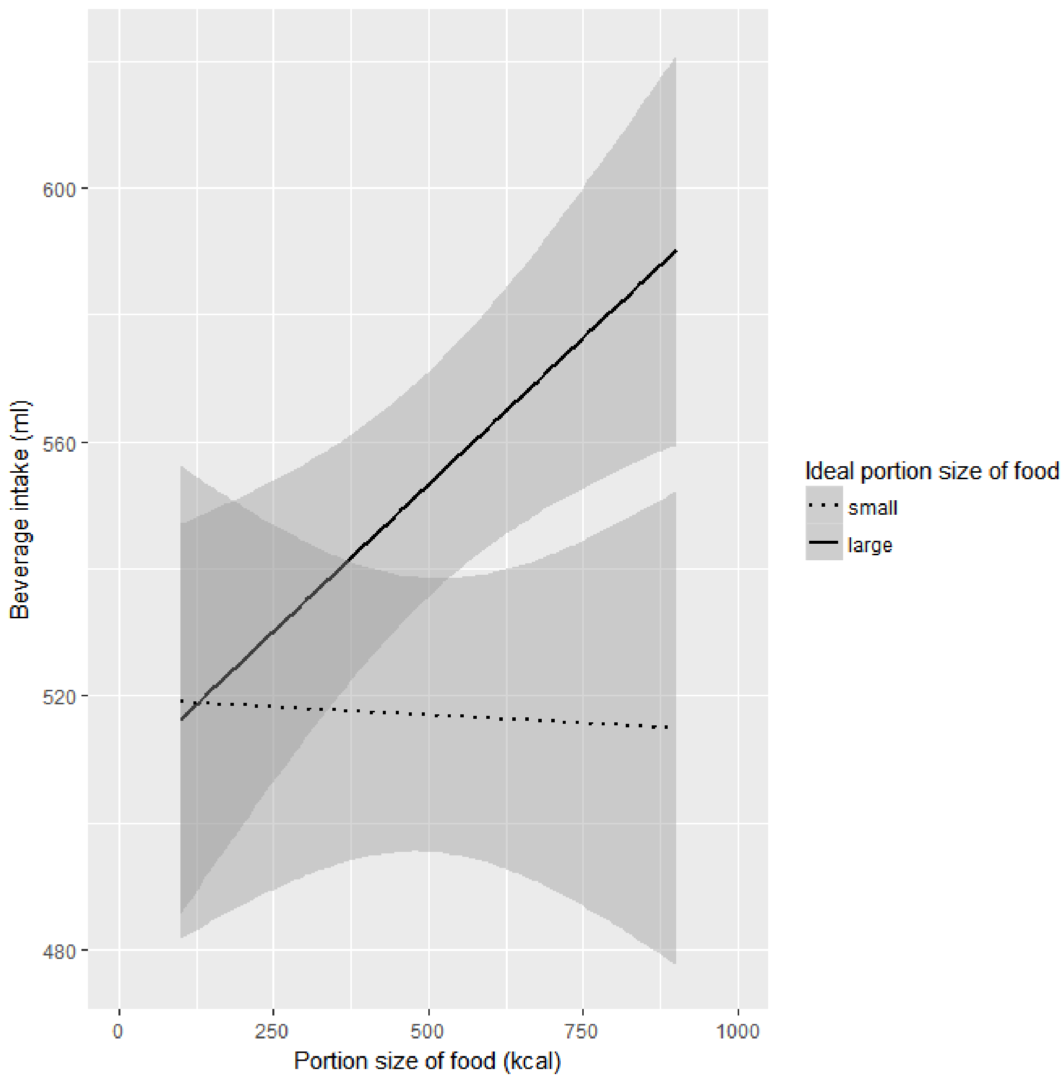


Figure 13 Beverage intake with 100, 300, 500, 700, and 900 kcal portions of food as a function of the portion size of food that participants would ideally consume.

5.7.4 Exploratory models

Individual characteristics which would theoretically affect expected eating enjoyment, expected satiety, expected caloric intake, and expected thirst were included as covariates in exploratory models. Specifically, how enjoyable, thirst-causing, filling, and energy-dense the food was perceived to be, how thirst-quenching, filling, and energy-dense the drink was perceived to be, and an individual's level of dietary restraint. The only significant improvement to the model occurred when how thirst-causing the food was perceived to be (grand-mean centered) was controlled for. Complete results for the model are presented in Table 16. The AIC and BIC of Model 3 (AIC = 13414.9, BIC = 13478.4) was an improvement over the AIC and BIC of Model 1 (AIC = 20332.35, BIC = 20348.23). This indicated that including expected thirst as a covariate improved the fit of the model. . Further, expectations of thirst after consuming Spaghetti Bolognese affected the amount of beverage that participants expected to consume (p = .001). Post-hoc Tukey's tests revealed that participants with a greater expectation that eating the food would trigger thirst selected larger amounts of fluid (M = 602.8, SD = 2.8) than participants with less of an expectation of this outcome (M = 473.0, SD = 2.8), t(94) = 4.6, p < .001, d = .90. Food portion size no longer had an effect on beverage intake (p = .147).

Table 17 Multilevel mixed effects linear regression results (exploratory). [1]Reference category: water

	β	t	ρ	*95% C.*	
Intercept	449.8	8.73	<.001	349.0	550.5
Beverage type (Ribena light)[1]	**-125.2**	**-9.05**	**<.001**	**-152.3**	**-98.2**
Beverage type (Ribena)[1]	**-136.1**	**-9.83**	**<.001**	**-163.1**	**-109.0**
Food portion size	-28.7	-1.45	.147	-67.2	9.9
Ideal food portion size	24.8	1.68	.097	-4.4	53.9
Ideal beverage type	38.2	1.92	.057	-1.08	77.5
Expected thirst	**2.4**	**3.31**	**.001**	**.98**	**3.9**
Food portion size x Ideal food portion size	**29.6**	**5.18**	**<.001**	**18.4**	**40.7**
Food portion size x Ideal beverage type	1.19	0.15	.878	-13.9	16.2
Food portion size x Expected thirst	**0.65**	**2.27**	**.023**	**0.09**	**1.2**
Participant variance	176				
Residual variance	466				

Further, there was an interaction between food portion size and expected thirst (p = .023).To interpret the interaction, a median split (Mdn = 6.7) was used to separate participants into two groups based on how thirsty they expected to be after eating the food. A comparison of how food portion size affected beverage intake in each of the groups is depicted in Figure 14. Post-hoc Tukey's tests revealed that as the food portion increased, participants with a greater expectation of thirst increased their fluid intake (intake at 900 kcal differed from intake at 500 kcal, $p = .03$, at 300 kcal, $p = .002$, and 100 kcal, $p =.02$) while participants with less of an expectation of thirst did not Therefore, the effect of food portion size on beverage intake (seen in Model 1) likely occurred because larger amounts of food are likely to cause increased expected thirst, which in turn will increase how much individuals expect to drink. A test of the Model 3 against a constant only model was statistically significant (chi square = 165.9, $p <.001$, df = 9) ('lmtest' package, version 0.9-35, Hothorn et al., 2017).

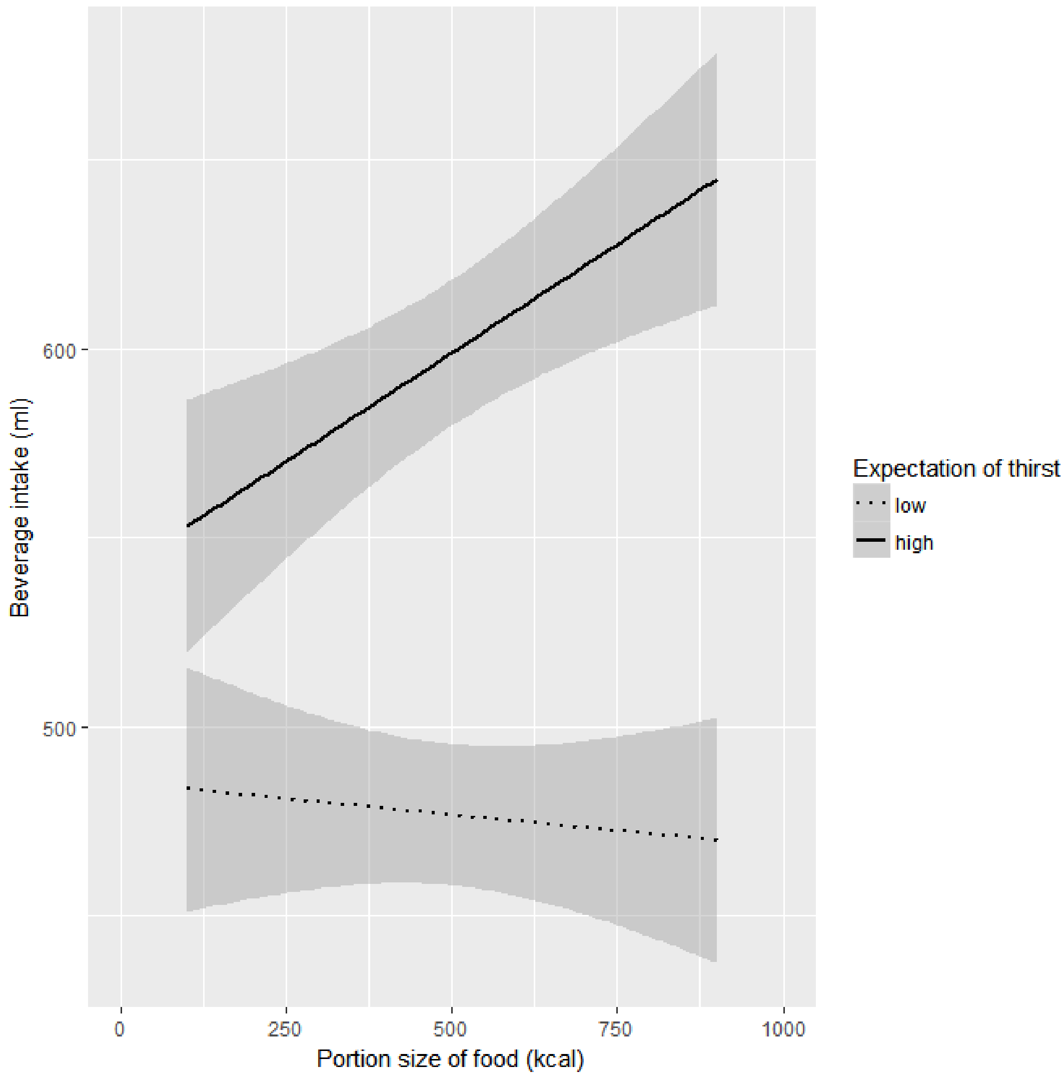


Figure 14 Beverage intake with 100, 300, 500, 700, and 900 kcal portions as a function of how thirsty participants expected to feel after consuming the presented food portion size.

5.7.5 Degree of compensation

On average, participants anticipated consuming 536.6 ml of fluid with lunch. Participants who expected to feel thirsty after eating anticipated consuming 599.1 ml whereas participants who expected to not feel very thirsty after eating anticipated consuming 476.7 ml. To understand the significance of the effect on intake in terms of calories, the amount of Ribena and Ribena light which participants expected to consume needs to be considered. Consuming Ribena light with lunch would increase energy intake by about 25 kcal and consuming Ribena with lunch would increase energy intake by 200 kcal. Table 17 combines the energy intake (kcal) from consuming each portion size of food with the energy intake from consuming the average amount that participants anticipated consuming of Ribena light and Ribena with that portion. Changing the portion size of the food by 200 kcal in either direction caused marginal changes in the amount of beverage selected. Therefore, the reduction in calories from the food was offset by the increase in calories from Ribena.

Table 18 Combined energy intake of food (100, 300, 500, 700, and 900 kcal portions of Spaghetti Bolognese) and beverage (Ribena light vs. Ribena) separated by expected thirst from consuming Spaghetti Bolognese.

