Impact of glass design on consumption of alcohol and non-alcoholic drinks

Tess Isabel Ruth Langfield

Christ's College, University of Cambridge

March 2020

This thesis is submitted for the degree of Doctor of Philosophy

This thesis is the result of my own work and includes nothing which is the outcome of work done in collaboration except as declared in the Preface and specified in the text. It is not substantially the same as any that I have submitted, or, is being concurrently submitted for a degree or diploma or other qualification at the University of Cambridge or any other University or similar institution except as declared in the Preface and specified in the text. I further state that no substantial part of my thesis has already been submitted, or, is being concurrently submitted for any such degree, diploma or other qualification at the University of Cambridge or any other University or similar institution except as declared in the Preface and specified in the text. It does not exceed the prescribed word limit for the relevant Degree Committee.

Tess Langfield

Impact of glass design on consumption of alcohol and non-alcoholic drinks

Much of the global burden of disease is attributable to behaviour, including consumption of alcohol and sugar-sweetened beverages. Developing ways to reduce intake of these drinks could thus improve population health. Glassware has the potential to moderate drinking, including how much is consumed. This thesis explores the impact of glass design on drinking behaviours in four pre-registered experiments.

Study 1 investigated the effect of glass shape on total drinking time. Drinking was 21.4% faster from outward-sloped tumblers than straight-sided ones (95%CI[0.2%,38.0%]). Drinking time did not differ between inward-sloped and straight-sided tumblers. Though drink midpoints were underestimated more from outward-sloped than straight-sided glasses (mean difference=-12.9ml, 95%CI[-6.6ml,-19.2ml], midpoint-bias was not associated with drinking time (r(162)=0.01, p=.87).

Study 2 extended Study 1, comparing straight-sided vs outward-sloped tumblers, and exploring drinking trajectories. Total drinking times did not differ between glasses (0.3% difference, 95%CI[-21.4,18.1], p=.98). Drinking trajectories were more decelerated from outward-sloped glasses. Midpoints were underestimated more from outward-sloped glasses (mean difference =-14.1ml, 95%CI[-9.5ml,-18.7ml], p<.0001), though midpoint-bias was not associated with drinking time (r(198)=-.09, p=.20).

Study 3 investigated the effect of glass shape on volume consumed in a bogus taste test. Participants consumed 72ml less from straight-sided flutes than outward-sloped coupes, 95%CI[-11.7ml,-132.6ml], p =.022. Number of sips did not differ between glass shapes, but was positively associated with amount consumed, r(71)=.48, p<.0001. Midpoint-bias did not differ (mean difference -1.4ml, 95%CI[-5.8,3.0], p=.53), and was not associated with amount consumed, r(72)=-.03, p=.83.

Study 4 used electromyography (EMG) to measure 'embouchures' – the positioning of the lips – during sipping. When sipping from straight-sided flutes, participants used 8.9% more upper lip muscle activity (95%CI[3.3,14.8], p=.0017), and 20.0% more lower lip muscle (95%CI[14.7,25.6] p<.0001), than when sipping from outward-sloped martini coupes, suggesting more pursed lips during sipping from straight-sided glasses.

Using a combination of methods including objective measures of volume drunk and physiological measures, this thesis describes findings which have the potential to contribute to the development of novel, effective interventions which target glassware design to reduce consumption of health-harming drinks.

Acknowledgments

Table of Contents

List of Tables

List of Figures

Chapter 1: Thesis overview

Rationale

Overconsumption of drinks that harm health – including those that contain high levels of sugar and/or alcohol – is a focus for public health research and a target for policies aimed at improving population health. Understanding the drivers of drinking behaviours is key to developing effective interventions to change behaviour and thereby to improve population health. How much we drink, what, and when, is determined by a number of overlapping factors ranging from physiological needs and feelings of thirst, to the social setting including the drinking behaviours of those around us. Over the past decade, there has been an increasing interest in understanding how the design of environments – or 'choice architecture' – might influence our behaviour, often outside of awareness. In the drinking environment, several cues may influence drinking including the glass in which drinks are served. This thesis first summarises the limited existing evidence on the impacts of glassware design (including size, shape and – influenced by both of these – fullness) on drinking behaviours affecting the consumption of both alcoholic and non-alcoholic drinks. While many studies have explored the impact of glass size and shape on amount poured, few have measured drinking directly. This thesis thus reports four experimental studies conducted in laboratory settings, measuring drinking behaviours using a range of paradigms and outcome measures. While the title of this thesis and literature review focus on consumption of alcoholic and non-alcoholic drinks, the empirical work presented in this thesis focuses on non-alcoholic (soft) drinks, for pragmatic reasons, and to try to build a coherent narrative relating to one particular drink type to add to the limited evidence base identified in the review. Finally, to better understand and optimise any effects, this thesis also explores potential mechanisms that may underlie the effects of glassware design on drinking behaviours.

Aims of the thesis

1) To review evidence on the impacts of glassware design (size, shape, and/or resulting fullness) on consumption of alcoholic and non-alcoholic drinks

2) To conduct experiments investigating the impact of glass shape (straight-sided vs sloped) on consumption of non-alcoholic soft drinks, and to characterise the 'mechanics' of that consumption

1

3) To develop and test hypotheses about mechanisms that may underlie effects of glassware design on drinking behaviours

Overview of chapters

Chapter 2 - Glassware design and drinking behaviours: a review of impact and mechanisms using a new typology of drinking behaviours

Chapter 2 comprises a review of evidence on the impact of glassware design on drinking behaviours for alcoholic and non-alcoholic drinks. This review presents a logic model that describes two mechanisms (namely, perception and affordance) – neither exclusive nor exhaustive – that may underlie some of the effects of glassware design on drinking behaviours. This chapter also presents a typology of drinking behaviours – delineating smaller-scale 'micro-' and larger-scale 'macro-' drinking behaviours, to enable more systematic reporting on these behaviours in future studies.

Publication status: this literature review has been submitted for publication. Note. The submitted version (see Appendix 2.1) includes reference to the studies presented in Chapters 3 - 6 in this thesis.

Chapter 3 - Impact of glass shape on time taken to drink a soft drink: A laboratory-based experiment

Chapter 3 presents Study 1 – a laboratory-based experiment measuring the impact of glass shape (straight-sided vs. outward-sloped vs. inward-sloped tumblers) on time taken to drink a soft drink. Study 1 builds on limited evidence that glass shape (straight-sided vs. outward-sloped) may influence drinking rate for alcohol (Attwood, Scott-Samuel, Stothart & Munafò, 2012), as well as extending this by including inward-sloped glasses. Study 1 also explores potential mechanisms that may contribute to the findings – including midpoint bias (reflecting the accuracy of estimates of a drink's midpoint), as well as micro-drinking behaviours.

Publication status: the content of this chapter has been published in PLOS ONE (see Appendix 3.2).

Chapter 4 - Impact of glass shape on drinking time: a laboratory-based replication study exploring mechanisms

Chapter 4 presents Study 2 – a laboratory-based experiment which extends Study 1 by replicating the study using a statistically more powerful design, focusing only on straight-sided vs. outward-sloped glasses, and using a larger sample. As well as exploring midpoint bias and micro-drinking behaviours (as in Study 1), Study 2 also considers the patterns of cumulative intake over time or 'drinking trajectories', and whether these differ depending on the glass used.

Publication status: the content of this chapter has been published in Scientific Reports (see Appendix 4.2).

Chapter 5 - Impact of glass shape on consumption of a soft drink during a bogus taste test

Chapter 5 presents Study 3 – a laboratory-based experiment which extends Studies 1 and 2 by measuring the impact of glass shape (straight-sided vs. outward-sloped) on *ad libitum* consumption of soft drinks, using stemmed wine flutes and martini coupes. While total drinking time may be a proxy for, or predictor of, consumption, Study 3 measures amount consumed directly, using a bogus taste test. Study 3 also includes measures addressing two potential mechanisms (midpoint bias and micro-drinking behaviours).

Publication status: the content of this chapter has been published in Scientific Reports (see Appendix 4.2).

Chapter 6 - Impact of glass shape on amplitude of activity in *orbicularis oris* and sip size: an electromyography study

Chapter 6 presents Study 4 – a laboratory-based experiment which extends all three previous studies by examining a novel potential mechanism for the effects of glass shape on the consumption of soft drinks. Using facial electromyography (EMG), Study 4 explores lip embouchures – the extent of lip pursing – during sipping from glasses of different shapes.

Publication status: the content of this chapter has been published in Scientific Reports (see Appendix 4.2).

Chapter 7 - Thesis summary and conclusions

Chapter 7 provides a summary of the thesis findings (Chapters 3 – 6), including how the findings relate to the existing literature summarised in the review (Chapter 2) and what the new contributions to knowledge are. This chapter also discusses possible moderators of the effects reported in this thesis, and outline strengths and limitations of the body of research as a whole. Finally, this chapter outlines how future research might build on these findings, the implications for potential behaviour change interventions, and routes to implementation of interventions involving glassware design.

Chapter 2: Glassware design and drinking behaviours: a review of impact and mechanisms using a new typology of drinking behaviours

Summary

Much of the global burden of disease is attributable to unhealthy behaviour, including excessive consumption of alcohol and sugar-sweetened beverages. Developing effective methods to change these drinking behaviours could inform policies to improve population health. In line with an increasing interest in environmental-level interventions – i.e., changing the environment in which a behaviour occurs in order to change the behaviour of interest – this review first describes the existing evidence of the impact of glassware design (including capacity and shape) on drinking behaviours (e.g., at the 'micro' level – including sip size, as well as at the macro level – including amount consumed). The roles of two sets of possible underlying mechanisms – perception and affordance – are also explored. Finally, this review sets out a provisional typology of drinking behaviours to enable more systematic approaches to the study of these behaviours. While there is a paucity of evidence – in particular on measures of consumption – this growing evidence base suggests promising targets for novel interventions involving glassware design to reduce the consumption of drinks that harm health.

Publication status: an edited version of this chapter which includes discussion of research findings presented later in the thesis (Chapters 3 – 6) has been submitted for publication to Health Psychology Review, "Glassware design and drinking behaviours: a review of impact and mechanisms using a new typology of drinking behaviours" (Langfield, Pechey, Pilling & Marteau, submitted; see Appendix 2.1. for details).

.

Background

Changing drinking behaviour to prevent disease

Much of the global burden of disease is attributable to several unhealthy behaviours, including excessive consumption of alcohol and sugar-sweetened beverages (Stanaway et al., 2019; Chazelas et al., 2019; WHO Global Status Report on Alcohol and Health, 2018; Singh et al., 2015). Alcohol alone is linked to over sixty different health conditions (Room, Babor & Rehm, 2005), and the consumption of sugar-sweetened beverages is associated with obesity, type 2 diabetes, cardiovascular disease, and a number of other health conditions (e.g., Malik, Popkin, Bray, Després & Hu, 2010; Te Morenga, Mallard & Mann, 2013; Scientific Advisory Committee on Nutrition, 2015). Measures aimed at reducing the intake of alcohol and sugary drinks are thus high on national and international government agendas (e.g., Department of Health, 2016a; 2016b; World Health Organisation, 2015; U.S. Department of Health and Human Services and U.S. Department of Agriculture, 2015).

Historically, attempts to change population health behaviours have largely targeted individuals through the provision of persuasive information outlining the harms of the behaviour and the benefits of changing it, explicitly or implicitly making the individual responsible for their own behaviour and health. This approach is generally deemed acceptable by the public (e.g., Diepeveen, Ling, Suhrcke, Roland & Marteau, 2013; Petrescu, Hollands, Couturier, Ng & Marteau 2016; Reynolds et al., 2019), yet it is generally ineffective at changing behaviour at the scale needed to improve population health. Interventions that are more effective (and cost-effective) at changing behaviour are those that reduce the affordability, availability, and marketing of unhealthy products (McGowan et al., 2018). Indeed, many mass-media public health campaigns have had little to no effect on reducing alcohol intake, possibly due to the pervasive effects of alcohol industry marketing (e.g., Wakefield, Loken & Hornik, 2010). Even approaches that provide more targeted, personalised risk information (e.g., DNA-based risk estimates) fail to change health-harming behaviours, including alcohol intake, smoking cessation, physical activity, and diet (e.g., Hollands, French, et al., 2016; French, Cameron, Benton, Deaton & Harvie, 2017).

Automaticity of behaviour

Individual-level approaches to changing behaviour often require conscious engagement with the intervention – such as communicating an individual's DNA-based risk – in order for it to be effective. However, growing evidence now supports a shift away from the conceptualisation of behaviour as determined largely by conscious, intentional processes, towards a 'dual-process' model (e.g., Strack &

Deutsch, 2004; Webb & Sheeran, 2006). Acknowledging the important role of automatic, non-conscious processes in determining human behaviour may lead to the development of more effective behaviour change interventions across populations (e.g., Marteau, Hollands & Fletcher 2012; Hollands, Marteau & Fletcher, 2016; Hagger, 2016). Information-based approaches to changing behaviour across populations can thus be said to be founded on "partial models of human behaviour" to the neglect of automatic, non-conscious processes which "effortlessly activate most of our behaviour" (Marteau, 2018; p.116-117). Though this idea has gained traction among researchers and policymakers in recent years, its origins can be traced to the end of the 19th century, when William James (1899) wrote that "ninety-nine hundredths, or possibly, nine hundred and ninety-nine thousandths of our activity is purely automatic and habitual" (p.65).

Changing behaviour by changing cues in physical environments

One approach to changing behaviour that likely targets the underlying automatic processes governing behaviour is *choice architecture,* also known as *nudging.* Here, environments or cues within environments are targeted as a means to change behaviour, regardless of an individual's awareness of it. A well-known example of nudging involved a fly painted onto a urinal in Amsterdam airport to 'improve aim'. These ideas were popularised by Nobel Prize winner Richard Thaler and co-author Cass Sunstein in their 2008 book 'Nudge: Improving decisions about health, wealth and happiness' (Thaler & Sunstein, 2008), though, again, it is not an entirely new idea. The Behaviourism paradigm that dominated mid-20th century Psychology held the environment or situation as central in determining behaviour (e.g., Skinner, 1974), and couched behaviour "in its environmental context" and "in relation to events occurring outside rather than inside the behaving organism" (Blackman, 1985; p.260). Indeed, in an early semi-naturalistic study investigating factors influencing drinking, Rosenbluth, Nathan & Lawson (1978) found that the setting in which drinking takes place (including the characteristics and numbers of companion drinkers) influenced drinking behaviours including amount consumed and drinking rate. The authors suggested that contextual factors were at least as important in driving drinking as the characteristics of the drinker and their drinking history, in line with the "widespread behavioural view" (p.120). The authors concluded that "the environment within which drinking occurs plays a key role in the nature and extent of that drinking" (p. 117).

With the recent popularisation of interventions to change behaviours via *nudging*, a lack of clarity in the definitions of key concepts and terms has become apparent (e.g., Marchiori, Adriaanse & De Ridder, 2017). In response to this lack of clarity, a Typology of Interventions in Physical and Proximal Micro-Environments (TIPPME) has been developed (Hollands et al., 2013) and refined (Hollands et al., 2017) for use as a framework for conceptualising physical environment interventions. Such interventions

include altering the placement or properties of products, associated objects, and the wider environment in which the products exist, in order to change behaviours.

Glassware as a cue to consume

One property of the physical, proximal micro-environment that may influence consumption is the drinks container. Although many foods can be consumed directly – such as fruit, biscuits, and sandwiches – drinks are almost always consumed from some form of drinking vessel. Thus, the drinks container can be seen as a mediator of drinking (Spence & Wan, 2015). Drinks containers take many forms, varying with type of drink - e.g., beer vs. coffee - and drinking context – e.g., picnic vs. formal banquet. The focus of this review is on both alcoholic and non-alcoholic drinks, and glassware in the form of glasses and cups – but not cans or bottles – consumed in any drinking context.

Glassware can take many different forms and designs including different capacities and shapes. It has been suggested that design of a glass – including its size and shape - has become "an integral part of marketing activity", warranting careful consideration to maximise sales (Stead, Angus, Macdonald & Bauld, 2014; p.318). Indeed, wine glasses have increased in capacity over the last three hundred years and particularly since the 1990s when their size has almost doubled, likely contributing to the increase in wine consumed over the last thirty years (Zupan, Evans, Couturier & Marteau, 2017). Given that the number of people drinking wine was roughly constant over this period, increased wine glass size is a good candidate for understanding the increase in consumption ("British wine glasses have got bigger over the years", 2017, para 4), though changes in number of drinks consumed and the amount consumed per drinking occasion could also play a role. Due to the potential impact of glassware design on drinking behaviour and outcomes, glassware design is a target for reducing consumption of health-harming drinks. The primary aim of this review is therefore to examine the existing evidence on the impact of glassware design on drinking behaviours and outcomes, with a means to identifying gaps in the literature, and to inform the design and implementation of empirical experiments.