	Average energy intake (kcal)				
	Food	Ribena light	Food **+** Ribena light	Ribena	Food **+** Ribena
Low expectation of thirst after eating	900	21	921	188	1088
	700	21	721	178	878
	500	21	521	169	669
	300	20	320	179	479
	100	24	124	179	279
High expectation of thirst after eating	900	32	932	242	1142
	700	29	729	231	931
	500	27	527	216	716
	300	26	326	210	510
	100	28	128	213	313

5.8 Discussion

The results of this experiment demonstrated that as the portion size of the food increases, participants expect to drink increasing amounts of a beverage. Exploratory analyses suggest that the increase in expected beverage intake with larger food portions results from attempts to aid ingestion of the food and/or to avoid thirst. Beverage intake with the smallest food portion deviates from this trend. One plausible explanation is that expected thirst is much less relevant when consuming a small portion of food. But why then would expected beverage intake with a 100-kcal food portion surpass that of 300- and 500-kcal food portions? Perhaps, the expectation of eating such a small amount of food primes individuals to consider expected enjoyment of taste, expected caloric intake, and expected satiation, and therefore increase the amount they expect to drink.

Unlike in the beverage choice experiment, in this experiment participants' ideal portion sizes did interact with the food portions presented to them to predict anticipated beverage intake. A pictorial representation of the data suggests that individuals who are used to consuming smaller amounts of food are less likely to increase the amount that they expect to drink with increasing portions of food. However, it is not possible to further explore this interaction effect as part of this experiment. The effect size is small and therefore a larger sample size would be required to run the appropriate post-hoc analyses.

The findings are consistent with those presented in Chapter 4. Both anticipated and actual beverage intake are motivated by fluid needs. In this experiment, irrespective of the food portion, participants anticipated consuming greater amounts of water compared to the sweetened beverages. However, when the amount of food was considered, anticipated intake of all three beverages was similar (around 500 ml), demonstrating that potential consequences of energy intake and satiation are largely ignored. When the beverage in question is unsweetened or reduced sugar-sweetened, this relationship has negligible impact. However, replacing the beverage with a sugar-sweetened option indicates that energy intake would be increased by around 200 kcal. In the context of this experiment, the increased energy intake from the beverage would offset the calories saved from reducing the portion size of the food. As beverages are often included in meals (McKiernan et al., 2009), this lack of energy compensation observed when selecting how much to drink with varying portions of food should be considered when encouraging individuals to reduce portion size as a means to reduce energy intake (Ferrar, Ferriday, et al., *under review;* Rogers, Ferriday, et al., 2016; Rolls, Roe, & Meengs, 2006a).

While the experiments described in this chapter need to be replicated in laboratory settings to confirm if anticipated beverage intake predicts actual beverage intake, previous research suggests that this would be the case. For example, computer-based measures of expected satiety of a food predicted both virtual and actual self-selected food portions, and actual food intake (Wilkinson et al., 2012). Expected intake is likely predictive of actual intake because consumption is largely determined by the amount served (*e.g.,* pre-meal planning is the most important predictor of food consumption (Fay et al., 2011) and serving larger portions of beverages increases beverage consumption (Flood et al., 2006)). Finally, comparing the results of the two experiments in this chapter suggests that emphasis should be placed on the choice of beverage. This is because when selecting *which beverage to consume*, energy and taste properties are prioritized over the hydrating and thirst-quenching properties of beverages. When selecting *how much* of that beverage to consume, the hydrating and thirst-quenching properties take precedent.

Chapter 6 Deconstructing beverage reward: the effect of two types of thirst on liking and desire to drink

6.1 Introduction

Chapters 4 and 5 illustrated that being in a physiological state of fluid deprivation (or the anticipation of being in such a state) appears to motivate beverage intake of water, a reduced-sugar-sweetened beverage, and a sugar-sweetened beverage to the same degree. What might underlie this generalised motivation? It has been suggested that the physiological state under which consumption occurs affects the ingested item's physiological usefulness and thus the item's pleasantness (Appleton, 2005; Bell, 1993). For example, liking for sweet and salty tasting foods/fluids might represent physiological need for energy (Cabanac, 1971, 1989) and electrolytes (K C Berridge, Flynn, Schulkin, & Grill, 1984; Denton, 1982), respectively.

In terms of fluid needs, an experiment by Appleton (2005) demonstrated that beverages are rated as more pleasant after fluid loss, especially beverages with low osmolality (*i.e.,* water, very weak sports drink, and very weak fruit drinks). Further, the effects were greater in a group of exercisers with water loss that was approximately 1% of their original body weight compared to a group of exercisers with water loss that was approximately 0.4% of their original body weight. Research has also demonstrated that cool drinks (< 22°C) are rated as most pleasant and are often ingested in larger volumes (Burdon et al., 2012), but cold beverages (0–10 °C) are often ingested in smaller volumes (Boulze et al., 1983; Sandick, Engell, & Maller, 1984). One explanation of why temperature affects preference and intake is that consuming cool beverages (compared to warm beverages) more effectively reduces thirst (Brunstrom & Macrae, 1997). It has been proposed that wetting the mouth increases saliva production which decreases mouth dryness and subsequently thirst levels (Mendelson & Chillag, 1970). This effect might be stronger in cooler beverages than in warmer beverages, as cooler water may cause greater amounts of saliva production than warm water (Adolph, 1947; Pangborn, Chrisp, &

Bertolero, 1970; Rolls et al., 1980). Consequently, liking for beverages may depend on the individual's fluid, electrolyte and energy status and the beverage's composition (water, sugar, and sodium) and temperature.

However, more pleasant items are at a higher risk of overconsumption (Robinson, Gray, Yeomans, & French, 2005; Yeomans, Lee, Gray, & French, 2001) which does not support the theory that an item's pleasantness reflects an underlying physiological deficit. An alternative explanation is that the effect of physiological state on the item's usefulness most likely represents a change in wanting (incentive salience), not liking (hedonic impact) (Kent C Berridge, Robinson, & Aldridge, 2009) for that item. To illustrate this point, consider energy intake. Food choice (Mustonen, Hissa, Huotilainen, Miettinen, & Tuorila, 2007) and intake (Bellisle, Lucas, Amrani, & Le Magnen, 1984; Bobroff & Kissileff, 1986; Spiegel, Shrager, & Stellar, 1989; Yeomans et al., 1997; Yeomans, 1996) are predicted by how much that food is liked. However, as increasing amounts of a food are ingested, satiety increases. If an item's pleasantness reflects the individual's physiological state, increased satiety would decrease liking for the food. While previous research has demonstrated that liking declines more for consumed items than for uneaten items (Brunstrom & Mitchell, 2006; Havermans, 2011; Rogers & Hardman, 2015; Rolls, Hetherington, & Burley, 1988a; Rolls, Rolls, Rowe, & Sweeney, 1981), the effect known as sensory-specific satiety, Hardman and Rogers (2015) argue that if liking for the food is defined as the "pleasantness of taste experienced in the mouth", then liking for the food may not change with hunger and fullness states. Changes in satiety instead affect wanting for the food: as satiety increases, the food becomes less rewarding to the individual so he or she has less of a desire to ingest more of it. It is difficult to measure wanting directly, as assessing the degree to which a food is wanted will be influenced by how much the food is liked (Havermans, Janssen, Giesen, Roefs, & Jansen, 2009; Rogers & Hardman, 2015). By measuring desire to eat the food (*i.e.,* how pleasant it is to eat that food) and liking for the food (*i.e.,* how pleasant food tastes in the mouth), wanting for the food can be deduced.

This model of reward has not yet been investigated in relation to fluid ingestion. Following the model, beverage reward can be measured via desire to drink (*i.e.,* how pleasant it is to drink that beverage). Theoretically, beverage reward should be made up of two components: beverage liking and beverage wanting. To test this theory, the effect of beverage liking on beverage reward will be assessed. Beverage liking (*i.e.,* how pleasant the beverage tastes in the mouth) is directly measureable and should not be affected by thirst (unless participants fail to make the distinction between pleasantness of taste of the beverage in the mouth versus pleasantness of drinking the beverage). Therefore, any significant change to desire to drink can be contributed to beverage wanting which theoretically should be affected by thirst. Therefore, this study will investigate if the measures “how pleasant the beverage tastes in the mouth” and “how pleasant it is to drink that beverage” represent discernible constructs, namely beverage liking and beverage reward. This distinction will be confirmed if thirst affects beverage reward to a greater degree than it affects beverage liking. The study will also investigate if the measure of beverage reward predicts beverage intake (Rogers & Hardman, 2015).

Chapter 2 suggested that two types of “thirst” exist: The first is thirst that is of a physiological nature. Physiological thirst is initiated when fluid is lost from the intracellular or extracellular compartments (McKinley & Johnson, 2004). For example, when fluid is lost from the extracellular compartment, plasma tonicity increases and plasma volume decreases. To correct these physiological changes, osmoreceptors detect plasma tonicity and osmosis draws water from the cells to maintain blood volume (Verbalis, 2007). This causes cells to shrink in volume. The hypothalamus then stimulates thirst to initiate drinking and restore the intracellular fluid (McKinley & Johnson, 2004). People who do not live in a hot and dry environment or do not regularly participate in strenuous activity can easily maintain the fluid levels needed to sustain cellular function (Tucker et al., 2015; Valtin, 2002). It has been suggested that constant access to beverages under these conditions leads to drinking in anticipation of thirst, avoiding thirst entirely (SJ French et al., 1994; Nicolaidis, 1998; Phillips et al., 1984; Popkin et al., 2010). In this context, the experience of thirst is unlikely to reflect immediate physiological need for fluid, but instead of can be thought of as ‘psychological’. Becoming aware of deviations in personal norms regarding drinking (*e.g.,* time in between drinking episodes; amount consumed over a day) provokes concern about impending dehydration. The relationship between thirst, beverage reward, and beverage intake might depend on the type of thirst experienced. For example, the degree of fluid loss can influence the perceived pleasantness of beverages (Appleton, 2005). Arguably, this difference in liking ("How pleasant is this drink?") actually represented a difference primarily in wanting based on the degree of physiological changes to plasma. It then follows that an individual experiencing physiological thirst (as a result of changes to plasma) would have a stronger desire to drink compared to an individual experiencing psychological thirst (as a result of drinking less than usual). This difference should be manifested via differences in beverage reward, and consequently, beverage intake.

Modern beverages are composed of water, carbohydrates, and sodium in varying degrees. For example, the carbohydrate content (weight/volume) is approximately 3% in tomato juice, 6% in sports drinks and 11% in colas and other juices. Sodium content is approximately and 10 mmol/l in tomato juice, 24 mmol/l in sports drinks, and 3 mmol/l in colas and juices (Shirreffs, 2009). If ingestive behaviour occurs to correct a physiological deficit (*e.g.,* lack of water), then increased reward should occur only for (or to a greater degree in) items which can correct the deficit. This does seem to occur: for example, the effect of fluid loss on perceived pleasantness ("How pleasant is this drink?") of beverages is more pronounced in beverages with low osmolality (Appleton, 2005). This finding, and the findings presented in Chapter 4, strengthen the argument that fluid requirements are prioritized over requirements for electrolytes or energy (Maughan & Leiper, 1995; Maughan, 1998; Takamata, Mack, Gillen, & Nadel, 1994).

If ingestion of water is the priority, then desire to drink should be greatest for beverages with low carbohydrate content and low osmolality. However, the experiments discussed in Chapters 4 and 5 demonstrated that when participants anticipated or experienced being thirsty, intake of beverages with varied carbohydrate content and osmolality (Ribena, Ribena light, and water) was similar. Since food reward predicts food intake, it is reasonable to expect that beverage reward might predict beverage intake. Similar intakes of water, Ribena light, and Ribena among individuals when they were (or expected to be) thirsty suggests that the three beverages were perceived as equally rewarding.

It is possible that fluid deprivation, but not fluid loss, (which was used in the experiment discussed in Chapter 4) is not sufficient to elicit changes in beverage reward. This might explain why the effect detected in Appleton's (Appleton, 2005) experiment (which caused fluid loss in participants) differentiated between beverages with low and high osmolality. In Appleton's experiment, fluid loss was equal to 1%, 0.7%, and 0.4% of body weight. In this experiment, the manipulation will be taken a step further: in addition to losing approximately 1% of their body weight, participants will ingest salt after the loss of fluid to maximize fluid needs. To be more specific, sweat is hypotonic compared to plasma (*i.e.,* sweat contains a lower concentration of solutes than plasma does). Thus, perspiration leads to a greater loss of water than solutes from the body (Senay, 1975). These effects will be more extreme if water losses are not replaced, and more solute is ingested. Sodium is the major solute of the extracellular fluid. Thus, the ingestion of salty food and restricted fluid intake will add a hypertonic solution to the extracellular compartment and further increase plasma tonicity and decrease blood volume (McKinley & Johnson, 2004).