Potential Mechanisms: Perception and Affordance

To further understand and optimise any potential effects of glassware design on drinking, and to facilitate the design of effective interventions, it is helpful to conceptualise potential 'mechanisms of action' (Michie et al., 2016). This is related to the 'experimental medicine' approach, which highlights the importance of understanding not only *whether* a behaviour change intervention is effective, but how it works to change behaviour (e.g., Sheeran, Klein & Rothman, 2017). Figure 2.1 illustrates two – neither exhaustive nor exclusive – potential mechanisms which have been highlighted by research to

date as factors that may mediate or contribute to the effects of glassware design on drinking behaviours. First, there may be *perceptual effects* of glassware design. In this review, as in previous papers (e.g., Spence & Wan, 2015), perceptual effects of glassware design will include subjective judgments (e.g., liking for drinks and other subjective responses), as well as visual judgments (e.g.,visual perceptions of liquid volume). Second, there may be *affordance* by glassware design. This relates to the observation that some glasses, by dint of some feature of their design, appear to invite or afford faster drinking rates, larger gulps, or other patterns of behaviours that may, in turn, influence how much is drunk from them. The penultimate aim of this review is to describe and evaluate the evidence in support of these proposed mechanisms.

Defining drinking behaviours

'Drinking behaviour' is a broad term, encompassing a number of behaviours. The primary aim of this review is to understand the effects of glassware design on measures of consumption – the key outcome of interest to researchers and policymakers interested in reducing consumption of health-harming drinks and increasing consumption of healthy drinks. When organising and discussing the evidence in relation to the primary aim, it is important to distinguish between larger-scale (*macro*) drinking behaviours – amount consumed and proxies for it – and smaller-scale (*micro*) drinking behaviours – the micro-structure of drinking behaviours such as sip size, and the evidence is organised as such. On one level, micro-drinking behaviours are a fundamental feature of drinking: any drinking episode can be characterised by different micro-drinking elements, for example, how large the sips were, how many sips were taken, and whether pace of consumption was consistent over time. On another level, these micro-drinking behaviours might be seen as proxies for, or predictors of, larger-scale 'macro' drinking behaviours such as volume consumed. Thus delineating drinking behaviours by contrasting micro- with macro- behaviours can uncover the mechanics of *how* effects on consumption might work, which may yield new insights beyond what is captured from studying consumption outcomes alone. In the absence of an existing typology, the final aim of this review will be to develop a provisional typology of micro- and macro- drinking behaviours on the basis of the existing evidence, to enable more systematic study and better reporting of these behaviours.
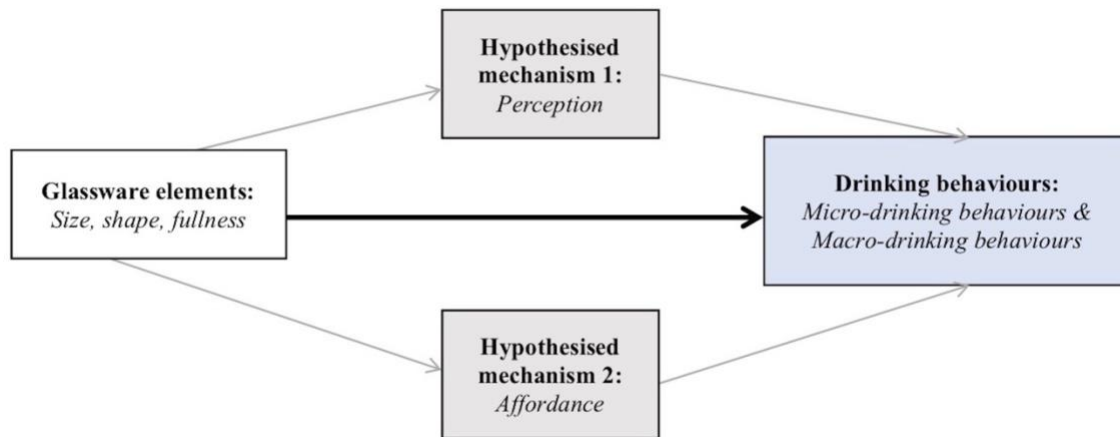
Figure 2.1. Logic model to organise evidence on the impacts of drinks containers on micro- and macro- drinking behaviours, with two proposed mechanisms: perception and affordance.

Review aims

I.   To summarise evidence of the impact of glassware design – notably size, shape, and resulting fullness – on macro-drinking behaviours.

II.   To summarise evidence of the impact of glassware design – notably size, shape, and resulting fullness – on micro-drinking behaviours.

III.   To describe two potential mechanisms through which glassware design might impact on drinking behaviours, namely perception and affordance.

IV.   To develop a preliminary typology of drinking behaviours

I. Impacts of glassware design on macro-drinking behaviours

Searches were conducted for experimental studies manipulating glassware (size, shape, and fullness) and measuring human drinking behaviour (i.e., amount consumed, amount purchased, amount poured, and number of drinks), for alcoholic and non-alcoholic drinks. Observational studies and literature reviews were excluded. Studies were only included if they measured drinking behaviours (i.e., not online or via self-report). For a full list of included studies, and more information on the exact terms and databases used, see Appendix 2.2. Note that final database searches were conducted on 2 September 2020 after publication of Studies 1 – 4 (Chapters 3 – 6). Though the present chapter excludes discussion of these findings to aid the narrative flow of the thesis, database searches (see Appendix 2.2), and the

published version of this review (Appendix 2.1), contain discussion of findings reported in subsequent chapters.

i.   Amount consumed

Three studies have examined the impact of glassware design on amount consumed. Kersbergen and colleagues (2018) investigated whether reducing the serving size of alcohol could reduce alcohol consumed (measured in UK units) in a semi-naturalistic laboratory setting. Pairs of participants were offered beer, cider, or wine in either standard or reduced serving sizes. Findings suggested that by reducing the serving size of alcohol, by 25%, alcohol units consumed were reduced by ~20% . However, though the intended manipulation was portion size, in order to keep glass fullness constant, glass sizes also varied with portion size. As a result, the reduced consumption which was observed may have been caused by reduced portion size, reduced glass size, or a combination of the two variables.

In a follow up study, Kersbergen et al. (2018) investigated whether reducing the serving size of alcohol reduced the volume of alcohol consumed – expressed in units (UK definition) of alcohol – in a bar setting. Again, participants were offered beer, cider, or wine in either standard or reduced serving sizes, with the price of drinks proportional to the serving size. The primary outcome measure was amount of alcohol consumed (expressed in UK units) within 3 hours of observation. Consumption was measured through covert observation of drinking in the bar by researchers – in particular by counting the number of beverages consumed at each table (given known serving sizes), and through counting the number of beverages sold (minus wastage). Findings suggested that by reducing the serving size of alcohol, by ~30%, alcohol units consumed were reduced by ~35%. As before, given that glass size varied with serving size, it is possible that the reduction in intake found was in part due to the reduction in glass size.

The third and final study reported on the impact of glass shape on amount consumed. Raghubir & Krishna (1999) compared amount of a soft drink consumed when served in a taller and wider glass of identical capacities, finding more was consumed from the taller glasses.

Given the limited existing evidence on amount consumed, this thesis will endeavour to address this gap by adding evidence investigating the impact of glass shape on *ad libitum* intake.

ii.   Amount purchased

11

Nine studies report on the impact of glassware design on amount of drinks purchased. In the first of a series of studies, Pechey and colleagues (2016) investigated the impact of wine glass size on sales of wine in a bar/restaurant setting. In this study, as in all the following studies in this section, drinking was not directly measured, with purchasing of wine for immediate consumption used as a proxy for actual consumption. Wine sales increased by 9.4% when sold using larger glasses (370ml), as compared with standard glasses (300ml), with no differences in sales observed when using smaller (250ml) glasses compared with standard glasses (300ml). Six follow up studies have been conducted in bars and restaurants (Pechey et al., 2017; Clarke et al., 2019), and summarised in a mega-analysis by Pilling and colleagues (2020), the results of which will be reported here (but see Appendix 2.3 for further details on each study). This analysis indicated that, when combining all data, there were no effects of wine glass size on sales of wine in bars. However, in restaurants, compared with the 300ml glass, wine sales were 7% higher when 370ml glasses were used. There was also a trend to suggest that wine sales decreased by around 10% from smaller (250ml) glasses, though this was not significant.

Using a similar design, Troy, Maynard, Hickman, Attwood & Munafò, (2015) compared pub sales between weekends when straight-sided vs. outward-sloped beer glasses were used. Though the primary aim of this field study was to assess feasibility, the authors noted that sales were 24% lower when beer was served using straight compared with curved glasses. This finding awaits replication in a larger field study, currently underway in 24 bars (see Brocklebank, 2019 for trial pre-registration).

iii.   Amount poured

Another possible proxy for consumption, particularly for drinking at home where drinks are typically self-served rather than served by staff as in a commercial establishment, is amount poured. Sixteen studies have investigated the effect of glassware design (size and shape) on amount poured, including 4 which measure the free pouring of self-defined drinks (e.g., "typical serving"), 11 which stipulate an exact amount to be poured (e.g., a "standard drink" serving of alcohol), and 1 which measures both.

In two field studies measuring volume poured in freely poured self-servings for subsequent consumption, Wansink and van Ittersum (2003) found between 19-74% more juice was poured into short-wide glasses than tall-narrow ones (capacity both 659ml). In a laboratory study measuring self-defined pours of alcohol (not for consumption), Knibb, Jones & Christiansen (2018) found no evidence that short-wide vs. tall-narrow glasses differed in terms of amount poured. It is worth noting here that variation in "self-defined" servings might contribute to the absence of an effect of glass shape on poured volumes in between-subjects designs (such as Knibb et al., 2018). Walker, Smarandescu & Wansink (2014) compared amount of wine poured into wine glasses of different shapes and sizes, for self-defined

typical servings, and found 12% more wine was poured into wider glasses than narrower ones of the same capacity, but no difference for wine glasses of different sizes. De Visser & Birch (2012) found that increasing cup size for wine (150ml vs. 250ml) and beer (340ml vs. 570ml) led to increased alcohol units poured for both self-defined usual servings and alcohol units ("standard drinks").

Six further studies measure the effect of glassware design on "standard drink" pours. Three studies by Wansink and van Ittersum (2003; 2005) measured pours of single shots of spirits, finding pours were 3-30% larger in short-wide vs. tall-narrow glasses (capacity both 355ml). White, Kraus, McCracken & Swartzwelder (2003) investigated amount of alcohol poured among college students, for "standard drinks" of beer, straight shots - i.e., single serving of spirits - and mixed drinks - i.e., spirit served with a mixer. Participants poured each standard drink into glasses of different sizes. The amount poured was generally higher than a "standard drink", an effect that increased in magnitude with increasing cup size, for all drink and glass types. In a follow up study, White et al. (2005) asked participants to pour standard drinks (beer, straight shots, mixed drinks, and wine) into cups of various sizes (three per drink type). Increasing cup size led to increased volume poured for beer, mixed drinks, and wine. There was an effect of cup size on volume poured for shots in shot glasses, though it was non-linear: there was a U shaped relationship, with less poured into the middle-sized cup. Extending these findings to a Singaporean sample, Zandy, Pang, Ho & Matthews (2013) found that increasing cup size led to increased volume pours of "standard drinks" (30ml and 220ml, for shots and beer respectively, based on Singapore Health Promotion Board), for both beer and liquor.

Two studies report the impact of glass design on set volumes (i.e., not standard-drinks or self-defined servings). Chen and Lee (2019) found between 7-27% more was poured into larger vs. smaller glasses of different shapes, and that between 10-17% more was poured into tall-slender vs. short-wide glasses, when participants were asked to pour either 100ml or 200ml. A second study reports on glass shape and pouring to drink midpoints. Troy and colleagues (2018) found that when asked to pour the glass midpoint (284ml) for pint glasses (568ml), less was poured into outward-sloped and tulip glasses than straight-sided ones, though there was no evidence of a difference between inverted and straight-sided glasses. Given that the focus of the empirical studies will be straight-sided vs sloped glasses, the studies reported in this thesis also measure midpoint bias, using pouring tasks similar to Troy et al. (2018).

Three studies highlight that the effects of glassware design (shape and size) on amount poured for set portions may vary with features of the pouring task and nature of the instructions. Caljouw & van Wijck (2014) measured volume of lemonade poured in "drink" and "shot" portions, poured into glasses of different shapes (short-wide vs. tall-narrow, both 300ml). There was an interaction between glass shape and drink portion, such that when pouring shots, more was poured in short-wide glasses, but when pouring drinks, more was poured into the tall-narrow glasses. Chen, Lee, Lee & Chen (2017) found that

13

while glass size (large vs. small) and shape (tall-narrow vs. short-wide) did influence amount poured for a set portion, the direction of these effects depended on viewing angle, with the direction of the effects reversing when poured at 0 and 30 degrees vs. 60 and 90 degrees. Chandon & Ordabayeva (2009) measured amount of alcoholic and non-alcoholic drinks poured into various outward-sloped and straight-sided glasses. They found that 'supersizing' – pouring three times the volume, vs. 'downsizing' – pouring a third of the volume, reversed the effect of glass shape on amount poured. In particular, more was poured into outward-sloped glasses when supersizing, but the opposite was true when downsizing.

II. Impacts of glassware design on micro-drinking behaviours

Searches were conducted for experimental studies manipulating glassware (size, shape, and fullness) and measuring human drinking behaviour (i.e., total drinking time, sip size, number of sips, sip and interval durations, and drinking trajectory), for alcoholic and non-alcoholic drinks. As for macro-drinking behaviours, observational studies and literature reviews were excluded, and studies were only included if they measured drinking behaviours (i.e., not online or via self-report). For a full list of included studies, and more information on the exact terms and databases used, see Appendix 2.2. Note that final database searches were conducted on 3 September 2020 after publication of Studies 1 – 4 (Chapters 3 – 6). Though the present chapter excludes discussion of these findings to aid the narrative flow of the thesis, database searches in Appendix 2.2, and the published version of this review, contain discussion of findings reported in subsequent chapters.

i.   Total drinking time

One factor related to the amount consumed, for food at least, is speed of consumption (for a review see Robinson et al., 2014). Quicker eating rates may increase *ad libitum* consumption through one or more of several processes, including lower levels of satiation (e.g., Andrade, Greene & Melanson, 2008) and decreased orosensory exposure to the food – the time the food spends in the mouth (de Graaf, 2011). It is plausible that the speed at which drinks are consumed may also influence, or be a proxy for, the total amount consumed. Thus, exploring the conditions under which people consume drinks more quickly – for example, depending on the glass used – may inform why people consume more or less overall. Three studies have investigated the effect of glass shape and size on time taken to consume alcoholic and non-alcoholic drinks, described below.

One study has investigated the impact of glass shape on total drinking time of an alcoholic cocktail, using straight-sided glasses of different shapes (narrow/tall vs. short/wide), and measuring drinking in a semi-naturalistic bar-laboratory setting (Cliceri, Petit, Garrel, Monteleone & Giboreau, 2018). Participants consumed the 150ml cocktail about 7% slower from the tall/narrow glass than the short/wide one, although there was no statistical evidence that this difference was meaningful. It is worth noting that straws were used in both conditions, which may have masked differences in drinking afforded by sipping from glasses directly (see section on Affordance).

Glass size has also been investigated in the context of drinking speed. Zupan, Pechey, Couturier, Hollands & Marteau (2017) explored the effect of wine glass capacity on total drinking time in a

laboratory setting. Based on previous evidence that larger wine glasses elicited higher sales of wine (Pechey et al., 2016), Zupan and colleagues predicted that wine is consumed more quickly from larger glasses, keeping serving size constant. Contrary to predictions, consumption was 18% slower from larger than smaller wine glasses (370ml, 250ml respectively).

The effect of glass shape (outward-sloped vs. straight-sided) on drinking speed has been investigated in one study. Attwood et al. (2012) found that individuals consumed 340ml of beer 60% more slowly from straight 340ml, compared with outward-sloped 340ml, beer glasses, although no differences were found for a soft drink, or for smaller (170ml) portions. Glass fullness predicted total drinking time, with full glasses (larger portions) consumed more slowly than half-full glasses (smaller portions). These authors attributed their key finding – that glass shape influenced total drinking time for alcohol – to titration of drinking rate based on biased perception of volumes, with greater bias for outward-sloped glasses, due to the nonlinear relationship between height and volume (see later section on perception for more discussion of this perceptual mechanism). It is worth noting that the soft drink – a clear liquid – was not matched visually to beer – an amber liquid. This may have contributed to the null finding for soft drinks, in particular because one proposed mechanism for differences in consumption relates to visual cues of volume, and clear liquid may impact on ability to perceive cues to volume. Given limited existing evidence (one study), and that the soft drink chosen in this study was not visually matched to the alcoholic one, it is premature to suggest that soft drink consumption does not differ by glass shape (straight-sided vs outward-sloped). The research reported in this thesis will address this by using an amber-coloured soft drink, and measuring the impact of glass shape on total drinking time. Study 1 will also use inward-sloped glasses, to explore the effect of this unstudied glass design.

ii.   Sip size

There is some evidence from studies on eating behaviour that show that larger portion sizes lead to larger bite sizes (Almiron-Roig et al., 2015) and that eating with large bite sizes increases how much is consumed, alongside an underestimation of the amount consumed – a possible mechanism underlying increased consumption from larger portion sizes (Hollands et al., 2015; Bolhuis, Lakemond, de Wijk, Luning & de Graaf, 2013). One study has directly manipulated sip size to examine the effect on the amount of a drink that is drunk. Weijzen, Smeets & de Graaf (2009) investigated the impact of manipulating sip size on the volume of orangeade consumed by giving participants small (5g) and large (20g) sips, delivered via a tube in their mouths. Participants self-administered the drink using a pump to initiate each sip, and decided when to terminate drinking. Although the drinking behaviour was highly artificial in nature, the study showed an increase in volume consumed of 20% and 40% when the drink was delivered in larger sip sizes, for sugar-free and sugar-sweetened beverages respectively. Taken together, this evidence suggests that understanding the conditions under which people consume

with smaller sips may be important in understanding why people may consume less overall. Two studies have measured sip sizes for non-alcoholic drinks taken from glasses of different sizes, described below.

Two studies report effects of glass size on sip size, albeit with some caveats. Lawless, Bender, Oman and Pelletier (2003) found individuals took sips that were about 15% larger from cups with 600ml vs. 150ml capacity, although cup size was confounded with portion size to keep fullness constant. This means it is not clear which variable(s) – portion size, cup size, or both – drove increased sip size. A second study manipulated the nature of drinking – i.e., whether drinking was "instructed" (participants were given a series of cups and instructed to sip from each) or "natural" (participants were given a glass of water without explicit instructions while completing a screening interview) – to determine the impact on sip size (Bennett, Van Lieshout, Pelletier & Steele, 2009). The aim of this study was to inform swallowing assessment procedures in clinical settings – which often require patients to take sips - for example, in patients with dysphasia – disordered swallowing. A large effect was found: sip sizes were four times larger in the natural phase compared with the instructed phase (24ml vs. 6ml). However, portion size, as well as cup size, varied between these conditions (from 20-50ml in the instructed tasks to 200ml in the natural task), meaning larger sips may have been driven by any of these factors - portion size, cup size, instructions - alone or in combination. As a means to assess individual sip sizes, the research reported in this thesis will attempt to measure sips in real-time, using a concealed scale.

iii.   Number of sips

Number of sips may be a proxy for sip size, especially when a set portion is consumed. That is, in the absence of real-time sip size measurements, a drink drunk in fewer sips can be said to have been consumed with larger gulps – on average – than an identical drink drunk in more sips. Three studies have counted number of sips taken to consume alcoholic and non-alcoholic drinks.

In three studies where participants consumed a set portion of drink at their own pace, numbers of sips were explored. Cliceri et al (2018) compared number of sips taken from a 150ml portion of cocktail served straight-sided glasses of different shapes (narrow/tall vs. short/wide). While slightly more sips were taken from the tall-narrow glass, there was no statistical evidence to support that the difference was meaningful. Attwood et al. (2012) compared numbers of sips taken from full (340ml) and half-full (170ml) portions of beer and lemonade, served in 340ml outward-sloped and straight-sided glasses. Incorporating all the data, there were main effects of glass shape and fullness, such that more sips were taken from straight-sided glasses than outward-sloped ones, and more sips taken from full portions than half-full portions. Zupan, Pechey et al (2017) found no evidence that consuming wine in a larger or

smaller glass led to differences in number of sips taken to consume a 175ml portion. In characterising micro-drinking behaviours, the studies reported in this thesis will analyse number of sips.

iv.   Sip and interval durations

Two studies have examined sip and interval durations from glasses of different sizes, shapes, and fullness. Zupan, Pechey et al. (2017) found shorter average sip durations for wine consumed in larger vs. smaller capacity wine glasses. Attwood et al. (2012) found that individuals tended to have longer intervals between sips from the straight vs. outward-sloped glasses – when sipping full (340ml) portions - for beer but not lemonade. These authors also found that glass fullness predicted total sip and interval duration, with longer total sipping and inter-sip time from full (340ml) glasses than half-full (170ml) ones. In characterising micro-drinking behaviours, the studies reported in this thesis will measure and analyse sip and interval durations.

v.   Drinking trajectory

One further micro-drinking behaviour that may differ by glassware design is drinking trajectory within a standardised period – i.e., the dynamic pattern of drinking over time. Here, instead of comparing summaries of micro-drinking behaviours – for example, mean sip size or total number of sips – these micro-drinking behaviours are considered over time within one drinking episode. Studies on eating behaviour have identified ways to monitor dynamic changes in consumption over time, using covert weighing scales which record weights at regular intervals during eating episodes (e.g., "Universal Eating Monitor"; Kissileff, Klingsberg, & Van Itallie, 1980; "Mandometer ®" (Zandian, Ioakimidis, Bergh, Brodin & Södersten, 2009). This continuous measurement allows researchers to plot participants' cumulative food intake curves, which can be characterised as 'decelerated' or 'linear' (e.g., Pudel, 1971; Kissileff, Thornton & Becker, 1982; Westerterp-Plantenga, Wouters & Ten Hoor, 1991; Zandian et al., 2009; Zandian et al., 2012). Decelerated eating would be characterised by more rapid consumption at the beginning, such that more is consumed in the first half of the eating episode, while a linear trajectory would be characterised by a more constant pace. It is possible that studies on drinking may also distinguish different drinking trajectories, and determining the conditions under which more 'decelerated' or 'linear' patterns are present may be informative. One study reports on the impact of glassware design on drinking trajectory (cumulative intake over time).

Cliceri et al. (2018) plotted consumption over time, and found that drinking from a short, wide glass was more decelerated than drinking from a tall, narrow glass. This decelerated pattern was characterised

by a larger volume consumed in the first half of the drinking period. Although a decelerated pattern of consumption was common in this study - only 30% had an accelerated pattern - a greater proportion of individuals drinking from the short, wide glass (81%) showed this pattern, as compared to those drinking from the tall, narrow glass (60.4%). It remains to be seen whether glasses of other shapes show similar patterns, and this will be explored experimentally in this thesis.

III. Hypothesised mechanisms for impacts of glassware design on drinking behaviours

To optimise and better understand effects of glassware design on consumption (micro- and/or macro-drinking behaviours), it is useful to consider plausible underlying mechanisms as targets for such optimisation. In the following sections, two distinct but not exclusive sets of mechanisms are presented: perception and affordance (see Figure 2.1 for logic model). These will also be investigated in the empirical studies presented later on in thesis (Chapters 3 – 6).

i.   Perception

Impact of glassware design on perception

There is a wealth of evidence concerning the effect of a drink's container on how the drink is perceived, including ratings of flavour, liking of the drink, and volume perception (Spence & Wan, 2015; Spence & van Doorn, 2017). Individuals discern differences in taste, depending on the shape of a glass. For example, beer may taste fruitier and more intense when served in curved compared with straight-sided glasses (Mirabito, Oliphant, Van Doorn, Watson & Spence, 2017). Identical wines have been perceived to be different wines, depending on the shape of the glass in which they were served (Spence, 2011). Perceived appropriateness of a drink's container may also influence how much one is willing to pay for alcoholic drinks (Wan, Zhou, Woods & Spence, 2015). Satisfaction with the amount of a drink consumed has been shown to be higher when it was served in a tall-narrow glass than when served in a short-wide one (Cliceri et al. 2018).

There are a number of ways that glassware design might influence liking of the drink. For example, it is possible that glasses – by nature of their physical design and properties – influence ability to perceive aromas, with glasses with narrow rims allowing fewer odour molecules to be released (e.g., Spence, 2011), or alternatively, ensuring aromas do not 'escape' prior to evaluation (e.g., Cliff, 2001). The surface area of drinks afforded by the width of the glass aperture may also influence chemical processes of oxidation, which may, in turn, influence how the drink tastes (e.g., Spence, 2011). There may also be cognitive effects of association and familiarity: glassware design may influence liking via perceived appropriateness, with incongruent glassware (i.e., glassware that is rarely used in conjunction with the drink served) deemed less enjoyable (e.g., Raudenbush, Meyer, Eppich, Corley & Petterson, 2002).

For perception of volume, the ability to judge liquid volumes may vary with glass shape and size for wine glasses (Pechey et al., 2015; Walker et al., 2014), glass shape for tumblers and hi-ball glasses (e.g., Wansink & van Ittersum, 2005; 2003), as well as glass shape (outward-sloped vs. straight-sided

vs. inward-sloped) for beer glasses (Attwood et al., 2012; Troy et al., 2018). Specifically, these latter two studies investigated the impact of glass shape on ability to estimate drink midpoints. When comparing straight-sided vs. outward-sloped glasses, individuals tended to underestimate the midpoint for outward-sloped glasses to a greater degree than for straight-sided or inward-sloped ones, with midpoints underestimated by between 22% and 30% for outward-sloped glasses, 5% and 7% for straight-sided glasses, and 5% for inward-sloped ones (Attwood et al., 2012; Troy et al., 2018).

Bias in midpoint estimation has been examined using both virtual (e.g., Attwood et al., 2012; Troy et al., 2018) and real-life (e.g., Troy et al., 2018) drink pouring tasks. These biases are consistent with conflating height with volume, or an 'elongation effect', such that volumes that are taller are perceived as greater (e.g., Raghubir & Krishna, 1999). This elongation effect has also been found to vary with portion size, or relative fullness of the glass, and may be reversed when pouring large drinks, as opposed to shots (Caljouw & van Wijck, 2014). Use of height as a cue to volume begins at a young age. Seminal experiments by Piaget showed that children aged 2-7 were generally unable to 'conserve' the liquid poured from one short-wide container to a tall-narrow one, perceiving the identical volumes differently, depending on the glass shape (e.g., Piaget, 1967).

Associations between perceptions and drinking behaviour

How a drink is *perceived* – including preferences for drinks, subjective ratings of flavour, and ability to estimate volume – may be one mechanism through which the design of a glass impacts drinking. However, relatively few studies have directly examined whether these *subjective* perceptions of drinks and glassware translate into tangible differences in *objectively* measured drinking behaviours. Indeed, there may be a disconnect between subjective perceptions and objective drinking behaviours. For example, Chandon and Ordabayeva (2017) found participants to be more accurate when estimating decreasing – as opposed to increasing – quantities, although this asymmetry was reduced when pouring quantities, as opposed to estimating numerically. A further study on eating behaviour found self-reported preference for one food item over another predicted selection of that food item, but did not predict the amount consumed – measured using covert video recordings (Iborra-Bernad, Wathelet & Giboreau, 2012). Taken together, these studies suggest perceptions, subjective ratings, and even selections, may not always be accurate predictors of behaviour.

As previously discussed, two studies report drinkers underestimating the midpoint of a glass to a greater extent for outward-sloped compared with straight-sided glasses (Attwood et al., 2012; Troy et al., 2018), and inward-sloped glasses (Troy et al., 2018). Midpoint bias might, in turn, impact drinking behaviour, via titration of consumption based on misperceptions about amount consumed. That is, if midpoints are underestimated, drinkers will have consumed more than half of their drink when they reach their perceived midpoint. This might speed up consumption, if drinking is titrated based on biased midpoints.

21

One study has examined this relationship directly. Attwood et al (2012) found a trend towards a positive association between the degree of perceptual midpoint bias and rate of consumption ($r = 0.15$). This might reflect an underpowered analysis or another mechanisms contributing to the differences in drinking speed. If midpoint bias is an important determinant of drinking behaviour, clear midpoint labels on outward-sloped glasses may slow consumption relative to unmarked outward-sloped glasses. Troy and colleagues (2017) found a trend suggesting that labelling the half-way point slowed drinking speed relative to unmarked glasses, but the confidence intervals were wide and also consistent with faster drinking. Taken together, these findings suggest that factors other than perception – and in this case volume perception – may be driving effects of glass shape on drinking speed more strongly, at least for outward-sloped and straight-sided glasses, though further work is warranted to explore this.

Thus, although there are many studies on the impact of drinks containers on how the drink is perceived, further studies are warranted to determine the extent to which perceptual effects, including bias in volume perception, as well as subjective ratings such as for liking and flavour, can explain variation in drinking behaviours. Given the final aim of this thesis is to explore possible mechanisms, the impact of glass shape on midpoint bias, and the relationship between midpoint bias (a perceptual effect of glassware design) and drinking behaviours will be examined in the experiments reported in this thesis. The impact of glass shape on drink enjoyment, and the association between drink enjoyment and drinking rate, will also be examined in this thesis.

ii.   Affordance

An alternative or additional mechanism that may underlie the effects of glassware design on drinking behaviours is *affordance*, described by Gibson (1979) as "what it (*an object or the environment*) offers to the animal, what it provides or furnishes, either for good or ill" (p.127). These ideas were later popularised by Norman, a student of Gibson's, in 'The Psychology of Everyday Things' (later 'The Design of Everyday Things'), and were applied to objects in our environment that were seemingly poorly designed, failing to *afford* the appropriate behaviour (Norman, 1988; 2013). The primary difference between the two conceptualisations is that, for Norman, the key insight is in how actors can *design* environments that afford behaviours more easily, while Gibson was more interested in how actors perceive existing environments (McGrenere & Ho, 2000). Further, for Norman, affordances can make actions easier or more difficult (rather than simply exist or not exist, as implied by Gibson; McGrenere & Ho, 2000).

In the context of drinking behaviours, there are a number of ways affordance might be a useful concept. Two studies have characterised the ecological affordances of *alcogenic* environments such as pubs, through observation and interviews (Hill, Pilling & Foxcroft, 2018; Hill, Foxcroft & Pilling, 2018). One

example of an affordance identified by these researchers was faster drinking rates when individuals could not place their drinks on tables. That is, a pattern of drinking – in this case, increased drinking rate – was apparently afforded by the wider drinking environment, and in particular by a lack of a "put-on-able" surface (Hill, Foxcroft & Pilling, 2018; p.459).

Glassware design and affordance

Broadly, then, characteristics of a drinking environment might be said to *afford* an increase or a decrease in drinking, for example, by the nature of the room layout. The glass from which a drink is consumed may also afford more or less of this drink being drunk, depending on its design. Indeed, some of the basic properties of the design of a glass such as its size, shape, and fullness might afford specific patterns of drinking behaviours. Taking straight-sided and outward-sloped glasses as examples, the flow of liquid when a glass is tilted may differ depending on shape. When full, outward-sloped glasses – which resemble truncated cones – appear to spill easily. They require relatively less tilt than full straight-sided glasses – which resemble cylinders – to pour out the same volume. Figure 2.2 plots volume poured by pouring angle, for cones and cylinders, for (a) short tumblers and (b) more extreme versions. For more information on how these plots were obtained, see Appendix 2.4.

A

B

Plot to show volume remaining (%) by degrees tilted

Plot to show volume remaining (%) by degrees tilted

8cm

11.4cm

9cm

9cm

22.3°

5cm

10cm

15cm

5cm

45°
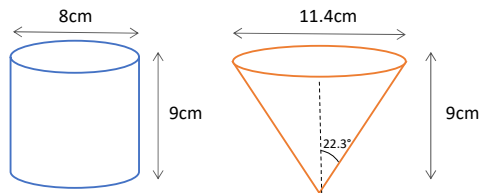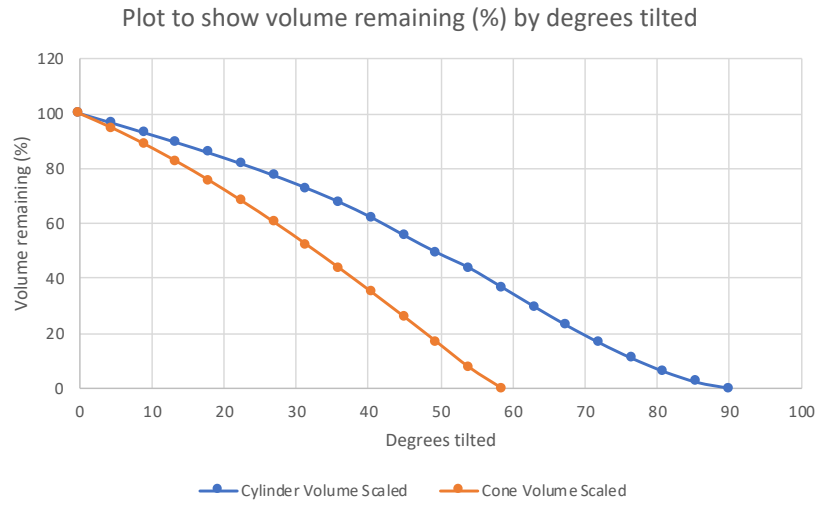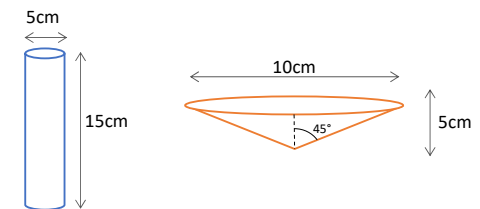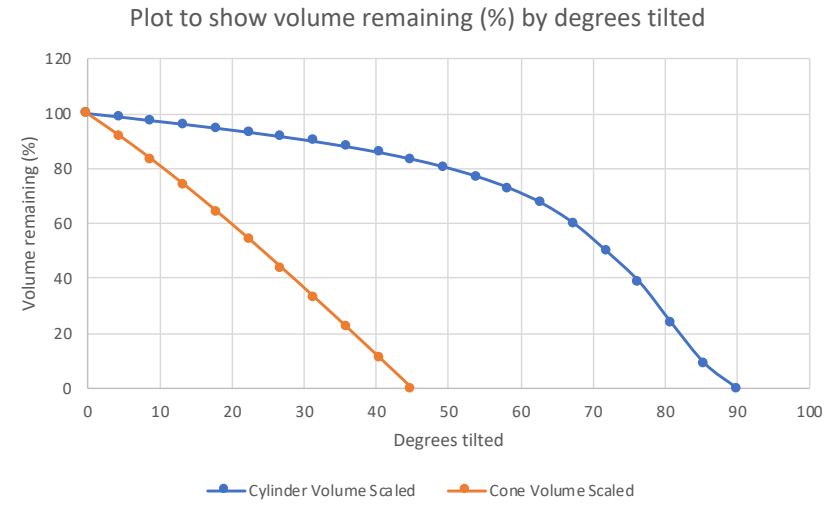
Figure 2.2. Plots to show affordance by glass shape of volume remaining (%) by angle of tilt. 'A' illustrates the relationship with tumbler glass dimensions 'B' illustrates the relationship with more extreme glass dimensions.