While various compensatory responses (*e.g.,* vasopressin secretion, stimulation of the renin-angiotensin-aldosterone system, sympathetic activation, and reduced renal solute and water excretion) will occur to minimize changes in body fluid volume, they will not fully restore fluid balance. The only way that fluid balance can be restored is if fluid losses are replaced (McKinley & Johnson, 2004). Therefore, the experimental manipulation which will include perspiration and salt ingestion should increase motivation to drink. By measuring liking, desire to drink, and intake, in those participants who have undergone the experimental manipulation, this experiment will assess if the food reward model proposed by Rogers and Hardman (Rogers & Hardman, 2015) can be applied to fluid ingestion. This experiment will also explore these relationships when an increased motivation to drink is, not of a physiological nature (*i.e.,* drinking to replenish fluid levels), but of a psychological nature (*i.e.,* drinking out of habit).

6.2 Methods

6.2.1 Participants

Participants (N = 30) were recruited from the Bristol area (U.K.) via an online database belonging to the Nutrition and Behaviour Unit at the University of Bristol and via social media. Ethical approval was granted by the University of Bristol Faculty of Science Human Research Ethics Committee. Written consent was obtained from all participants. Participants who were: (1) not fluent in English, (2) unable or unwilling to consume the study foods and beverages, (3) unable or unwilling to fast for 10 hours, or (4) were hypertensive were not eligible to take part. The study was advertised as investigating the sensory properties of beverages. Participants were informed that they would be assigned to either a condition including exercise and reimbursed £50 or excluding exercise and reimbursed £40. Participants were also informed that fluid intake may have been restricted in one of their two sessions.

6.2.2 Study design

This study utilised a mixed measures design (3 groups x 2 repeated measures). Each participant took part in a baseline session when they were not thirsty (control) and a test session when they participated in one of three thirst conditions: not thirsty (control), psychologically thirsty, or physiologically thirsty. Participants in the control condition had ad-libitum access to water during the session. Participants in the psychologically thirsty condition were fluid restricted. Participants in the physiologically thirsty condition were fluid restricted, exercised on a stationary bike for 45 minutes in a heated room (30°C) and ingested salt. To ensure participants exercised safely but to a degree which would cause perspiration, their heart rate, blood oxygen level, and perceived exertion (Borg, 1982) were monitored at regular intervals (data not reported). An image of the procedure can be found in Appendix B. Participants were not aware that they had ingested additional salt to prevent expectations associated with salt ingestion. To blind participants to this aspect of the experimental manipulation, the salt was administered to them via capsules, which they were told contained common dietary supplements. Participants in the psychologically thirsty and control conditions ingested placebo capsules containing corn flour. All participants were told that the capsules contained common dietary supplements. Participants were unable to taste the flavour of salt or corn flour when ingesting the capsules.

In each session, participants tasted and assessed seven beverages and one food (varying in temperature, flavour, energy density, salt/sugar composition, and form) on how much they enjoyed the taste of each sample and how much they expected to consume of each sample. All participants sampled room temperature water followed by chilled water. The order of the remaining six samples was balanced using an incomplete latin square. Participants were presented with the samples in the same order on both the baseline and test sessions. Participants expectorated each sample after tasting and did not rinse the mouth between samples in order to reduce even small contributions to fluid intake. Participants also selected one of the eight samples as the one which they preferred to consume. Finally, ad-libitum intake of chilled water was measured. This is because it is usual that in the UK water is consumed chilled, or at least below room temperature.

6.2.3 Hypotheses

The first hypothesis was that intake of water would be greater in the physiologically thirsty condition than the other two thirst conditions. The second hypothesis was that beverage reward would be predicted by beverage liking. The third hypothesis was that beverage reward, but not beverage liking, would be predicted by thirst. The fourth hypothesis was that liking for water would not be affected by thirst condition, but desire to drink water would be greatest in the physiologically thirsty condition, followed by the psychologically thirsty condition followed by the control condition. The final hypothesis was that desire to drink water would predict ad-libitum intake of water and that the predictive ability may have depended on water temperature and thirst condition.

6.2.4 Exploratory data analysis

a) If the results confirm the hypotheses, exploratory analyses will explore if similar patterns in liking and reward occur with Ribena light and Ribena.

b) Previous research suggests that decreased bodily salt levels increases preference for salt (Beauchamp, Bertino, Burke, & Engelman, 1990; Leshem, Abutbul, & Eilon, 1999; Takamata et al., 1994). In this experiment participants, who undergo the combined exercise and salt ingestion manipulation, will be assessing the samples while their plasma is hypertonic. Theoretically, this might decrease preference for salt. Therefore, exploratory analyses will be conducted on liking and desire to consume sports drinks (Powerade: high and low energy versions) and tomato juice, which have salt content (Shirreffs, 2009).

c) Chapter 4 and 5 demonstrated that thirst motivates intake of beverages with food-like properties. Does thirst then motivate intake of foods with fluid-like properties (*e.g.,* fruit)? To explore this question, exploratory analyses will be conducted on pineapple as it has a moisture content of 86.9% (Morais et al., 2017).

6.2.5 Power calculations

The sample size (N=30) was determined by assessing effect sizes from three related studies with the aims to achieve at least 80% power when testing for an effect of a within-subjects factor (baseline versus test session), an effect of a between-subjects factor (ad-libitum water, psychologically thirsty, or physiologically thirsty condition), and an interaction between the two.

Between-subjects: Previous work detected a between-subject effect of salt dosage on drink preference ($\eta p^2 = .2$, $f = .5$) suggesting a sample size of 22 participants to detect an effect between two groups and a sample size of 30 to detect an effect among three groups (Wald & Leshem, 2003)

Within-subjects: Previous work also detected a within-subject effect of sweat loss on drink preference ($\eta p^2 = .2$, $f = .5$) suggesting a sample size of 9 participants to detect an effect (Wald & Leshem, 2003).

Interactions: Using the data from earlier experiments in this thesis, an interaction effect of subjective thirst ratings between a fluid-deprived and food-deprived group was detected ($d = 2.2$, $f = 1.1$, $\eta p^2 = .5$), suggesting a total sample size of 12 participants to detect a similar effect. With the ad-libitum water group included, effect size calculations ($\eta p^2 = .5$, $f = 1.0$) suggest a total sample size of 9 participants to detect an interaction effect among three groups. Previous work compared pre- and post- pleasantness ratings between a group who had high fluid loss after exercise and a group who had low fluid loss after exercise ($\eta p^2 = 0.1$, $f = .3$) suggesting a sample size of 24 participants to detect an interaction effect between two groups, and 30 participants to detect an effect among three groups (Appleton, 2005).

6.2.6 Study foods and beverages

Pre-loads: Breakfast (~ 407 kcal) consisted of Nestle Cheerios Multigrain Cereal (60 g) with Sainsbury’s British Semi Skimmed Milk (200 ml) and banana (95 g). Lunch (~ 528 kcal) consisted of Sainsbury's Mediterranean Style Vegetable Quiche (200 g), Cadbury’s Dairy Milk Bubbles of Joy Chocolate Mousse (45 g), Water (50 ml or ad-libitum), and two capsules (containing 2 g salt or .65 g corn flour).

Test samples: The test samples (14 ml or 14 g) consisted of room temperature water ($M = 21.8 \pm 1.49$ °C) and six chilled liquids ($M = 14.3 \pm 1.69$ °C): water, fruit drink with sweeteners (.05 kcal/ml), fruit drink with sugar (.41 kcal/ml), sports drink with sweeteners (.01 kcal/ml), sports drink with sugar (.18 kcal/ml), savoury drink (.18 kcal/ml), and one chilled solid: fruit (.53 kcal/ml). The main analyses on liking and desire to drink focused on chilled and room temperature water. Exploratory analyses included the additional 6 samples. Table 18 contains further details of the samples. For the ad-libitum intake of chilled water, participants were provided with 2 L bottles of Sainsbury's Basics Water (note: all water served in the study was Sainsbury's Basics Water in case participants were sensitive to the taste of tap water). As the water for the ad-libitum intake was served in sealed bottles, the temperature could not be directly assessed before serving. Using the guidelines regarding the effect of beverage temperature on beverage intake outlined in Chapter 4 (Section 4.2.5), beverages were removed from a refrigerator (maintained between 1 and 4 °C) and were left out at room temperature for 20 minutes before being served.

Table 19 Sample properties

Sample	Water	Water	Ribena light	Ribena	Powerade Zero	Powerade	Tomato juice	Pineapple
Category	Unsweetened	Unsweetened	Fruit drink (sugar & sweeteners)	Fruit drink (sugar)	Sports drink (sweeteners & salt)	Sports drink (sugar and salt)	Fruit drink (sugar and salt)	Solid (sugar)
Flavour	Unflavoured	Unflavoured	Blackcurrant	Blackcurrant	Tropical Berry	Tropical Berry	Tomato	Pineapple
Temperature	Room temperature	Chilled	Chilled	Chilled	Chilled	Chilled	Chilled	Chilled
Osmolality	3.0	3.0	83.8	394.0	48.0	289.0	485.0	836.0
Nutritional composition (per 100 ml / 100 g)								
Energy, kJ/kcal	negligible	negligible	20/5	175/41	6/1	77/18	76/18	226/53
Fat	negligible	negligible	negligible	negligible	negligible	negligible	<0.5g	0.1g
Carbohydrate	negligible	negligible	0.6g	10g	negligible	4.1g	2.7g	12.1g
of which sugars	negligible	negligible	0.5g	10g	negligible	4.1g	2.6g	12.0g
Salt	negligible	negligible	0.01g	<0.01g	.13g	.13g	.43g	<0.01g

* Osmolality was measured in the laboratory using an osmometer. All samples were measured in duplicate. An image documenting the analysis procedure can be found in Appendix B.

6.2.7 Measures

Liking and desire to drink (or eat): Participants were instructed to taste the samples one at a time, by swilling the sample around their mouth and then expectorating it. For the pineapple chunks, participants were instructed to chew it and then expectorate. Participants were provided with plastic cups to dispose of the samples after tasting. Participants were instructed that after tasting the sample, they would be asked how it tasted and their desire to drink or eat more of it. Participants were allowed to re-taste the samples as many times as needed. For actual liking, participants were instructed, “Please rate how PLEASANT THE SAMPLE TASTES IN YOUR MOUTH. When making this judgment, IGNORE how much or little of the sample you would like to drink or eat. Instead, purely focus on, HOW THE SAMPLE TASTES IN YOUR MOUTH RIGHT NOW.” (Rogers & Hardman, 2015). For desire to drink (or eat), participants were asked, “How strong is your desire to drink an entire glass of this sample? For pineapple, the question was “How strong is your desire to eat a bowl full of pineapple?” (Rogers & Hardman, 2015). Participants were provided with reference glasses (200 ml) and bowls (200 g) when making these estimations.

Beverage choice: After tasting all of the samples, participants were asked, “If you could only choose a glass (or bowl) of one of the following samples to consume right now, which would you choose?”

Ad-libitum water intake: During the final 15 minutes of the experiment, participants were provided with ad-libitum water to drink.

Time since last eating and drinking episode: At the beginning of each session, participants were asked to record what they last ate and drank and at what time both events occurred.

Appetite ratings: During the baseline session, participants were asked to record how hungry and full they felt before lunch and before rating the samples.

During the test session, participants were asked to record how hungry and full they felt before breakfast, before lunch and before rating the samples.

Hydration measures: Changes in participant body weight and serum osmolality were measured to assess changes in hydration status.

Thirst ratings: During the baseline session, participants were asked to record how thirsty they felt before lunch and before rating the samples. During the test session, participants were asked to record how thirsty they felt before breakfast, before lunch and before rating the samples.