When drinking, volume tipped into the mouth can thus be influenced by the simple affordance of different glass shapes. Less tilt – and potentially less effort – is required to tip the same amount of liquid into the mouth from an outward-sloped glass than a straight-sided one (see Figure 2.2 A and B).

An additional affordance by glassware design might involve embouchure – the extent of lip pursing - when sipping. Glasses of different designs may afford greater (or less) pursed embouchures, leading to smaller (or greater) sized sips, resulting in less (or more) being consumed. Using facial electromyography, one study found greater muscle activity used in the lips when participants sipped through a straw, as compared to sipping from a spoon or a cup (Murray, Larson & Logemann, 1998). Glasses of different shapes and sizes may also cue differences in embouchures, though this novel hypothesis awaits testing. This will be addressed in Study 4 in this thesis.

A final affordance of glassware design on consumption is the affordance of volume poured from larger vs. smaller glasses. Larger glasses afford larger pours, by nature of the maximum capacity of the container, and this may contribute to increased consumption from larger glasses. Indeed, in their analysis of the effects of wine glass size on wine sales from bars and restaurants, Pilling, Clarke, Pechey, Hollands & Marteau (2020) found that larger wine glasses led to increased purchasing of wine in the restaurants settings but not in bars. One explanation that is offered by the authors is that wine is more commonly served by the bottle in restaurants, which allows consumers to free-pour their wine, so larger wine glasses may have afforded larger pours, and thus, increased consumption.

IV. Typology of drinking behaviours

Table 2.1. Typology of macro- and micro- drinking behaviours

	Behaviour	*Definition*	*Measurement*	*Example references*
Macro	**Amount consumed**	Amount that is consumed (e.g., ml). Also referred to as *ad libitum consumption, total intake, volume ingested, volume consumed etc.*	Measure the volume consumed (ml), for example by weighing the drink(s) before and after consumption.	*Kersbergen et al. (2018)*
	Amount purchased	Amount that is purchased. This can be used as a proxy for amount consumed (particularly in field studies with no direct measurement of behaviour).	Calculate the amount spent (e.g., £), and transform into volume (ml) purchased.	*Pechey et al. (2016); Clarke et al. (2019); Troy et al. (2015)*
	Amount poured	Amount that is poured (e.g., ml). This can be a self-defined serving, a specific volume (e.g., "standard drink"). Can be used as a proxy for consumption, (or, combined with number of drinks to calculate b amount consumed)	Measure the volume poured (ml), for example by weighing the drink(s) before and after the pour, or by using measuring cylinders.	*Wansink and van Ittersum (2003); Knibb et al. (2018*
	Number of drinks	Number of drinks consumed. This can be calculated for a given consumption occasion (e.g., how many times people pour themselves another glass) or across consumption occasions (e.g., number of drinks per week). Can be used as a proxy for consumption (or, combined with amount poured or served to calculate amount consumed).	Count the number of drinks served, poured, purchased, or consumed. For example, observe and count the total number of beverages (e.g., pints of beer) sold over an evening.	*No studies identified*
Micro	**Total drinking time**	Time taken to consume a drink (e.g., min). Also referred to as *speed of consumption, drinking speed, drinking rate, total time drinking etc.*	Measure the time it takes to consume a given drink, from start to finish (e.g., with a stopwatch, or from coding video recordings).	*Attwood et al. (2012); Zupan, Pechey et al. (2017); Troy et al. (2017); Brunstrom et al. (2000)*
	Sip size	Size of sip (ml). Also known as sip volume, bolus volume.	To measure exact sip sizes, hidden weighing scales can be used, or participants can be asked to spit into a cup. To determine average sip size, divide total volume consumed by number of sips, which can be counted from video recordings of drinking sessions.	*Lawless et al. (2003); Bennett et al. (2009)*
	No. of sips	Number of sips taken to consume a drink. Also known as *sip frequency.*	Can count number of sips from video recordings of drinking sessions.	*Attwood et al. (2012); Zupan, Pechey et al. (2017); Troy et al. (2017)*
	Sip rate	Rate of sipping (e.g., ml/s).	Mean sip size is divided by total time spent drinking, to give sip rate.	*Tomaszewski et al. (1980)*
	Sip duration	Time taken to drink a sip. Related concepts are *orosensory exposure time* and *total bout duration* (although these are often operationalised as a *total –*	Can measure sip durations using video recordings of drinking sessions, and coding when each sip is initiated, and when it ends.	*Attwood et al. (2012); Zupan, Pechey et al. (2017); Troy et al. (2017); Brunstrom et al. (2000)*

		i.e., across all sips – while sip durations often refer to an average based on individual sips).		
	Interval duration	Length of time between sips. Also known as *inter-sip interval / idle time / inter-bout interval*	Can measure interval durations using video recordings of drinking sessions, and coding when each sip ends, and when the next is initiated.	*Attwood et al. (2012); Troy et al. (2017); Brunstrom et al. (2000)*
	Drinking trajectory	Dynamic pattern of drinking rate across the drinking period. Also known as *dynamic drinking rate, drinking rate across the drinking period.*	Extract height information from video recordings and map height of liquid:glass to volume, based on a model of volume by height ratios. Alternatively use a hidden weighing scale (for example, in a drinks coaster), to plot the weight of the glass periodically on a graph. Helpful to plot drinking trajectories within a standardised period, if comparing between individuals. Some example drinking trajectories include: *'S' shaped (cubic); accelerated (exponential); decelerated (logarithmic); linear.*	*Cliceri et al. (2018)*
	No. of swallows	Number of swallows taken during the consumption of a drink. Note - may differ from number of sips – e.g., a large sip may be swallowed in two gulps.	Microphone attached to throat can be used, to identify timing of swallow (and thus the number of swallows in a given time period).	*Bennett et al. (2009)*

Note. Macro-drinking behaviour: measures of drinking outcomes involving consumption, or proxies for consumption. Micro-drinking behaviour: a form of short-term influence on drinking. Also known as: drinking topography, oral processing behaviours, microstructure of drinking behaviour.

Discussion

Summary of key findings

The first aim of this review was to summarise evidence on the impact of glassware design on consumption of alcoholic and non-alcoholic drinks. The review reveals a paucity of evidence on the effects of glassware design on drinking behaviour and in particular on volume consumed. Together, the evidence indicates potential effects of glassware design – including size and shape (and relatively less on fullness) – on drinking behaviours using outcome measures that may be correlates or proxies of consumption, such as amount poured and amount purchased. There are many studies – with some consistent findings – examining the impact of glassware design (size and shape) on amount poured, across a range of drink types, sizes, portions, and shapes. Taken together, this research suggests that more is poured into larger than smaller glasses, short-wide than tall-narrow glasses, and straight-sided than outward-sloped glasses, though these effects may vary depending on how much is being poured (e.g., Caljouw & van Wijck, 2014), whether pouring is 'supersizing' or 'downsizing' (Chandon & Ordabayeva, 2009), viewing angle (e.g., Chen et al., 2017), and whether the pour is self-defined (e.g., Knibb et al., 2018) or a specific volume (e.g., Wansink & van Ittersum, 2003). There were relatively fewer studies examining amount consumed directly (three studies identified in two papers: Kersbergen et al., 2018; Raghubir & Krishna, 1999). This might be important given that it is as yet unclear whether proxies for consumption (i.e., amount poured or amount purchased) do predict intake.

There is also a growing evidence base on the impact of glassware design on micro-drinking behaviours such as total drinking time, and sipping behaviours. Some preliminary evidence indicates larger sips taken from larger cups, though confounds in the experimental design make it unclear which aspect of glassware design drove the effects (e.g., portion size or cup size; Lawless et al., 2003). Three studies investigated the impact of glass shape (straight-sided vs outward-sloped – Attwood et al., 2012; short-wide vs tall-narrow – Cliceri et al., 2018) and size (wine glass size – Zupan et al., 2017) on total drinking time, with limited evidence that it differs depending on the glass. While no evidence was found that total drinking time differed in the other two studies, Attwood and colleagues (2012) found evidence for slower consumption from straight-sided glasses, but only for beer (not lemonade). It remains to be seen whether a soft drink that is visually matched to beer might elicit similar effects (given the potential for visual cues to liquid volume to be important mechanisms underlying the effect). Measuring drinking trajectory – cumulative intake over time – might reveal additional insights beyond the 'crude' measure of total drinking time. Indeed, while

there was no evidence of a difference in total drinking time, Cliceri et al (2018) did find evidence that drinking trajectories differed, with more decelerated consumption from short-wide glasses vs tall-narrow ones.

An additional aim of this review was to explore potential mechanisms – namely, perceptions and affordance. There is a wealth of evidence on the effects of glassware design on perceptions of the drink, including how much the drink is liked and its flavour, as well as visual perception of liquid volumes. Certain glasses may lead to biases in ability to estimate drink volumes (e.g., Attwood et al., 2012; Troy et al., 2018). This is possibly related to the 'elongation effect' whereby height is used as a cue to volume, and there is a failure to adjust for the multiplicative impact of changing more than one dimension simultaneously (i.e., object height and width) (e.g., Raghubir & Krishna, 1999; Krider, Raghubir & Krishna, 2001; Chandon & Ordabayeva, 2009). While there is good evidence that glassware design influences perceptions, there is relatively less evidence on the associations between these perceptions and drinking behaviours. To examine whether perceptions are a good candidate mechanism underlying any effects of glassware design on drinking behaviours, one area for future research is to examine these associations further.

The idea that glasses might cue behaviours automatically by virtue of their design, is supported by a mathematical model which demonstrates amount of liquid poured by angle of tilt (see Figure 2.2). For example, when comparing straight-sided and outward-sloped glasses, straight-sided glasses afford less volume poured given the same angle of tilt. This might cue or encourage larger sips, to account for the increased flow of liquid from the rim of the glass. Research is required to examine the impact of glass shape (straight-sided vs outward-sloped) on sipping behaviours (particularly with granular measures including real-time sip sizes), which might validate this hypothesised mechanism. Additionally, glasses may cue or afford sips via the positioning or pursing of lips – or embouchure. There is some evidence that the implements from which drinks are consumed (i.e., spoon, straw, cup) influence extent of lip pursing (Murray et al., 1998). It remains to be seen whether glasses of different shapes also elicit differences in embouchure, and whether this influences drinking behaviours including sip size.

The final aim of this review was to develop a preliminary typology of drinking behaviours. It is clear when reviewing the existing evidence, that there has been a lack of consistency and clarity in reporting on drinking behaviours. For example, small-scale drinking behaviours – which reflect the micro-structure of a drinking episode – have been variously described as "micro-drinking behaviours" (*e.g.,* Zupan, Pechey, Couturier, Hollands & Marteau., 2017), "drinking topography" (Foy & Simon, 1978; Attwood, Scott-Samuel, Stothart & Munafo, 2012; Troy et al., 2017), "kinetics of consumption" (*e.g.,* Giboreau, 2018) or, borrowing from

the eating behaviour literature, "oral processing behaviours" (*e.g.,* Ferriday et al., 2016; Krop et al., 2018), "intrameal eating and drinking patterns" (Bellisle & Le Magnen, 1981; Warner & Balagura, 1975), and meal "micro-structure" (*e.g.,* Almiron-Roig et al., 2015; Doulah et al., 2017). The typology presented here contrasts "micro-drinking behaviours" with "larger-scale" drinking behaviours (consumption and proxies for it), which are termed "macro-drinking behaviours" in this thesis. See Table I for typology. Using this typology as a framework and starting point for understanding the micro-structure of a drinking episode may harness important insights for developing interventions aimed at reducing consumption. Indeed, this level of detail might illuminate *how* an intervention works to reduce intake. For example, certain glass designs may cue less consumption *via* smaller sips, or *via* slower-paced consumption characterised by long intervals in between sips. This level of detail in describing a drinking episode may also give clues to important effects on drinking behaviours that may not be captured by a 'macro' measure of drinking in a given study.

Implications for thesis

It is important to note the general paucity of evidence in this area. For this reason, the review is somewhat broad in scope, including many key outcome measures (i.e., all measured drinking behaviours – including proxies such as amount poured), design features (i.e., glass size, shape, fullness), and drink types (i.e., alcoholic and non-alcoholic). As a result, it is difficult to draw together the findings to provide an estimate of effect size of possible interventions involving glassware design, though as more research builds on these findings, this will likely become clearer. Additionally, there are many gaps that could be identified as the focus of future research. In order to produce a coherent narrative throughout this thesis, the empirical studies will attempt to add robust evidence to this limited evidence base, by investigating the impact of one particular glassware design feature on the consumption of one particular drink type. More specifically, this thesis will examine the impact of glass shape (straight-sided vs sloped-glasses) on consumption of soft drinks. The first study will attempt to replicate and verify initial findings on glass shape and total drinking time, with evidence suggesting the effect may only apply to alcoholic drinks (e.g., Attwood et al., 2012). The second study will extend these initial findings, using a more granular approach to measure micro-drinking behaviours (i.e., plotting the patterns of consumption over time, as in one previous study, Cliceri et al., 2018). The third study will investigate the impact of glass shape on amount consumed (given limited evidence in this important area). The final study will explore a novel potential mechanism: affordance of lip embouchures. Muscle activity in the lip – an indicator of embouchure – has been found to differ depending on the implement being sipped from (Murray et al., 1998), and may also differ depending on glass shape, though this hypothesis awaits testing. Throughout, midpoint bias will also be explored as a potential mechanism. As well as examining the impact of glass shape on midpoint bias, importantly, the

associations between midpoint bias and drinking behaviours will be assessed, given limited existing evidence.

Conclusion

There is a paucity of evidence on the impact of the design of glassware on drinking behaviours, although several studies suggest it might affect how much is consumed, with some evidence for several candidate mechanisms. The provisional typology presented here and analysis of the limited existing evidence provides a starting point for subsequent research in order to generate a coherent body of evidence that can advance understanding of the impact of glassware design on macro-drinking behaviours – consumption and its proxies – as well as micro-drinking behaviours that contribute to this including sip size. Micro-drinking behaviours may be important in understanding the mechanisms driving any overall consumption effects. The robustness of this research will be enhanced by more valid and granular measures of macro- and micro-drinking behaviours (including by measuring micro-drinking behaviours dynamically, over time), in both laboratory and field settings. In addition, to optimise these effects, the underlying mechanisms warrant further exploration. Two possibilities – neither exclusive nor exhaustive – concern perceptions and affordances. The design of a drinks container might affect how a drink is perceived – such as its perceived liquid volume and its taste – which in turn may affect how much is consumed. The drinks container might also influence drinking behaviour through the flow of liquid that is afforded when the container is tipped, or through the affordance of embouchures or mouth shape. Such affordances may influence sip size, and subsequently the amount that is consumed. Further work is warranted to explore these possibilities. The evidence summary presented here – including the logic model and typology – provides an initial basis for building an evidence base on a promising set of interventions to reduce consumption of alcoholic and non-alcoholic drinks that harm health.

Chapter 3: Study 1 - Impact of glass shape on time taken to drink a soft drink: A laboratory-based experiment

Summary

Background

Glassware design may affect drinking behaviour for alcoholic beverages, with glass shape and size influencing drinking speed and amount consumed. Uncertainty remains both about the extent to which these effects are restricted to alcohol and the underlying mechanisms. The primary aim of the current study was to examine the effect of differently shaped glasses on time taken to drink a soft drink. The secondary aim was to develop hypotheses about mechanisms concerning micro-drinking behaviours and perceptual effects.

Method

In a single-session experiment, 162 participants were randomised to receive 330ml of carbonated apple juice in a glass that was either inward-sloped, straight-sided, or outward-sloped. The primary outcome measure was total drinking time. Secondary outcome measures included micro-drinking behaviours (sip size, sip duration, interval duration), and perceptual measures (midpoint bias, drink enjoyment).

Results

Participants drank 21.4% faster from the outward-sloped glass than from the straight-sided glass [95% CI: 0.2%, 38.0%] in adjusted models. They were also 18.2% faster from the inward-sloped glass than the straight-sided glass, but this did not reach statistical significance with wide confidence intervals also consistent with slower drinking [95%CI: -3.8%, 35.6%]. Larger sips were associated with faster drinking times (Pearson's $r(162) = -.45$, $p < .001$). The direction of effects suggested sips were larger from the outward-sloped and inward-sloped glasses, compared to the straight-sided glass (15.1%, 95%CI: -4.3%, 38.0%; 19.4%, 95%CI: -0.5%,43.6%, respectively). There were no significant differences between glasses in mean sip or interval duration. Bias in midpoint estimation was greater for the outward-sloped glass (12.9ml, 95%CI: 6.6ml,19.2ml) than for the straight-sided glass, although the degree of bias was not associated with total drinking time (Pearson's $r(162) = 0.01$, $p = .87$).

Conclusion

Individuals drank a soft drink more quickly from an outward-sloped glass, relative to a straight-sided glass. Micro-drinking behaviours, such as sip size, are promising candidates for underlying mechanisms.

Note. The protocol for this study was pre-registered online on the Open Science Framework (see Appendix 3.1.).