Serum osmolality: Blood samples were an optional measure. Participants who opted in had blood samples taken prior to and after the exercise and salt manipulation to measure changes in serum osmolality. For comparison, pre and post-manipulation serum osmolality samples were also collected from the psychologically thirsty and ad-libitum water groups at the appropriate times. The analysis procedures were as follows: (a) blood samples were allowed to clot and then centrifuged. The resulting supernatant (serum) was extracted and inserted into an osmometer to measure serum osmolality. Each sample was measured in duplicate. Images documenting the collection and analysis procedures can be found in Appendix B.

Weight. Body weight was measured on a Tanita Digital Body scale by an experimenter and used to generate BMI scores for all participants. For participants in the physiologically thirsty condition, body weight was measured twice (pre-exercise and post-exercise) to assess water loss from perspiration during exercise. Change in body weight is a validated proxy of short term changes in body fluid (McArdle, Katch, & Katch, 1996).

Height: Participant height was measured by an experimenter and used to generate BMI scores for all participants.

Physical activity: Participants were asked: (a) What is your activity level? (b) How would you compare your activity level to your peers? (c) How often do you exercise? (d) Do you participate more in cardiovascular or strength-training exercises?

Familiarity with diet and regular beverages: Participants were asked (a) Do you often purchase reduced-sugar / sugar-free / "diet" products? (*e.g.,* items which substitute sugar for non-caloric sweeteners to save calories?) (b) Do you try to AVOID purchasing reduced-sugar / sugar-free / "diet" products? (c) What kind of sweet beverages (neither, regular, diet, or a mix of both) do you usually consume?

6.2.8 Procedures

Baseline session: Regardless of assigned group, all participants attended a baseline session. Participants arrived at the lab in the afternoon after abstaining from all food and fluid for three hours prior. They reported their last eating and drinking episode, completed appetite ratings, and then were given 15 minutes to consume a standard lunch with two placebo capsules and ad-libitum water. Participants were told that the capsules contained dietary supplements. After lunch, participants completed appetite ratings and then remained in the lab for 60 minutes. After the break, participants completed appetite ratings, and then tasted (via swilling and expectorating) and rated all eight samples. After the ratings, participants were asked to choose which sample they would consume if they could only select one. At the end of the session, participants were provided with access to ad-libitum water for 15 minutes while completing a questionnaire on demographics, familiarity with products with sugar and low-energy sweeteners, and physical activity. The baseline session assessed sample ratings, beverage choice and water intake when all participants were not thirsty. Participants' baseline measures acted as their own control measures for the measures collected on their test days.

Test session: For the test session, participants took part in one of the three following conditions:

Table 20 Test session procedures

	Control condition	Psychologically thirsty condition	Physiologically thirsty condition
	Participants arrived at the lab in the morning after abstaining overnight for 10 hours from all food and fluid.		
15 mins	Participants reported their last eating and drinking episode and were given 15 minutes to consume a standard breakfast.		
70 mins	After breakfast, participants completed appetite ratings and then remained in the lab for 70 minutes, during which ad-libitum access to water was provided.	After breakfast, participants completed appetite ratings and then remained in the lab for 70 minutes, during which participants were provided with no access to fluid.	After breakfast, participants completed appetite ratings and then remained in the lab for 70 minutes, during which participants were provided with no access to fluid.
30 mins	After the break, participants had their height measured and then in private, undressed and measured their weight. Serum samples were collected (if applicable).		
45 mins	The break then continued for 80 minutes, during which ad-libitum access to water was provided.	The break then continued for 80 minutes, during which access to fluid was restricted.	Participants then exercised on a stationary bicycle for 45 minutes in 30°C heat.
35 mins			After the exercise, participants in private, undressed, removed sweat from their body with skin wipes, dried their hair with a hair dryer, and measured their weight. Toilet breaks were restricted between the two weight measurements.
15 mins	Three hours after breakfast was consumed, participants completed appetite ratings and then consumed a standard lunch with two placebo capsules and ad-libitum access to water was provided.	Three hours after breakfast was consumed, participants completed appetite ratings and then consumed a standard lunch with two placebo capsules and 50ml of water.	Three hours after breakfast was consumed, participants completed appetite ratings and then consumed a standard lunch with two capsules containing 2 g of salt and 50 ml of water.
60 mins	After lunch, participants filled out appetite ratings and then remained in the lab for 60 minutes, during which ad-libitum access to water was provided. During the break, serum samples were collected, if applicable.	After lunch, participants filled out appetite ratings and then remained in the lab for 60 minutes, during which access to fluid was restricted. During the break, serum samples were collected, if applicable.	After lunch, participants filled out appetite ratings and then remained in the lab for 60 minutes, during which access to fluid was restricted. Thirty minutes into the break, serum samples were collected, if applicable.
15 mins	After the break, participants observed and rated all eight samples, and then tasted (via swilling and spitting) and rated all eight samples. After the ratings, participants were asked to choose which sample they would consume if they were only allowed to select one.		
15 mins	At the end of the session, participants were provided with access to ad-libitum water for 15 minutes while completing a questionnaire on the study foods and beverages and perceived aims of the study.		

6.2.9 Data analysis

All analyses were performed using SPSS. The mean and standard deviation for participant characteristics was calculated. When conducting repeated measures or mixed-model analysis of variance (ANOVA) tests, Greenhouse-Geisser corrections were used when any of the within-subject factors violated the assumption of sphericity.

To verify that the experimental manipulation affected feelings of hunger and fullness similarly throughout the test sessions across thirst conditions (i.e., physiologically thirsty, psychologically thirsty, control), a mixed-model analysis of variance (ANOVA) test was conducted. The within-subjects factors were appetite rating (i.e., hunger, fullness) and time-point (i.e., after breakfast, before lunch, after lunch, after tasting and rating the samples). The between-subjects factor was thirst condition.

To verify that the experimental manipulation influenced participants to be either physiologically thirsty, psychologically thirsty, or not thirsty, a mixed-model analysis of variance (ANOVA) test was conducted. The within-subjects factors was thirst rating and time-point (i.e., after breakfast, before lunch, after lunch, after tasting and rating the samples). The between-subjects factor was thirst condition. To interpret any overall differences, one-way analysis of variance (ANOVA) tests were conducted to assess differences in thirst ratings among the three thirst conditions for each time-point separately. The mean and standard deviation of % change in body weight for participants in the physiologically thirsty condition was calculated. A mixed-model analysis of variance (ANOVA) test was conducted. The within-subjects factor was time (i.e., pre- or post- experimental manipulation) and the between-subjects factor was thirst condition.

Percentages of participants who selected chilled water in the baseline and in the test sessions separated by thirst condition were reported. To control for individual differences, all the variables used in the analysis were change scores (i.e., the difference between the measures during the baseline session and the test session). The following analyses were conducted for both chilled water and room temperature water. To assess if beverage liking is a component of beverage reward, a linear regression was conducted to test if beverage liking predicted beverage reward. To assess differences in water intake, a one-way analysis of variance (ANOVA) test was conducted to test for differences between the three thirst conditions (i.e., physiologically thirsty, psychologically thirsty, control). To interpret any overall differences that were found, post-hoc pairwise comparisons were conducted (Tukey's tests were utilized to correct for multiple comparisons). To assess if beverage reward and beverage liking changed to different degrees based on thirst condition, one-way analysis of variance (ANOVA) tests were conducted. To interpret any overall differences that were found, post-hoc pairwise comparisons were conducted (Tukey's tests were utilized to correct for multiple comparisons). To assess if changes in beverage reward occurred to greater degree than changes in beverage liking, paired-samples t-tests were conducted. Finally, to assess if beverage reward predicted beverage intake, a linear regression was conducted.

6.3 Results

6.3.1 Participants

Thirty participants were recruited for this study. Due to attrition, the final sample consisted of 26 participants (physiologically thirsty, N = 10; psychologically thirsty, N = 8; and control, N = 8). The sample consisted of 15 females and 11 males with an average age of 26.9 ± 5.5, an average cognitive restraint score of 11.6 ± 3.1, an average uncontrolled eating score of 22.0 ± 5.3, and an average emotional eating score of 22.0 ± 3.6. BMI ranged from 16.9 to 39.4 (*M* = 22.4 ± 4.2) kg/m2.The groups were well-matched in their familiarity with diet and regular beverages and in their level of physical activity. Table 21 reports participant characteristics separated by thirst group. None of the participants correctly guessed the study aims. The data on time since last meal and drink were not analysed, but were included in the study to encourage participants to comply with the overnight abstinence requirements.

Table 21. Participant characteristics

		Control	Psychologically thirsty	Physiologically thirst
	Gender (% male)	25%	25%	30%
	Age (means ± SD)	25(3)	26(6)	28(7)
	Ethnicity (% Caucasian)	75%	87.5%	90%
	Education level (% university graduates)	100%	87.5%	100%
	BMI (means ± SD)	21.3(2.1)	23.9(6.6)	22.1(2.8)
TFEQ	Cognitive Restraint (means ± SD)	11.6(4.0)	10.9(3.3)	12.2(2.0)
	Uncontrolled Eating (means ± SD)	20.1(5.6)	22.0(5.5)	23.5(4.8)
	Emotional Eating (means ± SD)	13.3(4.3)	12.6(3.5)	13.5(3.5)

6.3.2 Appetite ratings

Mixed-model analysis of variance (ANOVA) tests revealed that all groups reported similar changes in hunger, $F(3,69) = 30.6$ $p < .001$, $\eta p^2 = .57$, and fullness, $F(3,69) = 22.4$ $p < .001$, $\eta p^2 = .49$, over the course of the test session.

6.3.3 Hydration measures

A mixed-model analysis of variance (ANOVA) test revealed that there was an interaction between time and condition on thirst ratings, $F(6,69) = 8.3$, $p < .001$, $\eta p^2 = .42$., for all thirst groups. Post-hoc comparisons revealed that all groups reported similar levels of thirst upon arriving at the lab, but as the session progressed, participants in the physiologically thirsty group reported the highest levels of thirst, followed by participants in the psychologically thirsty group, and the control group (results demonstrated in Figure 15).

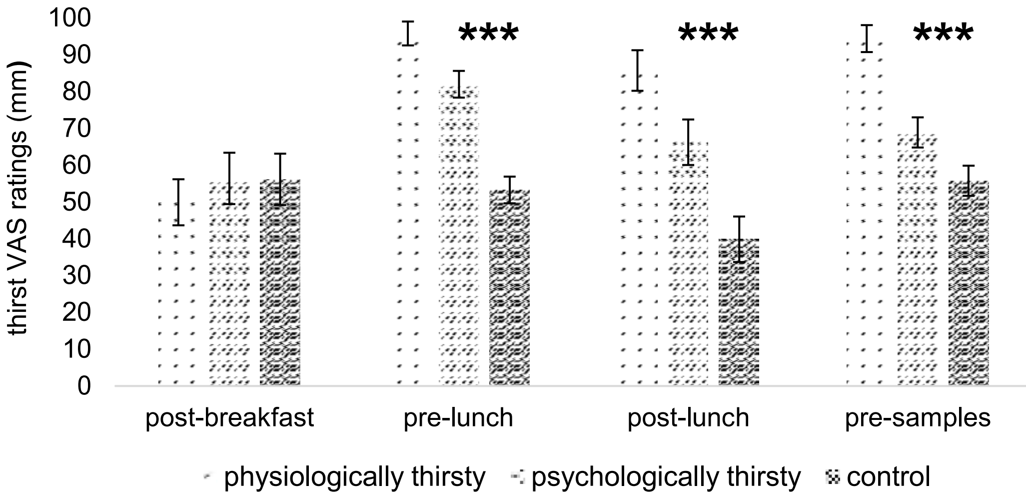


Figure 15 Thirst ratings over the duration of the session in the physiologically thirsty, psychologically thirsty, and control conditions. Physiologically thirsty participants exercised before lunch and ingested salt capsules with lunch.

Exercisers lost on average 0.6 kg (*SD* = 0.3 kg) or 1% of their body weight (*M* = 68.8 ± 19.3 kg). Nineteen participants provided serum samples, but the analysis only included samples from participants who had reliable and valid serum osmolality measurements for both their pre- and post- manipulation samples. A mixed-model analysis of variance (ANOVA) test revealed an interaction between time and thirst condition, $F(2,5) = 18.6$, $p = .005$, $\eta p^2 = .88$. As the sample sizes for serum osmolality among the three groups were small and uneven, post-hoc comparisons could not be conducted to further explore this interaction. Nonetheless, the trend of the data (depicted in Figure 16) suggests an increase in serum osmolality for the physiologically thirsty group and a decrease in serum osmolality for the control group, and no change for the psychologically thirsty group.

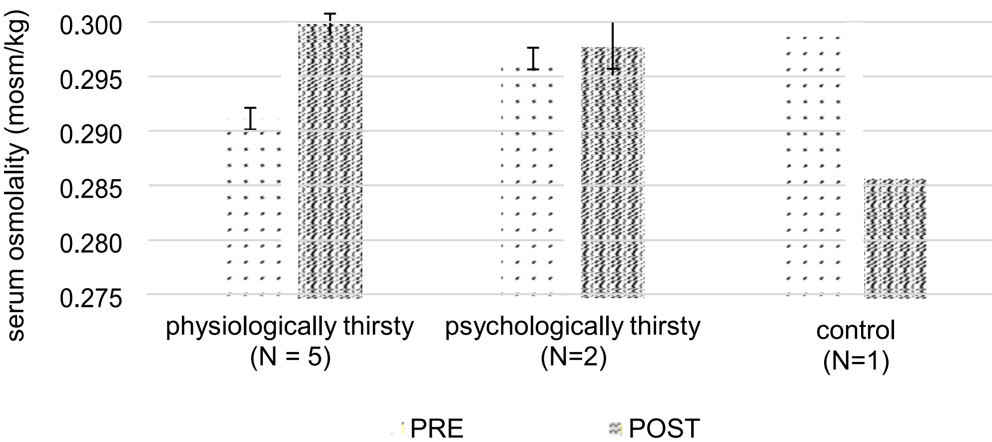


Figure 16 Serum osmolality measures prior to and after the experimental manipulation in the physiologically thirst, psychologically thirsty, and control condition.

6.3.4 The effect of thirst on water intake

To control for individual differences, all the variables used in the analysis were change scores (*i.e.,* the difference between the measures during the baseline session and the test session). Baseline intake of chilled water and baseline liking and desire to drink ratings for chilled water and room temperature water can be found in Appendix A. Table 20 demonstrates that desire to drink chilled and room temperature water were predicted by liking for the sample.

Table 22 Sample liking as predictors of reward ("desire to drink")

	Sample liking				
	R^2	ANOVA	β	t	*p*
chilled water	.59	F(1,25) = 34.93, *p* < .001	0.77	5.91	< .001
room temperature water	.43	F(1,25) = 18.14, *p* < .001	0.66	4.26	< .001

Chilled water. The percentage of participants who selected chilled water (when asked which of the eight samples they would prefer to consume) increased in both the physiologically thirsty (from 33% to 44%) and the psychologically thirsty conditions (from 25% to 50%) but remained unchanged in the control condition (25%). Intake of chilled water differed significantly among the thirst conditions, $F(2,25) = 13.8$, $p < .001$, $\eta p^2 = .53$ (results shown in Figure 17).

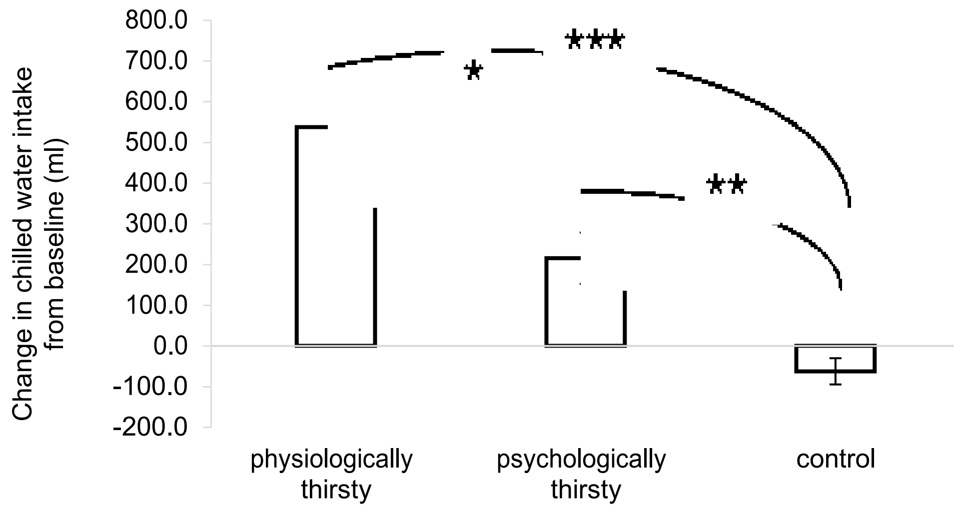


Figure 17 Average chilled water intake (change from baseline) based on thirst condition
*Asterisks denote comparisons that differ significantly at the .001 level***, .01 level**, and .05 level**

One-way analysis of variance (ANOVA) tests revealed that liking of chilled water was not significantly different among the thirst conditions, F(2,25) = 2.09, *p* = .147, ηp² = .14, but desire to consume chilled water was significantly different among the thirst conditions, F(2,25) = 3.52, *p* = .046, ηp² = .22 (results shown in Figure 18). Further, a paired samples t-test demonstrated that in the physiologically thirsty group, the increase in desire to consume chilled water was greater, by 17.9 ± 19.5 mm, than the increase in liking for chilled water, t(9) = -2.9, *p* < .017, d = .92. Finally, a linear regression analysis demonstrated that desire to consume chilled water (β= .69, t(25) = 2.53, *p* = .019), not liking of chilled water (*p* = .433), predicted intake of chilled water, R^2 = .29, F(2, 25) = 4.80, *p* = .018) (results shown in are depicted in Figure 19).

Room temperature water. The percentage of participants who selected room temperature water (when asked which of the eight samples they would prefer to consume) remained unchanged in the physiologically thirsty (11%) and control (0%) conditions, and decreased in the psychologically thirsty condition (from 25% to 0%). One-way analysis of variance (ANOVA) tests revealed that liking of room temperature water was not significantly different among the thirst conditions, F(2,25) = 2.15, *p* = .147, ηp² = .14, but desire to consume chilled water was significantly different among the thirst conditions, F(2,25) = 3.84, *p* = .036, ηp² = .24 (results shown in Figure 18). However, a paired samples t-test demonstrated that in the physiologically thirsty group, the change in desire to consume room temperature water was not greater than the change in liking for room temperature water, M = 14.0 ± 20.2 mm, $t(9) = -2.20$, $p < .056$, $d = .70$. In addition, a multiple regression analysis demonstrated that only desire to consume chilled water ($\beta = .44$, $t(25) = 2.53$, $p = .019$), not room temperature water ($\beta = .30$, $t(25) = 1.70$, $p = .102$), predicted intake of chilled water, $R^2 = .36$, $F(2, 25) = 6.36$, $p = .006$).

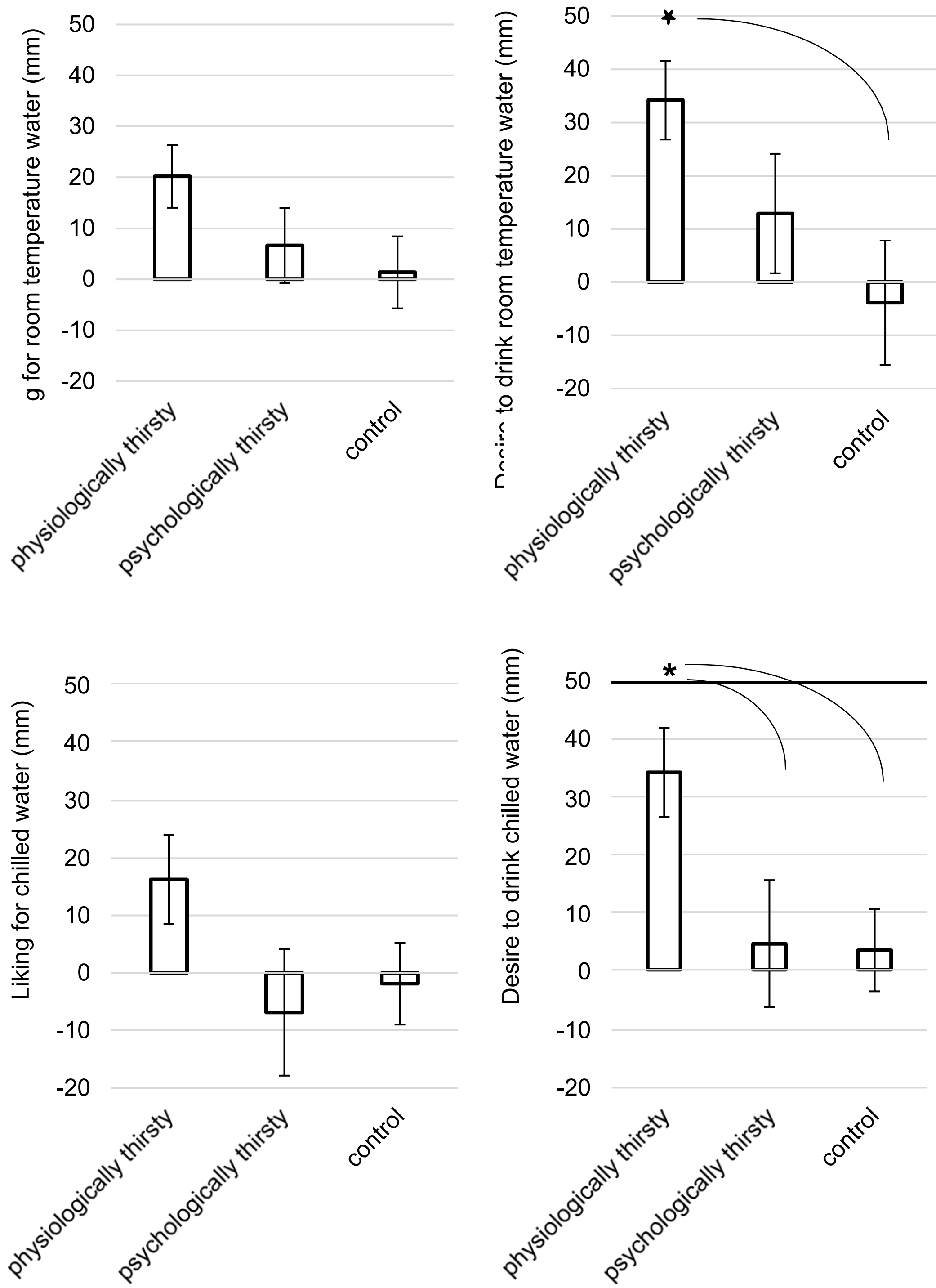


Figure 18 Average liking and desire to drink ratings (change from baseline) for room temperature water and chilled water.
*Asterisks denote comparisons that differ significantly at the .05 level**