Publication status: the contents of this chapter have been published in PLOS ONE (Langfield, Pechey, Pilling & Marteau, 2018; see Appendix 3.2).

Introduction

Overconsumption of sugary drinks and alcohol is a major public health concern, contributing to rising levels of obesity and premature preventable mortality and ill health (Singh et al., 2015; Gakidou et al., 2017; World Health Organisation, 2014). Interventions that inform people of the health risks associated with their behaviour are generally ineffective at changing their behaviour (Hollands, Marteau, et al., 2016). When delivered as part of more intensive behaviour change programmes, they lack the reach required to change health at a population level, potentially widening health inequalities through drawing on cognitive resources that tend to be more readily available in those who are less rather than more deprived (Marteau et al., 2012; McGill et al., 2015). There is thus increasing policy interest in 'choice architecture' interventions (Department of Health, 2010), which, through changing cues in the environments in which choices are made, are hypothesised to change behaviour without drawing upon our limited cognitive resources (Thaler & Sunstein, 2008). These interventions are thought to work through automatic processes, without relying much on conscious engagement or individual agency (Hollands, Marteau, et al., 2016; Marteau et al., 2012).

Popularised in the book 'Nudge', some examples of such interventions include introducing chevrons on roads to reduce driving speed, adding flies on urinals to improve aim, and increasing the time taken for lift doors to close to encourage stair use (Thaler & Sunstein, 2008). To change health behaviours, reducing consumption or selection of less healthy foods and drinks might involve reducing tableware size (Shah, Schroeder, Winn & Adams-Huet, 2011), altering the proximity of healthier snacks in a cafeteria environment (Rozin et al., 2011), reducing the availability of unhealthier snacks in a vending machine (Grech & Allman-Farinelli, 2015), and so on. For recent efforts to characterise these and other 'choice architecture' interventions see the TIPPME categorisation (Hollands et al., 2017; Hollands et al., 2013).

When we drink, we nearly always come into contact with a drinks container. Glassware, a modifiable cue in our drinking environment, is therefore a good candidate for interventions that aim to change drinking behaviour at a population level. It is widely documented that the design of a drinks vessel can influence subjective ratings of its contents, including flavour, perceived volume, liking for the drink, the amount an individual is willing to pay (for recent reviews see Spence & Wan, 2015; Spence & van Doorn, 2017), and taste expectations (Van Doorn et al., 2017). The extent to which these perceptual effects influence drinking behaviour is perhaps less certain. However, with growing evidence that the design of glass and tableware can influence the amount consumed, for food and non-alcoholic drinks (Hollands et al., 2015), as well as for wine (Pechey et al., 2016; Pechey et al., 2017), understanding the mechanisms behind these effects is key to optimising interventions to reduce consumption.

There is some evidence that glass shape influences drinking speed. Attwood and colleagues (2012) found that individuals consumed full portions of beer 60% slower from straight, compared with curved, beer glasses, although no differences were found for smaller portions, or for lemonade. These authors attributed the findings to biased midpoint estimation, which, their results indicated, was greater for curved glasses, attributed to the nonlinear relationship between height and volume. However, there was only a trend towards an association between the degree of this perceptual bias and rate of consumption, suggesting that other mechanisms may have contributed to the differences in drinking rate. Indeed, a subsequent study from the same group investigated whether labelling the glass with volume markers (at ¼, ½, ¾) could slow consumption rate from curved glasses (Troy et al., 2017). Findings suggested slower drinking from clearly-labelled glasses, relative to unmarked glasses, but the confidence intervals were wide and also consistent with faster drinking. Further research is warranted to explore the extent to which the effect found in this initial study is limited to alcoholic-drinks, as well as to further understand the role of biased volume estimation in influencing drinking behaviour.

An additional or alternative mechanism that may contribute to the effects of glass shape on drinking rate could be the cueing or affordance of 'micro-drinking behaviours'. These reflect the micro-structure of drinking behaviour, and include sip size (volume consumed in each sip), sip durations (length of time spent per sip), interval durations (length of time in-between sips), and drinking 'tempo' (the dynamic pattern of drinking rate across the drinking episode). Two studies report people taking larger sips from larger cups (Lawless et al., 2003; Bennett et al., 2009) although confounding of cup size with other variables in these studies mean it was not clear whether differences were due to effects of the container size (as interpreted by Lawless and colleagues, 2003), portion size (known to impact *ad libitum* consumption; for a review see Zlatevska, Dubelaar & Holden, 2014), or drinking context, namely, whether drinking was 'instructed' or 'natural' (as interpreted by Bennett and colleagues, 2009). Two further studies also reported a greater number of sips and slower drinking from larger vs. smaller wine glasses (Zupan, Pechey et al., 2017) and straight vs. curved beer glasses (Attwood et al., 2012).

Glasses might 'afford' sipping behaviours based on physical properties of the glass and the liquid it contains. Glasses with a curved, or outward-sloped design (as used in Attwood et al., 2012 and Troy et al., 2017) may automatically cue larger sips, relative to straight-sided glasses, due to the increased flow of liquid across a wider circumference when glasses are tilted to the same degree (see Chapter 2). Related to this, individuals might take large initial sips from outward sloped glasses to avoid spillages. There may be an additional effect of the volume of liquid contained in the glass, or glass fullness. For glasses that are

35

relatively empty, a larger angle of tilt is generally required to drain the drink, but for full glasses, relatively less effort is required. Exploring how micro-drinking behaviours change over time might therefore be informative. A recent study by Cliceri and colleagues (2018) identified dynamic drinking patterns (decelerated or accelerated), and compared these between two glass types (tall/narrow vs. short/wide). Though both glasses led to a decelerated pattern, this pattern was more marked for the short/wide glass, characterised by a greater proportion consumed in the first half of the drinking episode, as compared to the second half.

Taken together, the evidence suggests that micro-drinking behaviours might be important for understanding the effects of glass shape on drinking behaviour, but it is not clear which particular aspects of glass shape or size might cue differences in micro-drinking behaviours (for example, glass wall slope), nor which micro-drinking behaviours warrant further investigation (for example, sip size).

Study 1 investigates whether glass shape predicts total drinking time for a soft drink, using inward-sloped, straight-sided, and outward-sloped glasses. Previous research was inconclusive as to the effect of glass shape on drinking time for a soft drink (lemonade), with an effect found only for an alcoholic drink (beer; Attwood et al., 2012). However, the soft drink used was not matched visually to the alcoholic one (clear vs. amber liquid). This may have contributed to the null finding, in particular because one proposed mechanism for differences in consumption relates to visual cues (i.e., bias in midpoint estimation), and clear liquid may change or reduce the effect of glass shape on ability to perceive drink midpoints. As such, we used a drink that is visually more similar to beer – an amber liquid (Appletiser). We predicted that outward-sloped glasses would lead to faster consumption than straight-sided glasses, as Attwood and colleagues found for the alcoholic drink. We also predicted that, conversely, inward-sloped glasses would lead to slower consumption than straight-sided glasses. We also explored micro-drinking behaviours (sip size, sip and interval duration) and perceptual effects (bias in midpoint estimation and drink enjoyment) as two possible underlying sets of mechanisms.

Research questions

1. Do straight-sided glasses differ from outward-sloped glasses and inward-sloped glasses, in terms of total drinking time?
2. Do straight-sided glasses differ from outward-sloped glasses and inward-sloped glasses, in terms of:
    (a) Micro-drinking behaviours (sip size (ml), sip durations (sec), interval durations (sec))?

       (b) Perceptions (bias in mid-point estimates and drink enjoyment)?

3. Do micro-drinking behaviours and bias in midpoint estimates predict speed of drinking?

Methods

Participants

Between May – October 2017, participants were recruited from the students and staff at the University of Cambridge (UK), as well as the general population, using flyers, mailing lists, and word of mouth (forming a convenience sample; see Appendix 3.3 for recruitment ads). To take part, it was required that individuals: were over 18 years old; had English as a first language or an equivalent level of fluency; were prepared to consume a drink that contained sugar (and to confirm that this would not cause them any difficulties with their health); and had no known allergies to Appletiser® (sparkling apple juice, with 33.7g sugar per serving). One previous study on the impact of glass shape (straight-sided vs outward-sloped) on drinking time reported a large effect size for alcohol (f = .46), though no effect for soft drinks (Attwood et al., 2012). To be conservative, we calculated that in order to detect a medium overall effect size (f = .25) of glass shape on total drinking time, with 80% power, at an alpha level of .05, a sample of 159 was needed. To allow for equal numbers of males and females, a total sample size of N = 162 was sought.

Study setting

The study took place in a testing room in central Cambridge (Sir William Hardy Building, Department of Psychology, Cambridge, CB2 3EB, UK).

Study design

In a between-subjects design, participants were randomised to receive 330ml of Appletiser® served in one of three glasses: a) inward-sloped, b) straight-sided, or c) outward-sloped. Randomisation was constrained to ensure equal group sizes (n = 54), as well as equal proportions of males and females in each group (providing a more representative sample, and given the possible link between gender and drinking behaviours (e.g., Attwood et al., 2012; Lawless et al., 2003; Cliceri et al., 2018). The primary outcome measure was total drinking time (min), and secondary outcome measures included micro-drinking behaviours (mean sip size, mean sip duration, mean interval duration), and perceptual measures (bias in estimating midpoint of drink and drink enjoyment). The full study protocol was pre-registered and is available at https://osf.io/sj5wx/.

Materials and measures

Glasses

The inward-sloped glass was designed by Dartington and supplied by www.havens.co.uk (height: 90mm, weight: 125g, capacity: 440ml, rim diameter: 62mm). The straight-sided glass was designed and supplied by LSA International https://www.lsa-international.com/ (height: 85mm, weight: 110g, capacity: 400ml, rim diameter: 85mm). The outward-sloped glass was designed by Libbey and supplied by www.drinkstuff.com (height: 89mm, weight: 170g, capacity: 400ml, rim diameter: 115mm). See Figure 3.1 for images of the glasses.

Figure 3.1. Glasses used in the study. From left to right, inward-sloped, straight-sided, outward-sloped.

Primary outcome measure

Total drinking time (min) was measured using video recordings of the drinking sessions. These video recordings were coded using a program to extract the time at each sip initiation and sip end (indicated by key press). Total drinking time was calculated by taking the difference in time between: (1) the initiation of the first sip (when the glass touches the lips for the first time), and (2) the endpoint of the last sip (when the glass leaves the lips for the final time).

Secondary outcome measures

Micro-drinking behaviours

Micro-drinking behaviours were measured from video recordings of the drinking sessions, coded manually using a program with key presses signalling the initiation and endpoint of sips.

Mean sip size (ml), or the average volume consumed per sip, was measured by dividing 330ml (total volume consumed in the task) by the number of sips (extracted from the coded video data).

Mean sip duration (sec), or the average time spent sipping, was calculated by taking the average of all sip durations (the difference between the initiation and end point of a given sip), again derived from the coded video data.

Mean interval duration (sec), or the average time spent in between sips, was calculated by taking the average of all inter-sip intervals (the difference between the endpoint of a given sip and initiation of the next sip), again derived from the coded video data.

Bias in midpoint estimation

Midpoint bias was assessed using a task involving six trials of filling or emptying drinks from the allocated glass until the glass was perceived to be half-full. The six poured estimates of the midpoint of the drink were averaged to provide a single estimate for each participant. To determine bias, 165 (the true midpoint) was then subtracted from their midpoint estimate. Negative values reflect underestimation of the true midpoint (pouring too little liquid into the glass), while positive values indicate overestimation of the true midpoint (pouring too much liquid into the glass).

Drink enjoyment

Two questions, rated on a ten-point scale anchored at one end by 1 (Not at all) and at the other end by 10 (Extremely), asked how 'pleasant' and 'tasty' the drink was. Together, these ratings formed 'drink enjoyment' (Cronbach's a = .90). These two questions formed part of a 'taste perception' task in which participants rated the drink along 10 different descriptors ('fruity', 'smooth', 'sweet', 'refreshing', 'bitter', 'strong tasting', 'gassy', 'pleasant', 'light' and 'tasty'). The results of all other ratings were not analysed. This rating task and measure of 'drink enjoyment' has been used previously in a laboratory study investigating drinking behaviour (Maynard et al., 2018).

Filler task

Participants completed a computer-based word-search task. They were asked to find as many words as possible in 4-minutes. This was included to obscure the true aim of the study, and to make the cover story

(that we were investigating the impact of glucose on cognitive performance) more believable. The data from this filler task were not analysed.

Awareness of the purpose of the study

Participants were asked to indicate what they thought the main purpose of the study was, choosing from nine possible answers. Those who correctly identified 'To investigate the impact of glass design on drinking rate' were coded as aware.

Procedure

The study was approved by the University of Cambridge Psychology Research Ethics Committee (reference: PRE.2017.018). Eligible participants were invited to attend a single study session, scheduled between 8 am and 8 pm, Monday to Saturday. As a cover story, participants were informed they were taking part in a study on the impact of glucose on cognitive performance. On arrival, participants completed self-reported eligibility screening, and gave written informed consent (see Appendix 3.4 for information sheet and consent form). They then answered questions about their age, gender, level of education, and thirst. All questions were administered using the Qualtrics platform on the computer (see Appendix 3.5 for online questionnaire). During this time, the experimenter removed a 330ml can of Appletiser® from the fridge, and brought it into the testing room along with the glass the participant had been randomised to drink from. The full 330ml can was then poured into the glass, immediately prior to serving to ensure consistent carbonation across study sessions. The experimenter then placed the drink on a coaster and informed the participant to consume the drink at their own pace, whilst watching a nature documentary ("River without Frontiers: The Secrets of Nature", 2008). Before leaving the room, the experimenter turned on the documentary and switched on the video camera. Participants were asked to open the door when they had finished the drink.

Next, participants completed the computer-based four minute word-search, followed by the 'taste perception' task, in which they rated the drink along 10 descriptors. For the final task, assessing bias in midpoint estimation, the experimenter first placed the 330ml glass of Appletiser® directly in front of the participant - the same glass as they had been randomised to drink from. Participants were then instructed to pour half of the liquid in the glass into a jug containing 660ml of Appletiser®, which was placed behind the glass. After the experimenter had weighed the glass to determine the participant's poured estimate, the participant was instructed to pour another midpoint estimate, this time from the jug into an empty glass. Pours were attempted six times in total (three from the glass into the jug, and three from the jug into the

41

glass). For reference, they were presented with a full 330ml glass of Appletiser® (a 'Reference Glass'), placed to their left throughout the task.

Finally, participants were asked to indicate what they thought the aim of the study was, to examine the effectiveness of the cover story in blinding participants to the behavioural measures and the true nature of the study. A basic debrief was provided, and a full debrief was sent via email once testing for the study was complete (see Appendix 3.6). Participants received £7 in cash for taking part.

Data analysis

The primary analysis was a multiple linear regression to determine whether glass shape (inward-sloped, straight-sided, outward-sloped) predicted drinking rate. Using linear regression, two dummy-variables (inward-sloped, outward-sloped) were entered, with straight-sided as the reference variable. Analyses were run to adjust for differences in gender, age, thirst, maximum daily temperature, and time of day. Secondary analyses were conducted to determine whether glass shape predicted micro-drinking behaviours (mean sip size, mean sip duration, mean interval duration), as well as perceptual factors (bias in midpoint estimation, drink enjoyment). Sensitivity analyses excluded participants who correctly guessed the true purpose of the study. Reliability analyses, with an independent coder, were conducted on 20% of the videos.

The data for this experiment are available from the Open Science Framework: https://osf.io/fwmg9/ (DOI: 10.17605/OSF.IO/FWMG9).

Results

Baseline characteristics

One hundred and sixty two individuals took part in the study (50% female). The mean age was 24.0 years (SD = 6.72, range = 18 to 69), and all participants had at least AS/A Level education (40.7% had AS/A Level, 34.6% had an undergraduate degree, and 24.7% had a postgraduate degree). Baseline characteristics, split by condition, are given in Table 3.1.

Table 3.1. Baseline characteristics of participants and covariates, by group.

	Inward-sloped (n = 54)	Straight-sided (n = 54)	Outward-sloped (n = 54)	Total sample (N = 162)
Female (n)	27	27	27	81
Age	23.0 (5.05)	24.2 (7.14)	24.7 (7.70)	24.0 (6.72)
Thirst (1-10)	6.09 (1.40)	5.83 (1.69)	6.20 (1.48)	6.04 (1.53)
Maximum daily temperature (°C)	19.6 (3.64)	20.4 (3.90)	20.2 (4.00)	20.1 (3.84)
Time of day (hours after midday)	1.43 (3.17)	1.50 (2.54)	1.26 (2.89)	1.40 (2.86)

Note. Values given are mean (SD).

Primary analysis

Impact of glass shape on total drinking time

Visual inspection of the distributions indicated positive skew in total drinking time. The primary analyses were therefore conducted on log10 transformed (total drinking time). Where means are reported, they are geometric (back transformed) with 95% CIs (Bland & Altman, 1996; Olivier, Johnson & Marshall, 2008). We note that the actual effect size for an overall ANOVA was f = .20, p = .08, which is smaller than the

assumed effect size in the sample size statement. The equivalent regression analysis was preferred, to explicitly estimate the pairwise contrasts. Regression model diagnostics were checked and were acceptable.

Individuals drank slowest from the straight-sided glass (*Mdn* = 5 minutes 48 seconds, *IQR* = 5 minutes 53 seconds), fastest from the outward-sloped glass (*Mdn* = 4 minutes 46 seconds, *IQR* = 5 minutes 34 seconds) and between these two speeds from the inward-sloped glass (*Mdn* = 5 minutes 26 seconds, *IQR* = 3 minutes 38 seconds). See Figure 3.2 for geometric mean total drinking time by condition.
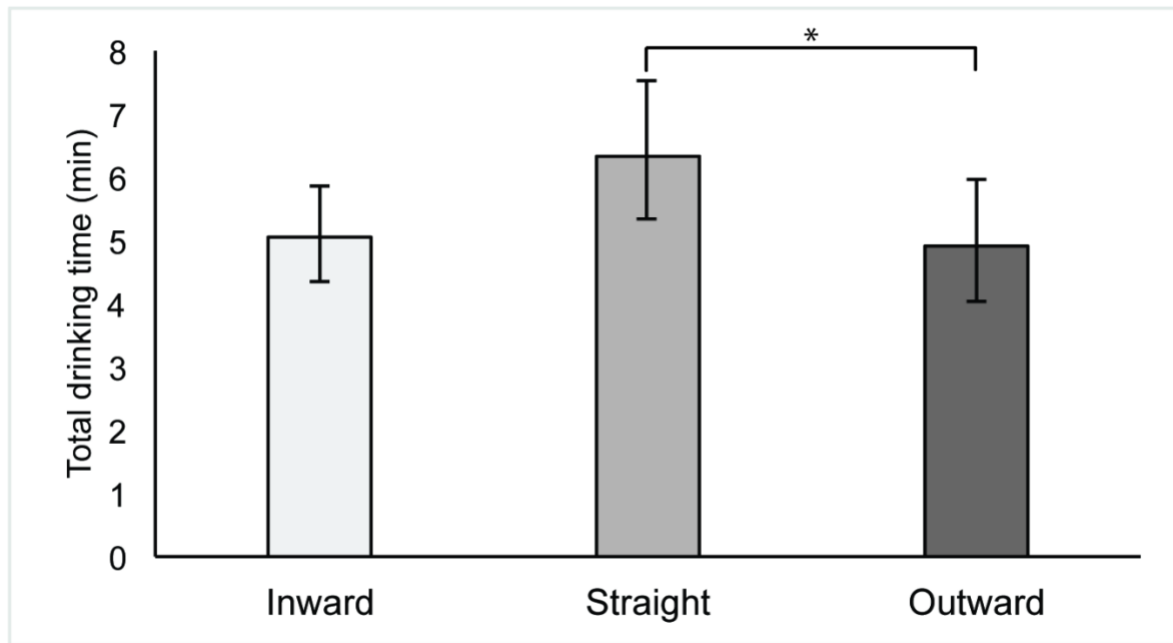
Figure 3.2. Drinking time (unadjusted geometric mean) and glass shape.
{Error bars show back transformed 95% CIs. * reflects significance at *p* < .05 level}.

Males drank faster than females taking, on average, 4 minutes 35 seconds (95% CI: 3 minutes 56 seconds, 5 minutes 20 seconds) and 6 minutes 22 seconds (95% CI: 5 minutes 37 seconds, 7 minutes 12 seconds) respectively, *p* = .001.

Adjusting for gender and other pre-specified covariates, total drinking time from the outward-sloped glass was 21.36% faster than from the straight-sided glass, (95% *CI*: 0.21%, 38.02%), *p* = .048. Total drinking time from the inward-sloped glass was 18.22% faster than from the straight glass, although this was also consistent with slower drinking (95% *CI:* -3.81%, 35.57%), *p* = .098. See Table 3.2 for adjusted and unadjusted models.

Table 3.2. Unadjusted (univariate) and adjusted (multivariate) regression, predicting log10(total drinking time).

Independent variable	Unadjusted regression analyses					Adjusted regression analyses			
	B	Exp(B)	95% CI Exp(B)	p-value	R^2	B	Exp(B)	95% CI Exp(B)	p-value
(Constant)	-	-	-	-	-	0.685	4.839	2.367 to 9.895	< .0001
Glass shape					.031				
Inward-sloped	-0.098	0.798	0.625 to 1.018	.069		-0.087	0.818	0.644 to 1.038	.098
Outward-sloped	-0.110	0.776	0.608 to 0.989	.041		-0.104	0.786	0.620 to 0.998	.048
Gender					.065				
Female	0.143	1.389	1.143 to 1.688	.001		0.145	1.397	1.145 to 1.706	.001
Age	0.0022	1.005	0.991 to 1.020	.51	.003	0.002	1.005	0.990 to 1.019	.52
Thirst (1-10)	-0.016	0.965	0.903 to 1.030	.28	.007	-0.018	0.959	0.899 to 1.023	.20
Maximum daily temperature (°C)	0.0090	1.021	0.995 to 1.048	.12	.015	0.0053	1.012	0.986 to 1.039	.35
Time of day (hours after midday)	-0.0003	0.999	0.965 to 1.035	.97	.000008	-0.0047	0.989	0.956 to 1.024	.53

Note. Adjusted analyses: $F(7,154) = 2.85$, $p = .008$, $R^2 = .115$. Exp = Power of 10.

45

Secondary analyses

Impact of glass shape on micro-drinking behaviours

Visual inspection of the frequency distributions of micro-drinking behaviours (mean sip size, mean sip duration, mean interval duration) indicated positive skew. Log(10) transformations improved the shape of these distributions so analyses were conducted on the transformed data for all three micro-drinking behaviours. For micro-drinking behaviours, where means are reported, these are Geometric (back transformed) with 95% CIs. See Table 3.3 for medians (IQRs) of micro-drinking behaviours, as well as mean (SD) for perceptual measures, for each glass shape.

Table 3.3. Summary of secondary outcome measures, split by condition.

		Inward	Straight	Outward
Micro-drinking behaviours	Mean sip size (ml)[a]	22.00 (16.50 to 30.00)	18.33 (12.11 to 25.91)	19.41 (15.00 to 30.75)
	Mean sip duration (sec)[a]	2.14 (1.72 to 2.89)	1.94 (1.47 to 2.72)	1.93 (1.65 to 2.80)
	Mean interval duration (sec)[a]	17.71 (11.77 to 29.46)	19.15 (11.26 to 38.34)	15.35 (11.76 to 23.50)
Perceptual measures	Bias in midpoint estimate (ml)[b, c]	-2.27 (21.05)	-3.00 (11.42)	-15.92 (15.95)
	Drink enjoyment (1-10)[b]	7.02 (1.65)	7.00 (1.68)	7.18 (1.66)

Notes.
a. Due to positive skew in all micro-drinking behaviours, these values given are Mdn (IQR).
b. Drink enjoyment and bias in midpoint estimation are M(SD).
c. 0ml reflects 0 bias in estimation, negative values reflect underestimation of true midpoint, positive values reflect overestimation of true midpoint.

Sip size

Females took smaller mean sips (*Geomean* = 17.79ml, 95% CI: 16.07ml, 19.68ml) than males (*Geomean* = 22.85ml, 95% CI: 20.41, 25.58), $t(161) = 3.29$, $p = .001$). To adjust for these differences, we included gender in the model for sip size.

Glass shape and gender explained 8.7% of the variability in log(10) mean sip size, $F(3,158) = 5.01$, $p = .002$. After adjusting for the effect of gender ($B_{Female} = -0.11$, $p = .001$), estimates suggested that individuals took sips that were 19.40% larger from the inward-sloped glass, compared to the straight-sided glass, although the data were also consistent with smaller sips (95% CI: -0.46%, 43.55%), $p = .057$. Sips were estimated to be 15.08% larger from the outward-sloped glass than from the straight-sided glass, although the data were again also consistent with smaller sips (95% *CI*: -4.28%, 38.04%), $p = .13$.

Sip duration & interval duration

Unlike mean sip size, gender did not predict mean sip duration or mean interval duration. It was therefore not included in these models. Glass shape did not meaningfully predict log(10) mean sip duration ($F(2,159) = 0.91$, $p = .40$), or log(10) mean interval duration ($F(2,159) = 0.39$, $p = .68$).

Relationship between micro-drinking behaviours and total drinking time

There was a medium-sized negative association between mean sip size and total drinking time, suggesting that larger mean sip sizes were associated with shorter total drinking times (Pearson's $r(162) = -.45$, $p < .001$), see Figure 3.3. Mean sip duration was not associated with total drinking time (Pearson's $r(162) = -.09$, $p = .25$).

47
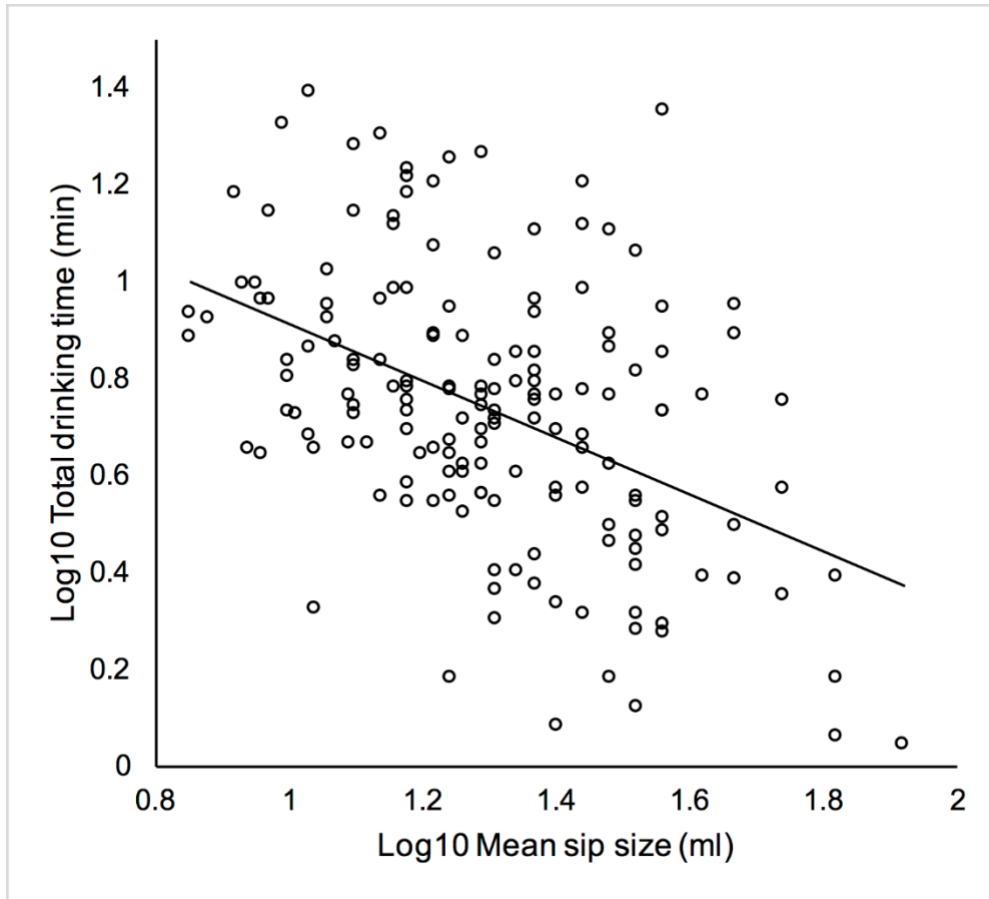
Figure 3.3. Relationship between mean sip size and total drinking time.

Impact of glass shape on drink midpoint estimation

Glass shape predicted bias in midpoint estimation, explaining 12.7% of the variance, ($F(2,159) = 11.54$, $p < .001$). All glasses were associated with an underestimation of the true midpoint (see Figure 3.4). Individuals poured 12.92ml less into an outward-sloped glass than into a straight-sided glass (95% CI: 6.61ml, 19.24ml), $p < .001$, suggesting greater underestimation of the midpoint, in line with using height as a cue for volume. Individuals poured 0.74ml more into an inward-sloped glass than into a straight-sided glass, but there was no evidence that this difference was meaningful (95% CI: -7.05ml, 5.58ml), $p = .82$. Bias in midpoint estimation was not associated with total drinking time (Pearson's $r(162) = 0.01$, $p = .87$).
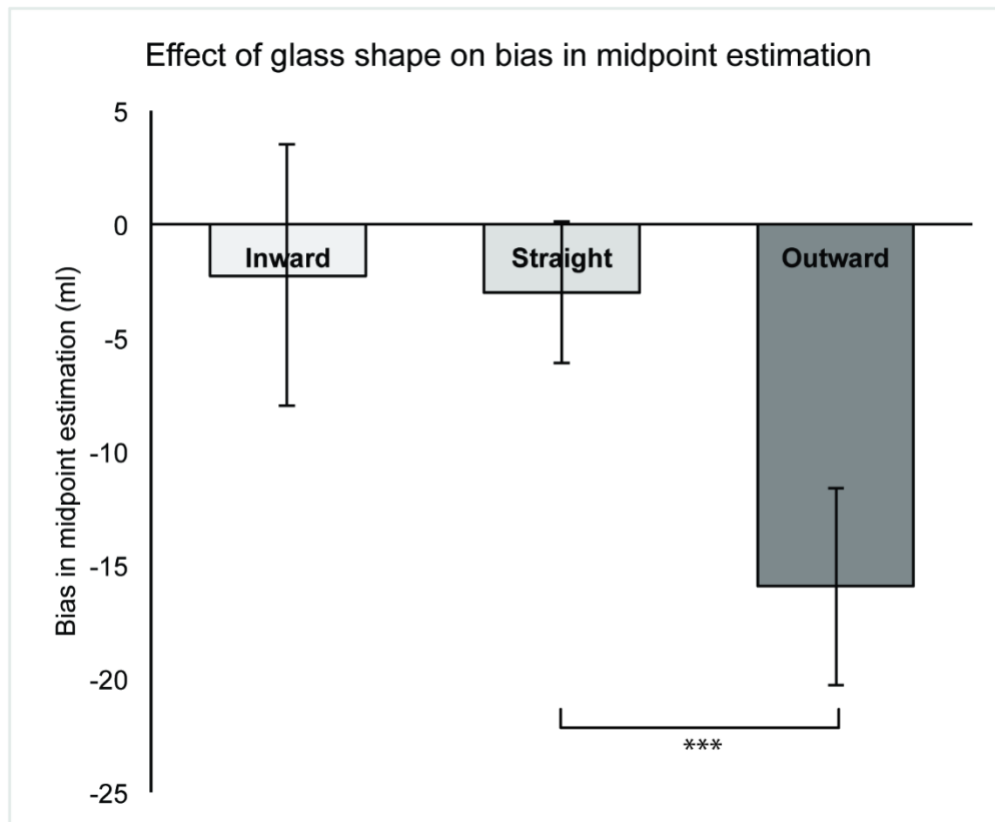
Figure 3.4. Mean bias in midpoint estimation and glass shape.

Error bars reflect 95% CIs. Negative numbers reflect under filling of glass when estimating midpoint. ***
reflects significance at $p < .001$ level.

Impact of glass shape on drink enjoyment

We found no evidence that glass shape influenced how much the drink was enjoyed ($F(2,159) = 0.18$, $p = .83$); means and standard deviations are given in Table 3.3. Drink enjoyment was not associated with log(10) total drinking time (Pearson's $r(162) = -.04$, $p = .62$).

Sensitivity analysis

Removing participants ($n = 5$) who correctly identified the purpose of the study (to investigate the impact of glass shape on drinking rate) did not alter the main conclusions. Unadjusted and adjusted estimates suggested outward-sloped glasses led to faster drinking than straight glasses (21.11%, 95% CI: -1.16%, 38.48%, $p = .06$; and 20.93%, 95% CI: -1.16%, 38.06%), $p = .06$, respectively), although the confidence interval for the outward-sloped vs. straight-sided glass comparison now crossed zero.

49

Reliability analysis

Inter-rater reliability was high for the video coded data. Single measures intra-class correlation indicated strong and positive associations for total drinking time (32) = .98, p <.001, sip size (32) = 1.0, p < .001, sip duration (32) = .99, p <.001, and interval duration (32) = .99, p <.001.