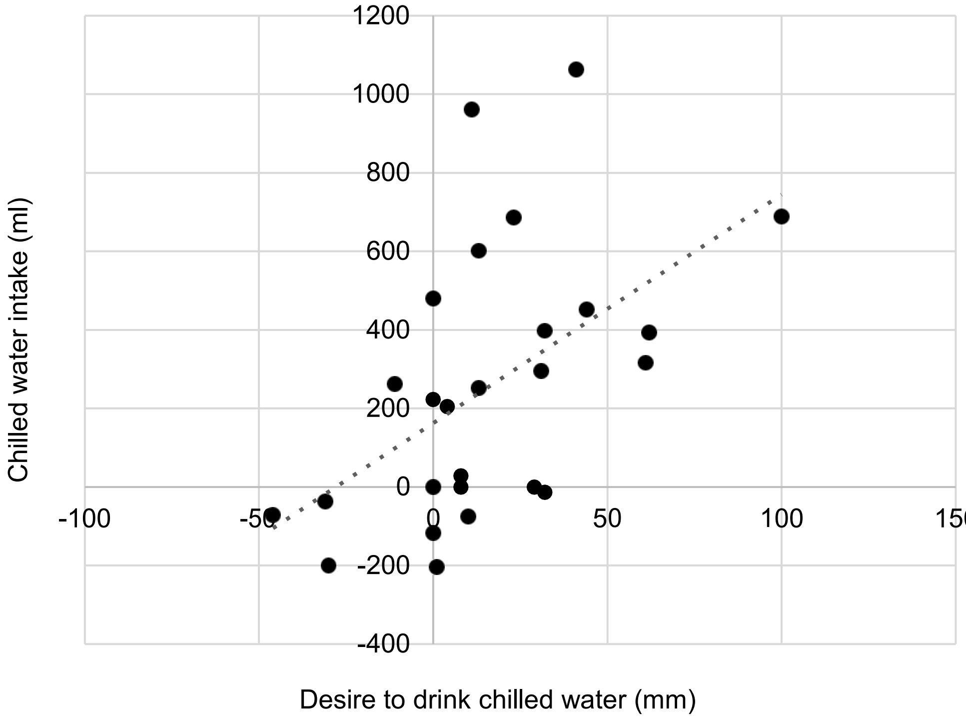
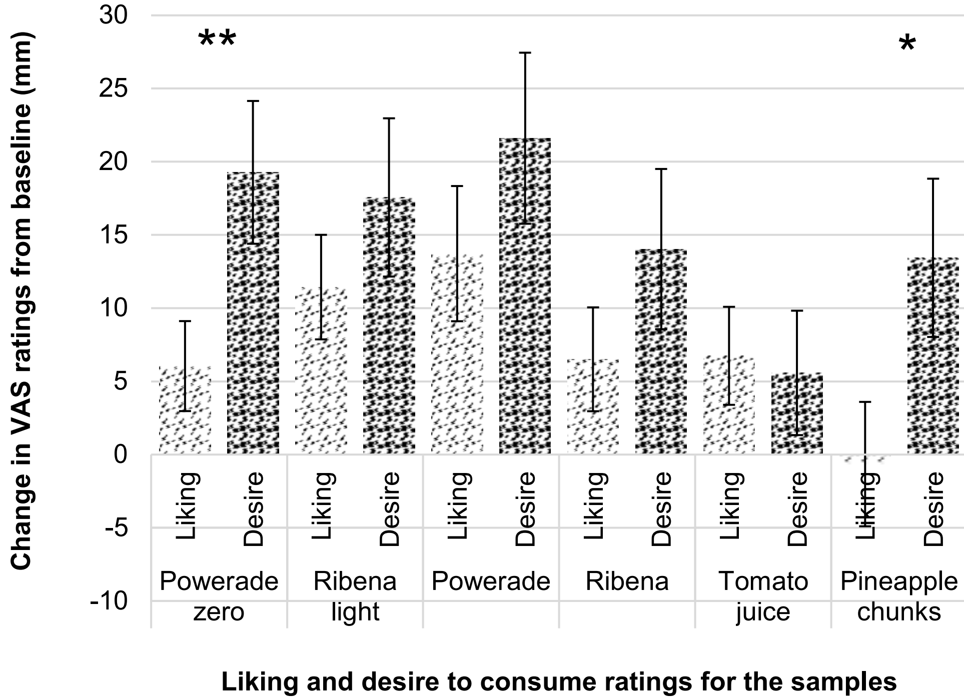


Figure 19 Average intake of chilled water (change from baseline) as a function of desire to consume chilled water (change from baseline)

6.3.5 Exploratory analyses

To control for individual differences, all the variables used in the exploratory analysis were change scores (*i.e.,* the difference between the measures during the baseline session and the test session). Baseline liking and desire to consume ratings for Ribena light, Ribena, Powerade zero, Powerade, Tomato juice, and Pineapple chunks can be found in Appendix A.

A 6 (sample) x 2 (rating) x 3 (thirst condition) mixed-model analysis of variance (ANOVA) test revealed a main effect of thirst condition, $F(1,23) = 4.2$, $p = .029$, $\eta p^2 = .27$, and a main effect of rating, $F(1,23) = 10.66$, $p = .003$, $\eta p^2 = .31$. Specifically, participants in the physiologically thirsty condition gave higher ratings than participants in the control condition (Mean difference = 16.03 ± 6.08, $p = .044$) and the change in desire to consume ratings was greater than the change in liking ratings (Mean difference = 7.95 ± 2.44 mm, $p = .003$). Liking and desire to consume ratings (averaged across the three thirst conditions) for the exploratory samples are depicted in Figure 20.



Osmolality (mosm/kg)	48.0	83.8	289.0	394.0	485.0	(pineapple juice) 836.0

Figure 20 Average liking and desire to consume ratings (change from baseline) for Ribena light, Ribena, Powerade zero, Powerade, Tomato juice, and Pineapple chunks. The figure demonstrates that collapsing across sample type, the increase in desire to consume was significantly larger than the increase in liking. This effect was particularly apparent in Powerade zero and Pineapple chunks.

*Asterisks denote comparisons that differ significantly at the .01 level** and .05 level**
Adjustment for multiple comparisons: Bonferroni

Desire to consume pineapple chunks increased to a greater degree than liking for pineapple chunks (Mean difference = 14.09, $p = .012$). Powerade zero was the only flavoured fluid to show a significant difference between liking and desire to drink ratings (Mean difference = 13.2 ± 3.5, $p < .001$). Powerade zero was also the sample most similar to the water samples, in terms of its osmolality. When chilled water, room temperature water, and Powerade zero are analysed together, there is a significant interaction between thirst condition and rating (liking versus desire to drink), F(2,23) = 4.1, p = .031, ηp^2 = .26 (results demonstrated in Figure 21).

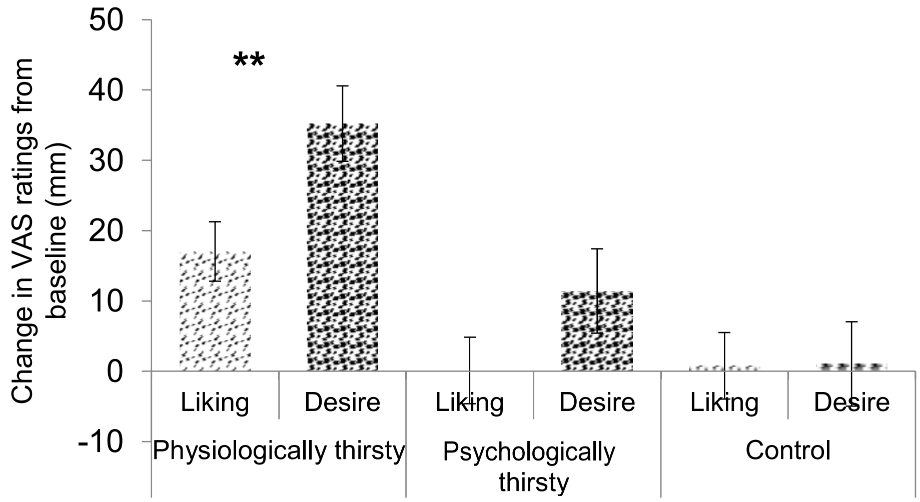


Figure 21 Average liking and desire to drinks ratings (change from baseline) for beverages with low osmolality (chilled water, room temperature water, and Powerade Zero) collapsed across beverage type and separated by thirst condition.

*Asterisks denote comparisons that differ significantly at the .001 level***, .01 level**, and .05 level**
Adjustment for multiple comparisons: Bonferroni

6.4 Discussion

It was hypothesized that thirst would increase motivation to consume the beverage (beverage reward), but that this would not occur as a result of an increase in beverage liking. The rationale was that beverage liking is how much an individual enjoys the taste of the beverage in the mouth (irrespective of ingestion), whereas beverage reward, measured by desire to consume, is how much an individual is motivated to ingest the beverage. This motivation (beverage reward) is likely influenced by beverage liking. However, if thirst affected beverage reward, but not beverage liking, then the difference could be attributed to a separate component, beverage wanting. Therefore, this experiment investigated if beverage reward was influenced by beverage liking, and if beverage liking and beverage reward were discernible constructs. To test this theory, participants made two distinct ratings: (a) how pleasant the sample tasted in the mouth (beverage liking), and (b) the desire to drink an entire glass of the sample (beverage reward). The results for chilled water were as follows: beverage reward was influenced by beverage liking (achieved 98%

power). Further, beverage reward, not beverage liking, was influenced by the thirst manipulation. This effect only achieved 61% power, and therefore a larger sample size should be used when investigating this effect in the future. Taken together, the results confirm the construct validity of desire to drink ratings as a measure of beverage reward, which is affected by, but discernible from, beverage liking, in that it is uniquely affected by thirst. These results applied only for those participants in the physiologically thirsty condition. Therefore, it can be deduced that thirst of a physiological nature, but not psychological nature, influences wanting for chilled water.

As previous research suggests that cool beverages (10-22 °C) are preferred and ingested to a greater degree (Burdon et al., 2012), this experiment investigated the role that temperature plays in beverage liking and beverage reward. Similar to chilled water, participants who were physiologically thirsty had an increased desire to drink room temperature water, and did not rate the taste as any more pleasant. However, unlike chilled water, the difference between the two ratings was not statistically significant. Considering these results alongside previous work on the effect of temperature on mouth dryness and thirst (Adolph, 1947; Brunstrom & Macrae, 1997; SJ French et al., 1994; Pangborn et al., 1970; Rolls et al., 1980), it is possible that tasting chilled water triggered salivation to a greater degree than tasting room temperature water did. Increased salivation may have increased expectancy of chilled water's thirst-quenching ability, and in turn, increased their desire to drink it to a larger degree than room temperature water.

If the ingestion of water is the priority, then desire to drink should be highest for beverages with a low carbohydrate content and low osmolality. This theory was supported by the results of Appleton's experiment, which found that only beverages of low osmolality became increasingly pleasant after fluid loss (Appleton, 2005), and the results of the present experiment . While desire to consume increased more than liking for all six flavoured samples, the effect occurred to a greater degree in Powerade zero and Pineapple chunks. Powerade zero was the beverage with the lowest osmolality level. When chilled water, room temperature water, and Powerade zero were analysed together, it was evident that being physiologically thirsty increased desire to drink, but not liking for, the beverages. This finding achieved over 99% power.

Participants liked the taste of the beverages in the mouth relatively more when they were thirsty, but this was not the case for Pineapple chunks. One possibility is that Pineapple chunks did not wet the mouth to the same degree as the liquids did. A sample's ability to wet the mouth might enhance liking for taste experienced in the mouth. Therefore, while it is possible that increased liking ratings were the result of some participants failing to distinguish liking in the mouth from desire to consume the fluid or food, the above rationale suggests that increased liking ratings were the result of beverages' mouth-wetting abilities.

As hypothesized, intake of chilled water reflected thirst differences. Intake was highest in the physiologically thirsty condition, intermediate in the psychologically thirsty condition, and lowest in the control condition (achieved over 99% power). It was also hypothesized that if rated desire to drink was a valid measure of beverage reward, then it could be used to predict beverage intake. As desire to drink was confirmed to be a proxy for beverage reward, the effect of desire to drink water on water intake was assessed. The results confirmed the predictive validity of desire to drink on beverage intake (at least when the beverage in question is water). This effect achieved 88% power. Future research should investigate if this predictive relationship extends to beverages other than water, or foods with fluid-like properties. Desire to drink water was assessed using a room temperature and chilled water sample. Only chilled water predicted intake of chilled water, suggesting that intake of room temperature water would have been lower, as previous research has demonstrated (Burdon et al., 2012).

In Chapter 4, participants increased their beverage intake when they were fluid restricted. It was unclear whether this effect was due to physiological or psychological mechanisms. Therefore, the current experiment investigated how water intake (and its associated reward) would differ between individuals who are euhydrated yet believe they are thirsty, and individuals who are hypohydrated. Participants who lost fluid and ingested salt increased their usual water intake by 537 ml. This is contrasted with participants who were fluid restricted and increased their usual water intake to a lesser degree (in the present experiment: by 215 ml; in the second experiment presented in Chapter 4: by 169 ml). In addition, only participants who lost fluid and ingested salt demonstrated an increased desire to consume water.

To mimic conditions that would occur in everyday settings, all participants were fluid restricted while working seated for several hours. Participants who were meant to experience physiological changes to fluid balance also engaged in vigorous physical activity and ingested salt. While participants were unaware that they ingested salt, it was not possible to blind participants to the physical activity aspect of the experiment. Therefore, future work should assess if the act of exercise itself had an effect on water reward and water intake. In order to assess the validity of the experimental manipulation, subjective and physiological measures of hydration status were collected. The change in thirst ratings, body weight, and serum osmolality suggest that participants in the physiologically thirsty condition did undergo a physiological change (*i.e.,* negative fluid balance), unlike participants in the psychologically thirsty condition. However, future work with a larger sample size of serum osmolality measurements is needed to draw firm conclusions.