Exploratory analyses

To understand the dynamic pattern of drinking rate across time, or 'drinking tempo', we explored the coded video data further. We plotted individual log(10) sip durations as a function of time, separated by condition. Time was normalised to each participant's total drinking time, with 100% reflecting each individual's total drinking time (see Figure 3.5). Visual inspection of these data suggested that glass shape influenced drinking tempo. For the outward-sloped glasses, sip durations were longer at the start, and shorter towards the end, while for the straight-sided and inward-sloped glasses, sip durations slightly increased over time. A linear mixed effects regression of log(10) sip duration with individual as a random factor and a fixed interaction term showed that first sip durations were longer from the outward-sloped glass (*Geomean* = 2.47 seconds, 95% CI: 2.12, 2.88) than the straight glass (*Geomean* = 1.83 seconds, 95% CI: 1.53, 2.20), p = .004. First sip durations from the inward-sloped glass (*Geomean* = 2.13 seconds, 95% CI: 1.84, 2.47) did not differ from the straight-sided glass, p = .386. The pattern of sip durations over time (line gradient) also differed significantly between the outward-sloped glass and straight-sided glass (p < .0001). Note: means and 95% CIs are back-transformed from log10 scale and p-values are Kenward-Roger adjusted.
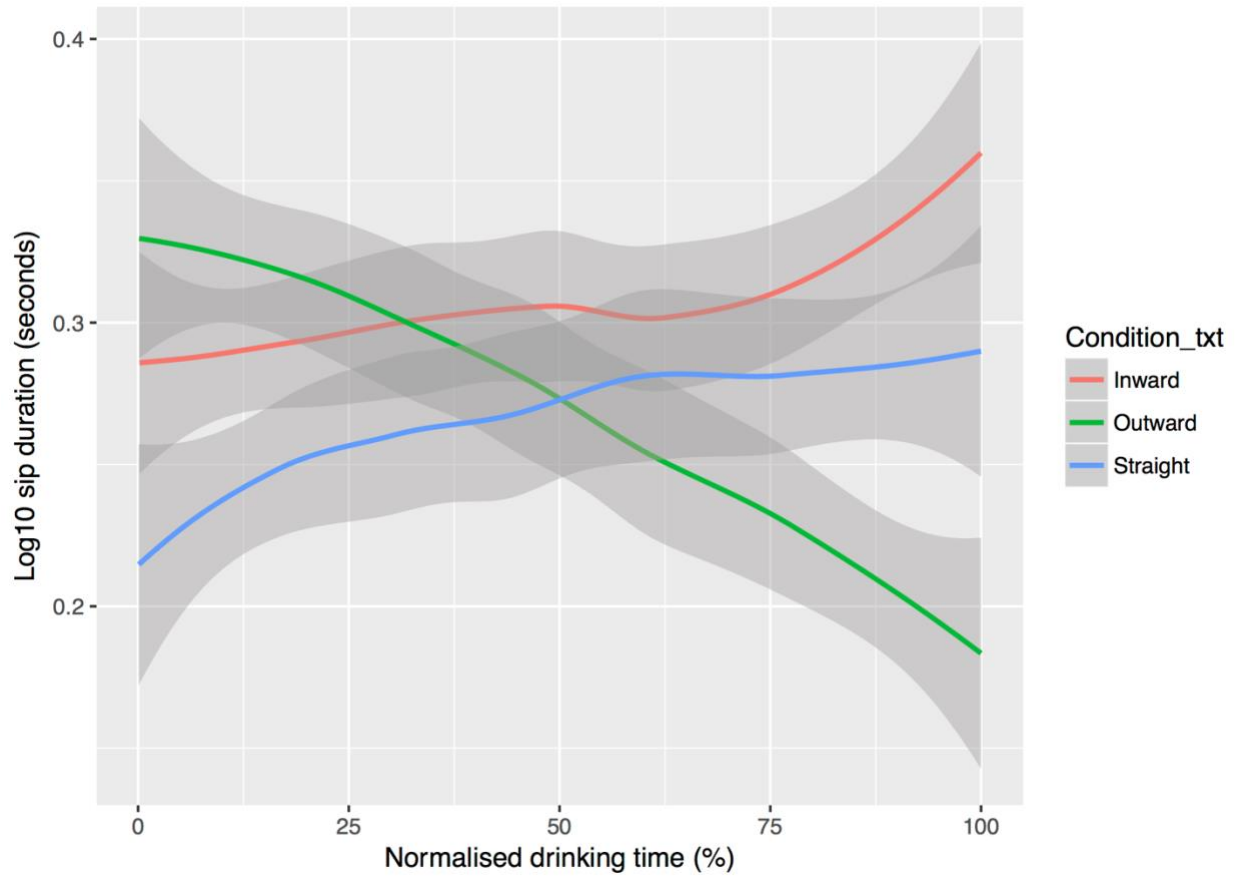
Figure 3.5. Change in sip durations across the drinking period, with LOESS smoothed lines.

Total drinking time is normalised (%) to allow for between subject comparisons. Line is fitted with locally weighted scatterplot smoothing (LOESS) and the grey shading is the 95% confidence region.

Discussion

The present study found an effect of glass shape on drinking rate for a soft drink: faster drinking was observed from outward-sloped glasses than from straight-sided glasses. Findings for inward-sloped glasses were inconclusive, although suggestive of faster drinking when compared with straight-sided glasses. To our knowledge, this study is the first to show an effect of glass shape on total drinking time for a non-alcoholic drink, with a previous study suggesting the effect might have been limited to alcohol (Attwood et al., 2012). The findings are in line with a growing evidence base suggesting that altering cues in the environment (including glassware, tableware, and packaging) can influence associated behaviours (speed of consumption and amount consumed) (Hollands et al., 2015; Pechey et al., 2016; Pechey et al., 2017; Attwood et al., 2012; Troy et al., 2017), and thus provide evidence for the effectiveness of these interventions in 'proximal physical micro-environments', also known as 'choice architecture' interventions or nudging (Hollands et al., 2017; Hollands et al., 2013).

The micro-structure of drinking behaviour - micro-drinking behaviours - was considered as a possible mechanism underlying the effect. Mean sip size was negatively associated with total drinking time, with larger sips associated with faster consumption. Individuals tended to take larger sips when drinking from the inward-sloped and outward-sloped glass, as compared to the straight-sided glass. However, the confidence intervals for these effects crossed zero. Thus, it remains unclear whether differences in sip size taken from smaller vs. larger cups shown in previous studies (Lawless et al., 2003; Bennett et al., 2009) are seen when drinking from glasses of different shapes. However, it is possible that '*mean* sip size', which is derived from dividing the amount consumed by the total number of sips, may not capture the complexity of sipping behaviours, and miss true differences where they exist. These might be better examined dynamically, or across the drinking period. Given that we did not measure individual sip sizes, to examine the dynamic changes in drinking rate, we explored individual-level (rather than average) sip durations, and plotted these as a function of time. From the outward-sloped glass, participants took longer initial sips, which then got shorter over time. By contrast, from the straight-sided and inward-sloped glasses, sip durations gradually increased over time. Using sip duration as a proxy for sip size, we speculate that sips were initially larger from the outward-sloped glass due to an automatic cueing of sip size. When full, and given the same angle of tilt, an outward-sloped glass affords a faster flow of liquid than the other glasses. These larger initial sips might therefore be a key determinant in the faster overall drinking rate seen from outward-sloped glasses. Taken together, these findings suggest that drinking glasses may cue specific patterns of micro-drinking behaviours, depending on both glass shape and relative fullness which in turn may influence total drinking time.

In addition to micro-drinking behaviours, we explored perceptions as another set of possible mechanisms underlying the observed effect. While the ability to estimate volume was poorest in the outward-sloped glass, as previously shown (Attwood et al., 2012; Troy et al., 2018), midpoint bias was unrelated to total drinking time in our study. One possibility is that individuals do not titrate their consumption for non-alcoholic beverages in the same way as for alcoholic beverages. This might mean that perceptual effects on volume estimation, though present, do not play a central role in determining, and/or do not have a linear influence on, drinking rate for non-alcoholic drinks (Attwood et al., 2012). As well as volume perception, we explored drink enjoyment. As with a previous study using different sized wine glasses for the consumption of wine (Zupan, Pechey et al., 2017), we found no evidence that glass shape influenced how much the drink was enjoyed. There was also no association between drink enjoyment and total drinking time. This suggests that shifts in behaviour, including slowing of consumption, might occur without influencing acceptability of the beverage, as found previously for alcohol and warning labels (Stafford & Salmon, 2017).

Strengths and Limitations

There were several strengths to the study. To our knowledge, this study is the first to find an effect of glass shape on total drinking time for a soft drink. This extends prior knowledge, suggesting that effects might not be limited to alcoholic drinks. We also used an objective measure of drinking, as well as subjective ratings and perceptual measures (which have previously received relatively more research attention, see Spence & Wan, 2015). There are also some limitations that should be noted. First, although the portion provided was identical across glass shapes, the glasses could not be matched in fullness, with the inward-sloped glass being less full when holding 330ml than the other two glasses. This confound was largely unavoidable, as manipulating container size (and often shape) inevitably leads to differences in capacity and/or fullness, when keeping other variables (e.g., height) constant. This confound might shed light on why inward-sloped glasses did not appear to slow drinking rate, and further testing could verify this. Further, the glasses, though matched in height (85-90mm), were not closely matched in weight (varying between 110g-170g). Weight of the drinks container may influence perception of the drink, with some evidence suggesting that heavier vessels *increase* desire for the drink (Kampfer, Leischnig, Ivens & Spence, 2017), and other evidence suggesting that heavier vessels *decrease* pleasantness ratings (Maggioni, Risso, Olivero & Gallace, 2015). However, given the overall paucity of evidence on the impact of glass weight on perception and/or micro drinking behaviours, it is not clear whether and how the variation in glass weight in our study might have influenced drinking behaviours or perceptions. Relatedly, rim diameter also varied

with glass shape (narrowest for inward-sloped, widest for outward-sloped). It is possible that the aperture of the rim may have influenced drinking behaviours including total drinking time. However, this would not explain the trend suggesting faster intake from inward-sloped glasses, if a linear pattern was expected (with narrower rims leading to progressively slower consumption). In addition, we did not measure BMI (which may be relevant here given its link with eating speed, see Ohkuma et al., 2015). Future studies should ensure BMI is recorded. Finally, it remains to be seen whether and how differences in total drinking time, the outcome variable of interest here, translate into differences in the amount consumed, for example in real world drinking settings when multiple drinks are consumed in a single session.

Future directions

Given that the effect of glass shape on total drinking time in the current study was substantially smaller than has been previously found using alcohol (Attwood et al., 2012), future studies are required to determine the likely size, as well as parameters, of the effect found. One aim will be to determine the extent to which drink-type (alcoholic vs. non-alcoholic) moderates the effect. A second aim will be to explore whether the effect is robust to further changes in the exact glassware used, which will inform as to the exact design elements worth targeting for interventions. A third aim will be to explore the effects of glass shape on drinking behaviour over a longer period, in both laboratory and field settings.

Conclusion and next steps

Study 1 provides preliminary evidence that glass shape influences drinking rate for a soft drink with consumption faster from outward-sloped glasses than from straight-sided glasses. Changes in the micro-structure of drinking – for example, sip size – may be a promising candidate for understanding this effect.

Study 2 builds on these initial findings by replicating the study with a larger sample, and focusing on the glass shape comparison of straight-sided vs. outward-sloped. Further, Study 2 includes dynamic measurement of sip sizes (rather than a crude measure of 'mean sip size'), providing a picture of cumulative intake over time, which may also differ by glass shape.

Chapter 4: Study 2 - Impact of glass shape on drinking time: a laboratory-based replication study exploring mechanisms

Summary

Background

Drinking may be influenced by cues in the drinking environment, including glassware design. Study 1 found faster drinking from outward-sloped glasses than straight-sided ones for a soft drink. Proposed mechanisms involved micro-drinking behaviours (e.g., sip size) and ability to perceive volume (midpoint bias). Study 2 aimed to replicate these findings, and to explore drinking trajectories (the pattern of consumption over time).

Method

In a between-subjects design, 200 individuals (50% female) were randomized to consume 330ml of Appletiser® in one of two glass shapes (straight-sided vs. outward-sloped). Drinking behaviours (total drinking time and micro-drinking behaviours including sip size, sip and interval durations, and drinking trajectories) were coded from video recordings. Midpoint bias was measured using a task involving pouring until participants perceived glasses to be half-full.

Results

Total drinking times did not differ between glass shapes (0.3% difference, 95%CI: -21.4%, 18.1%, $p = .98$). Drinking trajectories differed, with a more decelerated pattern from outward-sloped glasses ($p = .023$). The directions of effects also indicated larger and longer sips from outward-sloped glasses than straight-sided ones, though confidence-intervals crossed zero. Midpoints were underestimated, with more bias from outward-sloped than straight-sided glasses (mean difference = 14.1ml, 95%CI: 9.5ml, 18.7ml, $p < .0001$), though midpoint-bias was not associated with drinking time, r(198)= -.09, $p = .20$.

Discussion

Though total drinking times were equivalent from outward-sloped and straight-sided glasses in Study 2, micro-drinking behaviours - including drinking trajectories - differed. The extent to which these differences in the micro-structure of drinking might affect how much drink is consumed awaits investigation.

55

Note. The protocol for this study was pre-registered online on the Open Science Framework (see Appendix 4.1.).

Publication status: the studies reported in Chapters 4, 5, and 6 have been combined into one paper and published in Scientific Reports (Langfield, Pechey, Gilchrist, Pilling & Marteau, 2020; see Appendix 4.2).

Introduction

As stated in previous chapters, overconsumption of drinks containing excess sugars and alcohol is a major public health concern. Developing novel and effective techniques to change drinking behaviour is thus an important goal of research and policy. There is an increasing interest in health behaviour change approaches which work by changing cues in physical environments (e.g., Marteau et al., 2012; Hollands et al., 2013; Hollands et al., 2017). Broadly speaking, these interventions are thought to engage automatic (rather than reflective) processes, requiring relatively less active engagement or high-level cognitive processing to elicit a change in behaviour than other types of behaviour change techniques (e.g., Hollands, Marteau et al., 2016). As described previously, one aspect of the drinking environment that has the potential to influence drinking behaviour – possibly outside of awareness – is the glassware drinks are served in.

A previous study found evidence of slower drinking from straight-sided beer glasses than outward-sloped ones, for full portions of beer but not lemonade (Attwood et al., 2012). As discussed in the previous chapter, Study 1 attempted to extend these findings using tumblers, and using a soft drink matched visually to beer (i.e., a carbonated apple drink), finding that straight-sided glasses led to slower consumption of a soft drink than outward-sloped ones, though the effect was smaller than that found for beer by Attwood and colleagues (2012).

As well as examining total time taken to consume a drink, exploring micro-drinking behaviours *dynamically* may be informative in understanding the overall effects on consumption. Previous research has shown that cumulative intake over time – 'drinking trajectory' – may differ by glass shape. Cliceri and colleagues (2018) found a more decelerated pattern from short-wide tumblers, characterised by a higher speed of intake (and more consumed) at the start of the drinking episode, relative to tall-narrow glasses. As mentioned in the previous chapter, in exploratory analyses, Study 1 also showed that sip durations may change over time, and the pattern may differ by glass shape (with longer sips at the start and shorter sips at the end for outward-sloped glasses, and the opposite pattern for straight-sided glasses). These sip durations might be a proxy for sip size, suggesting that trajectories may also differ between straight-sided and outward-sloped glasses. This hypothesis awaits testing.

Study 2 explores whether drinking rates differed, depending on the glass being drunk from. We predicted that, in line with our previous study (Study 1), soft drinks would be consumed more slowly from straight-sided glasses than outward-sloped ones. Additionally, we explored whether micro-drinking behaviours,

57

including drinking trajectories – the pattern of consumption over time – mean sip size, mean sip duration, mean interval duration, as well as visual perceptions of drink midpoints, would differ.

Research questions

1. Does glass shape (straight-sided vs. outward-sloped) affect total drinking time?
2. Does glass shape (straight-sided vs. outward-sloped) affect:
    (a) micro-drinking behaviours of sip size (ml), sip durations (sec), interval durations (sec), and drinking trajectory?
    (b) bias in mid-point estimates?
3. Do micro-drinking behaviours and bias in midpoint estimates predict speed of drinking?

Methods

Participants and sample size

Between April – July 2018, a convenience sample of 200 (50% female) participants was recruited from the students and staff at the University of Cambridge (UK), using mailing lists, flyers, and word of mouth (see Appendix 4.4 for recruitment ads). Eligibility was assessed at the start of the study session, and required that individuals: had not taken part in our previous study (Langfield et al., 2018; Study 1); were over 18 years old; were in good physical health; had English as a first language or an equivalent level of fluency; were prepared to consume a drink that contains sugar; had no known allergies to any ingredients in Appletiser ®. The study protocol (including sample size) was pre-registered (https://osf.io/4tx3c/).

A power calculation with an alpha level of 0.05, power of 80%, and an effect size of 0.372 (observed in the Study 1, when comparing total drinking time between straight-sided vs. outward-sloped glasses) indicated that a sample of $N = 182$ (91 per group) was required. To ensure equal proportions of males and females in each group, and to allow for possible attrition due to video equipment malfunction or obscured video footage, a total sample size of $N = 200$ (100 per group) was used.

Study setting

The study took place in a room in central Cambridge (Christ's College Cambridge, St Andrew's St, Cambridge, CB2 3BU).

Study design

In a between-subjects design, participants were randomised to receive a soft drink served in one of two glasses: straight-sided or outward-sloped. Randomisation was stratified by gender to ensure equal proportions of males and females in each condition. The primary outcome measure was total time taken to consume the drink (min). Secondary outcome measures were micro-drinking behaviours of mean sip size, mean sip duration, mean interval duration, and drinking trajectory – cumulative intake over time, as well as midpoint bias.

59

Materials and measures

Drinks served

Participants were served a single 330ml portion of Appletiser ®, served in either a straight-sided or an outward-sloped tumbler (see Figure 4.1), based on randomisation. As in Study 1, the straight-sided glass was designed and supplied by LSA International https://www.lsa-international.com/ (height: 85mm, weight: 110g, capacity: 400ml, rim diameter: 85mm), and the outward-sloped glass was designed by Libbey and supplied by www.drinkstuff.com (height: 89mm, weight: 170g, capacity: 400ml, rim diameter: 115mm).

Figure 4.1. Image showing each glass type - straight-sided tumbler and outward-sloped tumbler.

Primary outcome measure

Total drinking time (min) was measured using video recordings of the drinking sessions, in the same way as Study 1.

Secondary outcome measures

Micro-drinking behaviours (mean sip size, mean sip duration, mean interval duration) and midpoint bias were measured in the same way as Study 1.