Chapter 7 General Discussion

This general discussion will consolidate the findings of this thesis in order to discuss the broader implications of its findings and offer suggestions of how to build upon this body of research. A brief overview of the key findings of each chapter can be found in Table 21.

7.1 Methodological considerations

This thesis utilized mixed methods. The qualitative methods consisted of a free association test and semi-structured interviews. The qualitative data was collected in the field and the analytical approach used was grounded theory. The qualitative data was analysed using NVivo (QSR International, 2012). Two research assistants, Rose O'Connell and Anna Kemp, helped to recruit participants and were the additional raters for the interrater reliability check.

The quantitative methods utilized in this thesis included self-report (*e.g.,* familiarity with diet beverages), psychological (*e.g.,* subjective thirst ratings), behavioural (*e.g.,* beverage intake), and biological measures (*e.g.,* serum osmolality). The quantitative data was collected both online and in the laboratory. For the laboratory-based studies, self-report and psychological data was inputted by participants and stored on computers using programmes that I created in Matlab (Mathworks, 2015); behavioural and biological data was measured by the researcher and research assistants, Rose O'Connell, Anna Kemp, Caroline Thomas, and Georgia Tyler. Harriet Carroll and Lewis James, colleagues at Bath University who are experienced in hydration research, assisted in the serum osmolality analysis. For the online-based studies, self-report, psychological, and behavioural data were inputted by participants and stored on virtual servers using programmes that a colleague, Andy Brown, wrote using Angular (Google, 2016). The quantitative data was analyzed using various inferential statistical tests (*e.g.,* one-way ANOVA, repeated measures ANOVA, mixed-model ANOVA, Friedman two-way ANOVA, Kruskal-Wallis by ranks test, Mann-Whitney U test, Wilcoxon rank sum test, multilevel logistic regression, multilevel linear regression, linear regression) using SPSS (IBM Corp, 2015), R (R Core Team, 2017) and Stata (StataCorp, 2015).

An introspective investigation of the hunger, thirst, and fullness VAS supported previous suggestions that the scales are best suited for within-subject, repeated-measure designs (Stubbs et al., 2000). In addition, the introspective investigation of the VAS also highlighted the different ways in which the questions can be interpreted and how that might affect the correlation between hunger and thirst. Comparison of the free-association test and semi-structured interviews to assess food choice demonstrated that while less thorough, the free association test is a useful and economical alternative to semi-structured interviewing. This thesis established the validity of a novel method of assessing compensatory drinking behavior: specifically, manipulating hunger and thirst status and measuring beverage choice and intake. This thesis also demonstrated that this novel method can be applied in both online and laboratory settings and can be used when assessing expected and actual drinking behavior. Finally, this thesis established that desire to drink ratings are indicative of beverage reward and are predictive of beverage intake (at least for water).

As many of the methods utilized in this thesis were novel, it was possible often to only loosely estimate effect sizes when determining sample sizes for the experiments. As a result, some of the relevant post-hoc comparisons were not sufficiently powered and therefore could not be conducted as part of this thesis. Going forward, the effect sizes calculated from the results of this thesis (especially those in Chapter 4 as they were replicated findings) can be used to more effectively power statistical analyses to answer the same or related questions.

7.2 Findings and Implications

Results from the qualitative study demonstrated that individuals generally believe that their ingestive behavior occurs in response to physiological and psychological cues. In actuality, the behavior occurs often in response to reward and habit. Rogers and Hardman (2015) reported similar findings (although informally). One possibility is that because individuals expect that the experience of hunger and thirst to be aversive, they attempt to prevent these states by engaging in anticipatory eating and drinking (SJ French et al., 1994; Phillips et al., 1984). Experiencing thirst infrequently may desensitize individuals to detecting thirst. Individuals seem to be aware of these inconsistencies in their expectations and actual behavior, but only when asked explicitly to compare their everyday experiences of hunger and thirst to more extreme experiences. Individuals admit that many of their anticipations about energy and fluid needs and resulting behaviours are unnecessary. They suggest that they catastrophise any deviation from usual ingestive behavior simply because they have become habituated to having constant access to foods and beverages. Results from the qualitative study also demonstrated that due to the wide range of beverages available today, drinking occurs not only for hydration, but for energy, taste, and health. McKiernan and colleagues (2009) have made similar claims. In addition, the results suggest that the definitions of beverages and food overlap. Individuals do not seem be aware of these inconsistencies in food and beverage and eating and drinking.

The lack of attention given to these distinctions may partly explain why liquid calories, that lack obvious satiety-relevant cues (*e.g.,* viscosity), are at risk of being overconsumed (Flood-Obbagy & Rolls, 2009; Malik et al., 2013, 2006; Mattes, 2005; McCrickerd et al., 2014; Mourao et al., 2007). A hypothesis of this thesis was that under certain circumstances (*e.g.,* if a sweetened beverage is the only source of taste, energy, and satiation available to an individual when he or she is food-deprived), the individual might become more aware of the sweetened beverages less obvious, but nonetheless satiety-relevant cues (*e.g.,* flavour and energy). This in turn, might increase intake. The results presented in Chapter 4 did not support this hypothesis: there was not an increase in intake of the sweetened beverages when participants were hungry in either experiment. The results of this thesis apply to a population of individuals living under ad-libitum food and beverage conditions, who have little need to rely on liquid calories as a significant source of energy.

However, the results presented in Chapter 5 demonstrated that a sweetened beverage can be identified as a significant source of taste, energy and satiation when consumed to supplement a more obvious source of taste, energy, and satiation. For example, in Study 1 (virtual beverage choice), participants were more likely to choose the sweetened beverages with small food portion sizes and less likely to choose the sweetened beverages with large food portion sizes. In Study 2 (virtual beverage intake), participants who were less concerned about thirst, expected to drink less as food portion size increased. The results suggest that participants were sensitive to beverage calories and/or satiation to some degree. However, participants who expected to feel thirsty after consuming the food expected to increase their beverage intake as food portion size increased. This relationship did not depend on the type of beverage which participants expected to drink. Likewise, the results presented in Chapter 4 demonstrated that being thirsty, but not hungry, increased actual intake. Again, this relationship did not depend on the type of beverage which participants expected to drink.

Collectively, the data on beverage choice and beverage intake suggest that participants are somewhat aware of food-like properties of beverages, but more so when thirst is not the major concern. Previous research has demonstrated that thirst motivates fluid intake, but not energy intake (Corney et al., 2015; Kelly, P. J., Guelfi, K. J., Wallman, K. E., & Fairchild, 2012; Shirreffs et al., 2004). The findings presented in this thesis add to the current literature by demonstrating that thirst motivates fluid intake regardless of the beverage properties and of hunger/fullness and as a result can increase energy intake. Therefore, emphasis should be placed on the choice of beverage, especially when the motivation to drink is to quench a thirst. This is because, when deciding what to drink, individuals consider the taste and energy properties over the hydrating and thirst-quenching properties of beverages.[1] However, once drinking begins, the amount consumed is largely affected by how thirsty an individual currently is or expects to be. The taste and energy properties are then largely ignored. This seems to be the case even when the beverage is consumed as part of a meal: the food might prime thoughts about taste and energy, but not enough to take priority over thoughts about thirst.

[1] *It should be noted that it is yet to be determined if individuals consider the taste and energy properties of beverages when deciding what to drink independent of an eating episode (the final chapter collected data on beverage choice outside the context of a meal, but inferential statistics were not used).*

How motivated an individual is to engage in a behavior is determined by how rewarding the outcome is. Therefore, it was inferred that beverage choice and intake were influenced by motivational states (actual and anticipated hunger and thirst) as a result of underlying changes to beverage reward. For example, participants decided to drink a sweetened beverage when they anticipated consuming a small amount of food or when liking for the food was low. Under these conditions, participants were probably more concerned with feeling hungry and experiencing reduced food reward than they were with becoming thirsty. Since both food and beverages can provide taste and energy and there is overlap in eating and drinking, the reward lost from eating the food could be compensated by the reward experienced from drinking the beverage. Participants decided to increase their intake of water, the reduced-sugar sweetened beverage, and the sugar-sweetened beverage, when they were thirsty (either from being fluid deprived or anticipating consuming a large amount of food). Under these conditions, participants were probably more concerned with preventing or relieving thirst than they were with maintaining orosensory reward and satiety. Since all of the beverages provided fluid (which would wet the mouth, wash food down, and restore fluid balance to a similar degree), they were likely perceived as equally rewarding, and therefore were consumed in similar amounts. Participants also decided to increase their intake of all beverages when they anticipated consuming a small amount of food. In that case, participants may have instead been motivated by concern that they would be experiencing less food reward and satiety, and therefore increased beverage intake (and therefore beverage reward and satiety) as a way to compensate.

In the experiments in Chapter 4, participants drank less than usual, but did not experience excess fluid loss. Therefore, a hypothesis in Chapter 6 was that the reward value of a beverage (the motivation to drink the beverage) would differ depending on whether the individual was physiologically thirsty (*i.e.,* needed to drink to correct negative fluid balance) or psychologically thirsty (*i.e.,* believed they needed to drink despite no significant physiological change to fluid balance). The results demonstrated that beverage reward is affected by, but discernible from, beverage liking, in that it is uniquely affected by thirst. Beverage reward can be measured by desire to drink ratings, and in turn desire to drink ratings can be used to predict beverage intake. In regards to the type of thirst, although beverage intake in physiologically thirsty participants differed significantly from beverage intake in psychologically thirsty participants, changes in beverage reward occurred only in physiologically thirsty participants. Further, changes in beverage reward occurred to a greater degree for the beverages with the lowest osmolality measurements. Similar findings were reported by Appleton (Appleton, 2005).

Chapters 4 and 5 demonstrated that intake when thirsty is similar despite the type of beverage being consumed. Therefore, when the beverage being consumed is high in calories, energy intake will likely increase (and not be fully compensated at subsequent ingestive events) (DellaValle et al., 2005; Flood et al., 2006; Panahi et al., 2013; Rogers, Hogenkamp, et al., 2016). In the virtual intake study, participants who anticipated feeling thirsty from the meal expected that they would drink around 600 ml with lunch. In the laboratory studies, participants who were fluid deprived for 11 hours and felt thirsty consumed around 380 ml (in both Study 1 and Study 2 of Chapter 4). If the beverage is a sugar sweetened beverage such as Ribena, the above values in terms of caloric intake range from 150 kcal to 246 kcal. Chapter 6 demonstrated that beverage intake, at least for water, will be increased further if the individual is hypohydrated. Participants who were fluid deprived for 15 hours and felt thirsty consumed around 460 ml of water, whereas participants who were fluid deprived and had fluid loss consumed around 750 ml water. The results presented in Chapters 4 and 5 suggest that intake of sweetened beverages when hypohydrated would be similar to that of water. However, the results presented in Chapter 6 revealed that (a) beverage intake is predicted by beverage reward and (b) the increase in beverage reward when hypohydrated was more pronounced in beverages with low osmolality. Therefore, intake of caloric beverages will likely be higher when in physiological need of fluid (as opposed to simply feeling thirsty) but would most likely not be as large as the increase as seen with water.

One strategy for reducing sugar-sweetened beverage consumption is to increase cost to the producer, retailer and/or consumer. In the United Kingdom, a sugar tax has been in effect 6th April, 2018. The tax applies to beverages containing more than 5g of sugar per 100 ml (beverages that do not contain added sugar like fruit juice or beverages that contain significant amounts of calcium like milk drinks are exempt). Ahead of the sugar tax, many UK beverage manufacturers have modified the beverage recipes to reduce sugar content or have reduced the size of the beverage bottles and increased prices (Musaddique, 2018). The Japanese company, Suntory, which now owns Ribena, cut the beverage's sugar content in half and used sweeteners acesulfame K and sucralose to maintain the sweetness, and polydextrose to maintain the mouthfeel (Lucozade Ribena Suntory, 2018). This change to the flavor and ingredients has been met with backlash from consumers (Joseph, 2018).

The research reported in this thesis supports the claim that substituting a reduced-sugar-sweetened beverage for a sugar-sweetened beverage could be a helpful strategy for reducing energy intake. The consumer is able to enjoy the taste of the beverage (reward) without ingesting a significant amount of calories. Analyses conducted on the National Consumer Panel[2] found that a 20% price increase on sugar-sweetened beverages led to limited compensation with other beverages (mostly fruit juices), and there was no evidence of compensation with sugary foods (Finkelstein et al., 2013). However, using a model of consumer demand to predict consequences of implementing a sugar-sweetened beverage tax revealed a potential increase in fat and sodium intake (Zhen, Finkelstein, Nonnemaker, Karns, & Todd, 2014). Further, the results of Chapter 4 suggest that less favourable opinions of reduced-sugar-sweetened beverages might cause individuals who drink them to seek out compensatory reward from food and fluid (*i.e*, by eating or drinking additional items sooner than they would have normally). Therefore, individuals avoiding sugar-sweetened beverages as a result of price increases, may begrudgingly consume reduced-sugar-sweetened beverages. In turn, they might not compensate with other sources of sugar, but might compensate by eating or drinking more in general. Perhaps, sensory-specific satiety for sweetness from consuming the reduced-sugar sweetened beverage will cause individuals to seek out compensatory reward that is savoury. This might explain the potential increase in fat and sodium predicted (Zhen et al., 2014). While this compensation is unlikely to fully offset the benefit to energy intake from switching to the reduced-sugar sweetened beverage (Rogers, Hogenkamp, et al., 2016), it is nonetheless a

[2] The National Consumer Panel is a database of store-bought food and beverage purchases. Each entry contains data on dollars paid and units purchased. Data is collected by U.S. consumers who scan their purchases into the database (The Nielsen Company (US), 2018).

potential obstacle to consider for individuals who are particularly averse to low-energy sweeteners. Therefore, future research should focus on increasing the acceptability of reduced-sugar beverages so as to keep both manufacturers and consumers content.

Table 23 Summary of key findings from each experimental chapter

Chapter	Key findings
2. Investigating beliefs about food and beverage choice, and associated hunger and thirst	Greater reliance on external cues (*e.g.,* time of day) than internal cues (*e.g.,* dry mouth) to determine thirst levels Due to wide variety of beverages, drinking occurs not only as a means to hydrate, but to obtain energy, to enjoy the taste of, or to benefit health Whether flavourful and/or energy-providing liquids are considered to be beverages (source of hydration) or food (source of calories) is context dependent and perhaps occurs at an implicit level
4. Food or fluid? The effect of motivational states (hunger and thirst) on how beverages are conceptualized and consumed	Participants consumed larger amounts of the beverages when thirsty and beverage intake relieved thirst (regardless of beverage type or participant hunger/fullness) Neither participant hunger/fullness levels nor beverage properties affected fluid intake or appetite ratings
5. The contribution of beverages to meal reward (Part 1. Beverage choice)	Reduced meal size (which likely reduced meal satisfaction) led to the addition of a sweetened beverage to the meal (which was likely an attempt to sustain meal satisfaction) Post-hoc analyses suggested that dislike for the food increases the likelihood of selecting sweetened beverages and mitigates the effect of food portion size on beverage choice. Post-hoc analyses also suggested that dietary restraint decreased the likelihood of selecting sweetened beverages except when the food is well-liked and served in a small portion.

5. The contribution of beverages to meal reward (Part 2. Beverage intake)	Increasing meal size (from 300 kcal to 900 kcal) increased the amount that individuals expected to drink (which was likely an attempt to aid the ingestion of food and/or avoid future thirst) With the 100 kcal portion, anticipated thirst was much less relevant; instead, anticipated enjoyment of taste, anticipated caloric intake, and anticipated satiation may have increased the amount that individuals expected to drink The increased energy intake from the sugar-containing beverage negated the reduction in energy intake from the food
6. Deconstructing beverage reward: the effect of two types of thirst on liking and desire to drink	Desire to drink is a valid measure of beverage reward, which is affected by, but is also partly distinct from from, beverage liking, in that it is uniquely affected by thirst (at least for beverages with low osmolality) Desire to drink chilled water (but not room temperature water) predicted intake of chilled water Participants who were physiologically thirsty had a stronger desire to consume the samples. Desire to consume the samples was similar among the psychologically thirsty and control groups. Participants who were physiologically thirsty consumed the largest amount of chilled water, followed by the psychologically thirsty group, and then the control group.

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Appendices

Appendix A

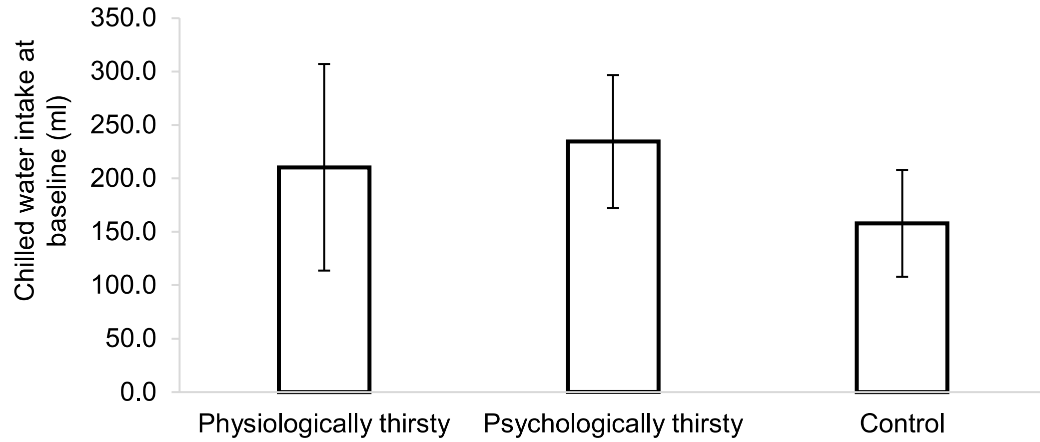

Figure 22 Intake of chilled water at baseline separated by thirst condition (Chapter 6)

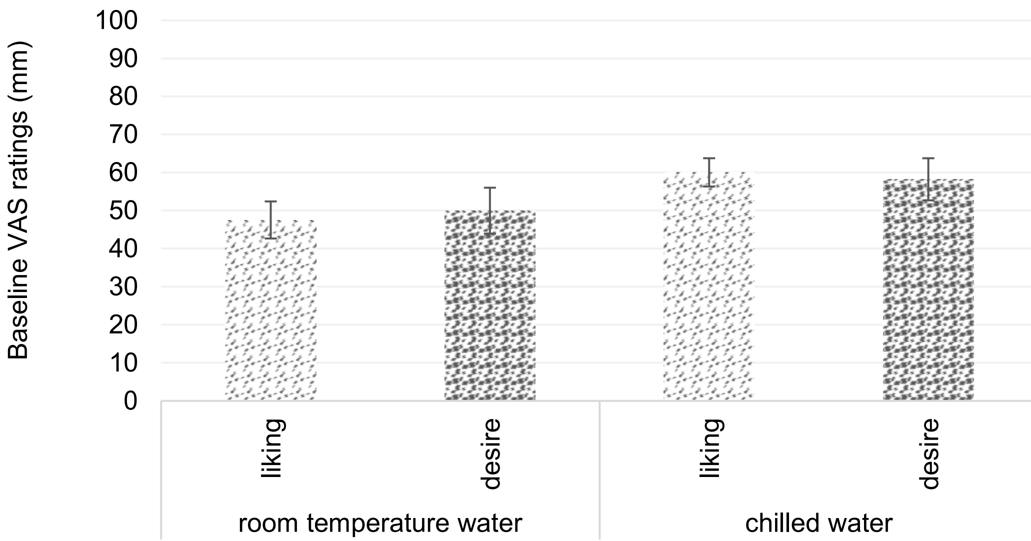

Figure 23 Baseline liking and desire to consume ratings for room temperature and chilled water (Chapter 6)

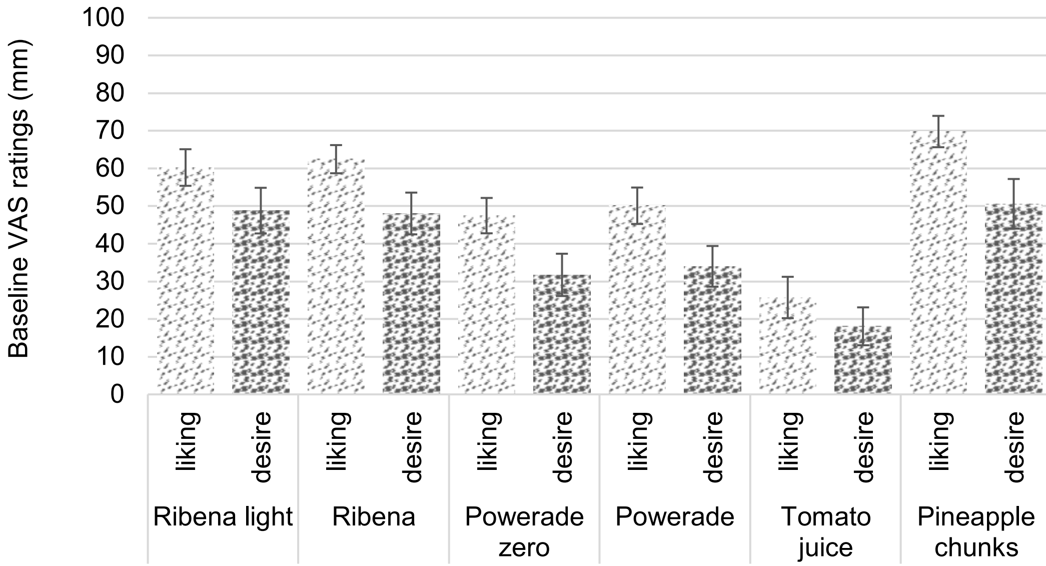

Figure 24 Baseline liking and desire to consume ratings for Ribena light, Ribena, Powerade zero, Powerade, Tomato juice, and Pineapple chunks (Chapter 6)

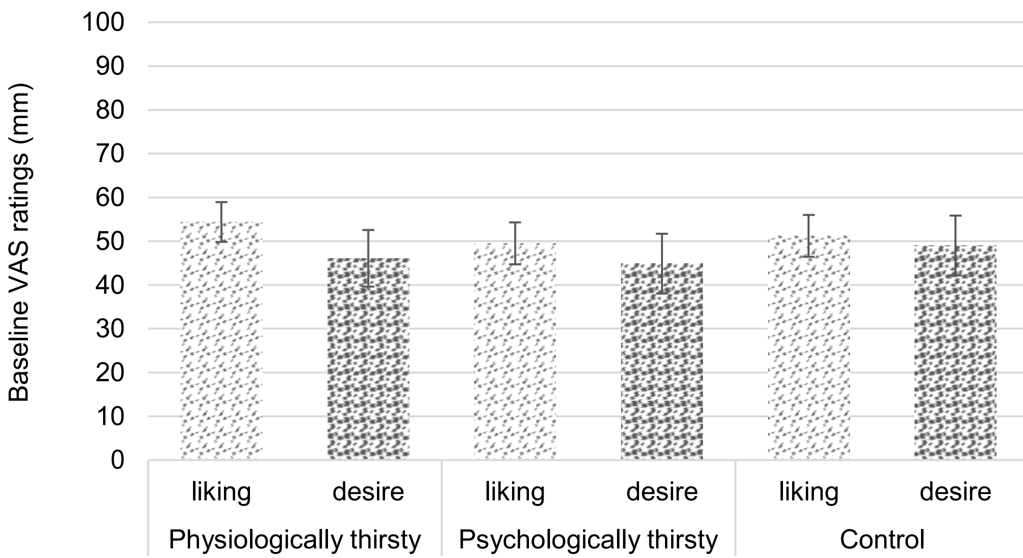

Figure 25 Baseline liking and desire to consume ratings separated by thirst condition for beverages with low osmolality (room temperature water, chilled water, and Powerade zero) (Chapter 6)

Appendix B

Figure 26 Images of exercise on the stationary bike (top left), venepuncture (top right), serum extraction (bottom left) and measurement of beverage osmolality (bottom right) (Chapter 6)