To measure drinking trajectory, we developed a method to determine volume remaining from images of the drinks alone (which would be captured from the video recordings of the drinking sessions). As in a previous study (Cliceri et al., 2018), we mapped drink volumes (at 10ml increments from 0-330ml) to images of the drinks at each volume increment. We measured height of the liquid relative to the height of the glass

(measured using a digital ruler – RulerSwift), for images of the glasses, at each increment, and used this data to create models predicting volume from height ratios alone. For more details on these models, see Appendix 4.3.

These models allowed us to estimate the volume remaining in the glass when it was placed on the table by a participant from liquid:glass height ratios (as long as there was only minimal occlusion to the liquid), along with a timestamp. We used these volume remaining estimates to plot each individual's cumulative intake (% of total consumed – i.e., 330ml) over time (% of total time – i.e., varies between participants). To determine drinking trajectory, we combined the plots and fitted models by condition. Using these models, we calculated amount consumed at 50% time. We also calculated the areas under each individual's drinking curve, as a proxy for trajectory (higher scores are indicative of more decelerated drinking).

Additional measures

Additional measures obtained included age, baseline thirst (1-10), BMI (kg/m^2) – calculated from self-reported height and weight - and gender, which were included to be adjusted for in the main analysis. To measure awareness about the aims of the study, and the aims of the 'drinking speed' measure, participants indicated what they thought the main purpose of the study was, in a free text response. Responses were coded as "aware" or "unaware", for both awareness of the study aims, and awareness of the drinking speed measure.

Procedure

The study was approved by the University of Cambridge Psychology Research Ethics Committee (reference: PRE.2018.015). Eligible participants attended a single session between 8 am and 8 pm, Monday to Saturday. They were told the study investigated 'the impact of glucose on cognitive performance'. The procedure was very similar to Study 1. On arrival, participants completed eligibility screening, and gave written informed consent (see Appendix 4.5 for participant information sheet and consent). They then answered demographic questions, including age, gender, level of education, handedness, and thirst (1-10). All questions were administered using the Qualtrics platform on the computer (see Appendix 4.6 for online questionnaire).

As in Study 1, the experimenter removed a 330ml can of Appletiser® from the fridge, and brought it into the testing room along with the glass the participant had been randomised to drink from. The full 330ml can was then poured into the glass, immediately prior to serving to ensure consistent carbonation across

61

study sessions. Participants were asked to consume the drink at their own pace, whilst watching a documentary ("River without Frontiers: The Secrets of Nature", 2008). Before leaving the room, the experimenter turned on the documentary and switched on the video camera. Participants were asked to open the door when they had finished the drink.

Participants then completed two filler tasks, as in Study 1 (a 'cognitive performance' word search, and the 'taste perception' task in which participants rated the drink along 10 different descriptors - 'fruity', 'smooth', 'sweet', 'refreshing', 'bitter', 'strong tasting', 'gassy', 'pleasant', 'light' and 'tasty'). Finally, they estimated the midpoint of their drink. For the midpoint estimate task, as in Study 1, the experimenter placed a glass containing 330ml of Appletiser® directly in front of the participant (the same glass as they were randomised to drink from). Participants were then asked to pour half of it away, into a jug with 660ml of Appletiser® already inside. After the experimenter weighed the glass to note the estimated pour (ml), the participant poured another midpoint estimate, this time from the jug into a now empty glass. There were six estimates in total (three from glass to jug, and three from jug to glass). Participants were invited to use a 'Reference Glass' throughout the task to aid accuracy, which contained the full 330ml portion.

Finally, participants were asked to indicate their height and weight, and what they thought the purpose of the study was. This was included to examine the effectiveness of the cover story in blinding participants to the behavioural measures and the true nature of the study. Participants were given an initial debrief, then fully debriefed via email once all participants had taken part (see Appendix 4.7). Participants received £7 in cash for taking part.

Data analysis

Analyses were pre-registered (https://osf.io/4tx3c/). The primary analysis involved a multiple regression, predicting total drinking time (min) from glass shape. Analyses also adjusted for pre-specified covariates (thirst, BMI (kg/m^2), and gender as a dummy variable).

Secondary analyses predicted micro-drinking behaviours (mean sip size, mean sip duration, mean interval duration, drinking trajectory), and bias in midpoint estimation from glass shape. We also explored whether micro-drinking behaviours and bias in midpoint estimates predicted drinking rate.

Results

Baseline characteristics

Two hundred participants took part in the study (50% female). Due to a video-recording malfunction, data from two participants (both female) were excluded from the analysis, leaving a total sample of N = 198. Baseline demographic and study-relevant characteristics are given in Table 4.1. A summary of all outcome measures split by condition is given in Table 4.2.

Table 4.1 Baseline characteristics of participants by condition, and overall.

	Straight-sided (n = 100)	Outward-sloped (n = 98)	Overall (N = 198)
Gender (%)			
Female	50.0	49.0	49.5
Male	50.0	51.0	50.5
Highest Educational Qualification (%)			
GCSE/O Level	1.0	2.0	1.5
AS/A Level	37.0	32.7	34.8
Undergraduate degree	35.0	47.9	41.4
Postgraduate degree	27.0	17.3	22.2
Age (years)	22 (20,26)	22 (21, 24.75)	22 (20,26)
Thirst (1-10)	6.09 (1.64)	6.16 (1.54)	6.13 (1.59)
BMI (kg/m^2)	22.76 (3.14)	22.75 (3.49)	22.75 (3.31)

Notes. Thirst was rated from 1 ("Not at all") to 10 ("Extremely"). Age is median (IQR); BMI and thirst are mean (SD). Four individuals in the outward-sloped condition opted to omit information on BMI.

Table 4.2. Summary of key outcomes, split by condition

		Glass Shape	
		Straight-sided	Outward-sloped
PRIMARY	Total drinking time (sec)[a]	299.96 (260.93, 344.83)	300.88 (259.87, 348.37)
SECONDARY	Drinking trajectory (AUC)[bc]	0.506 (0.03)	0.630 (0.09)
	Mean sip size (ml)[a]	22.61 (20.44, 25.01)	25.21 (22.76, 27.92)
	Mean sip duration (sec)[a]	1.83 (1.70 to 1.98)	1.98 (1.81 to 2.17)
	Mean interval duration (sec)[a]	18.33 (16.32 to 20.59)	20.29 (17.27 to 23.83)
	Midpoint bias (ml)[b]	-3.72 (15.53)	-17.81 (17.06)

Notes.
a. values are back transformed from log10 (Geometric mean and 95% CI), from unadjusted models.
b. values are unadjusted M (SD)
c. AUC refers to the area under the curve, calculated from individual plots of amount consumed (%) over time (%). Larger AUCs indicate more decelerated drinking. Values of AUC taken from participants for whom all sips were recorded as volumes (n = 16).

Primary analyses

Impact of glass shape on total drinking time

Visual inspection of distributions indicated a positive skew for total drinking time. This was transformed using a log10 function to satisfy regression modelling assumptions. Back-transformed geometric means (geomeans) with 95% CIs are thus reported. Adjusting for pre-specified covariates - gender, thirst, and BMI - there was no evidence that total drinking time differed between glass shapes (0.26% faster from the straight glass than the outward glass; 95%CI: -21.4%, 18.1%, p = .979, see Table 4.3 for adjusted and unadjusted regression analyses).

Table 4.3. Unadjusted (univariate) and adjusted (multivariate) regression, predicting log10(total drinking time).

Independent variable	Unadjusted regression analyses					Adjusted regression analyses			
	B	Exp(B)	95% CI Exp(B)	p-value	R^2	B	Exp(B)	95% CI Exp(B)	p-value
(Intercept)	-	-	-	-	-	2.762	577.70	271.96 to 1,227.12	< .0001
Glass shape					.00				
Straight-sided	-0.001	0.997	0.815 to 1.219	.976		-0.001	0.997	0.819 to 1.214	0.979
Gender					.075				
Male	-0.174	0.669	0.552 to 0.812	.0001		-0.174	0.669	0.548 to 0.817	.0001
Thirst (1-10)	-0.0013	0.997	0.936 to 1.062	.923	.00	-0.0076	0.983	0.922 to 1.047	.587
BMI (kg/m^2)	-0.010	0.977	0.947 to 1.007	.130	.0067	-0.0066	0.985	0.955 to 1.015	.325

Notes. Reference for Glass shape is Outward-sloped. Reference for Gender is Female. Thirst was rated from 1 ("Not at all") to 10 ("Extremely"). Adjusted analyses: $F(4,189) = 4.547$, $p = .0016$, R2 = .0685. Exp = Power of 10.

Secondary analyses

Visual inspection of distributions indicated a positive skew for mean sip size, mean sip duration, and mean interval duration. These were thus transformed using a log10 function to satisfy regression modelling assumptions. Back-transformed geometric means (geomeans) with 95% CIs are reported for these variables. Midpoint bias was checked but showed no evidence of skew. All secondary outcome measures, split by condition, are shown in Table 4.2.

Impact of glass shape on micro-drinking behaviours

<u>Drinking trajectory</u>

Drinking trajectories – cumulative intake over time – were compared between glass shapes. Drinking trajectory was determined by plotting estimates of volume remaining in the glass – which started at 330ml and ended at 0ml – over elapsed time. Time was standardized to represent the proportion of overall time taken, to account for differences between participants in total drinking times, and volume consumed was transformed to 0-100% cumulative intake.

For the great majority of participants (182/198), the volumes remaining in the glass were not recorded after every sip taken. This was due to not placing the glass on the table in-between sips, and/or holding the glass and occluding the liquid. These factors prevented the accurate measurement of heights of the liquid and glass to determine volume remaining after each sip. To deal with missing data, we excluded participants who had incomplete drinking trajectory data – leaving Subset A: participants for whom volume remaining was recorded after every sip (n = 16), and Subset B: participants for whom volume remaining was recorded after at least 50% of sips (n = 94). As a result, one limitation of the trajectory data is that the tendency of participants in these subsets to put down their glass may represent a particular style of drinking behaviour. For participant characteristics and outcome measures split by subset, see Table 4.4.

Table 4.4 Baseline characteristics of participants and drinking behaviours, for full sample, and Subset A (100% of sips recorded as volumes) and Subset B (>50% of sips recorded as volumes), used for drinking trajectory analyses.

	Full dataset (N = 198)	Subset A (n = 16)	Subset B (n = 94)
Condition (%)			
Straight	50.5	50	54.2
Outward	49.5	50	45.7
Gender (%)			
Female	49.5	37.5	43.6
Male	50.5	62.5	56.4
Highest Educational Qualification (%)			
GCSE/O Level	1.5	0.0	1.1
AS/A Level	34.8	37.5	33.0
Undergraduate	41.4	50.0	43.6
Postgraduate	22.2	12.5	22.3
Age (years)	22 (20, 26)	22 (20.75, 26.25)	22.50 (21, 26.75)
Thirst (1-10)	6.13 (1.59)	6.06 (1.39)	6.14 (1.60)
BMI (kg/m^2)	22.75 (3.31)	21.89 (2.27)	22.83 (3.23)
Total drinking time (min)[a]	300.61 (271.64, 331.89)	351.56 (235.50, 523.60)	380.19 (331.89, 435.51)
Mean sip size (ml)[a]	23.88 (22.23, 25.64)	38.19 (30.69, 47.42)	27.93 (25.53, 30.55)
Mean sip duration (sec)[a]	1.90 (1.79, 2.02)	2.33 (1.77, 3.07)	1.99 (1.83, 2.17)
Mean interval duration (sec)[a]	19.28 (17.46, 21.28)	37.33 (24.72, 56.36)	29.72 (26.24, 33.65)

Notes. Thirst was rated from 1 ("Not at all") to 10 ("Extremely"). Age is median (IQR); BMI and thirst are mean (SD).

a. values are back transformed from log10 (Geometric mean and 95% CI).

For both subsets, a cubic (S-shaped) model had the lowest AIC, as compared to quadratic models (used to represent the drinking trajectory data in a previous paper – see Cliceri et al., 2018), for both outward and straight conditions, and thus was the best fit of the drinking trajectory data. Using Subset A, the cubic model predicted that at 50% time, 66.0% had been consumed from outward glasses (95%CI: 59.6%, 72.7%), while 50.3% had been consumed from straight glasses (95%CI: 47.5%, 52.7%), see Fig. 3A. Using Subset B, this

model predicted that at 50% time, 59.2% had been consumed from the outward glasses (95%CI: 56.8%, 61.8%), while 55.5% had been consumed from straight glasses (95%CI: 53.4%, 57.8%), see Figure 4.2 Confidence intervals were calculated by bootstrapping.

A   **B**
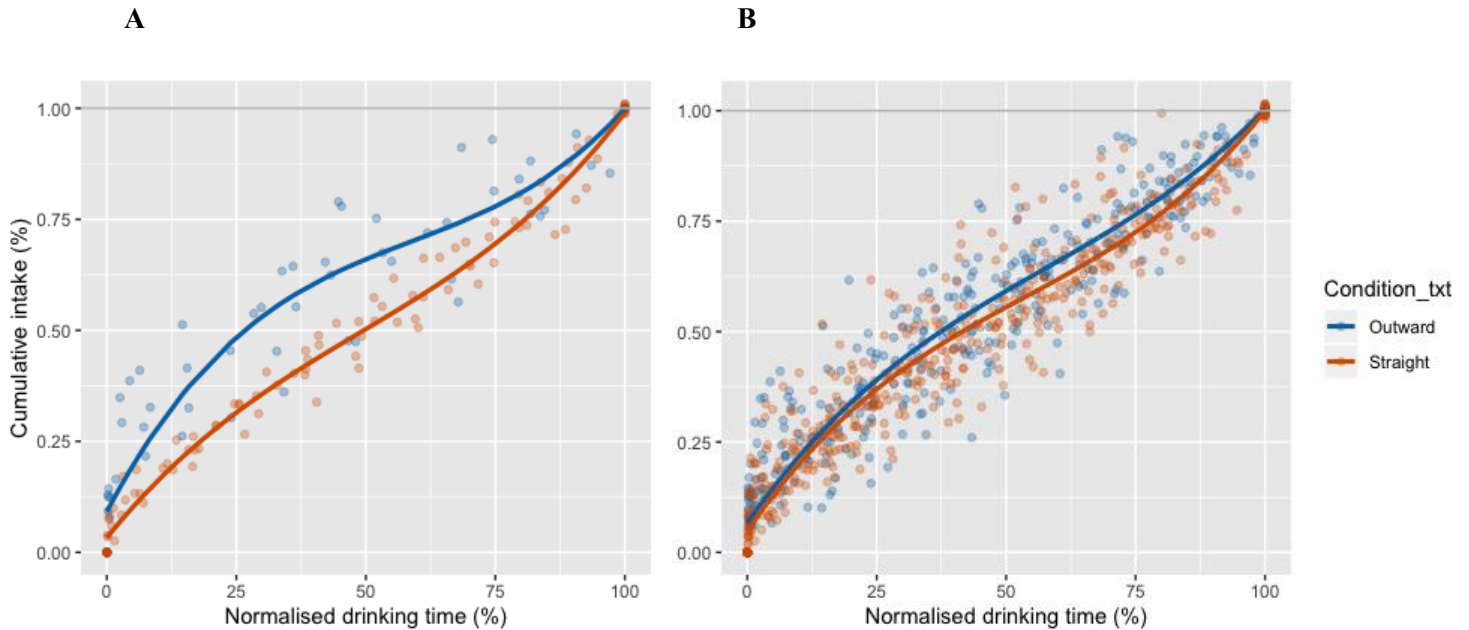
Figure 4.2. Cumulative intake over time, Study 1. Lines indicate cubic curve fits. A – participants with all sips recorded as volumes (n = 16), and B – participants with at least 50% of sips recorded as volumes (n = 94).

The area under the drinking curves (AUC) – a proxy for drinking trajectory – was also calculated. Larger AUCs (i.e., closer to 1) are indicative of a more decelerated pattern (characterized by more consumed in the first half of the drinking period). AUCs were 24.6% larger for the outward-sloped glasses for Subset A (95%CI: 8.9%, 40.3%; $t(8.264) = 3.60$, $p = .0067$) and 6.3% larger for the outward-sloped glasses for Subset B (95%CI: 0.91%, 11.7%; $t(85.06) = 2.32$, $p = .023$), see Table 4.5 for average AUCs, by condition, for both subsets.

Table 4.5. Impact of glass shape on drinking trajectory and other outcome measures, for Subset A (100% of sips recorded as volumes) and Subset B (>50% of sips recorded as volumes)

		Subset A (n = 16)		Subset B (n = 94)	
	Glass shape	**Straight**	**Outward**	**Straight**	**Outward**
Drinking trajectory	AUC	0.51 (0.03)	0.63 (0.09)	0.55 (0.07)	0.58 (0.07)
	Percentage consumed at 50% time	50.3 (47.5, 52.7)	66.0 (59.6, 72.7)	55.0 (53.4, 57.8)	59.2 (56.8, 61.8)

Notes. AUC refers to the mean areas under the drinking curves (calculated for each participant separately), given as M (SD). Larger AUCs (closer to 1) indicate more decelerated drinking. AUCs of 0.5 indicate linear drinking. AUCs closer to 0 indicate more accelerated drinking. Volume consumed at 50% time is calculated from cubic models of all participants' drinking trajectory data. Values given predict consumption at 50% time, with confidence intervals calculated by bootstrapping.

Sip size, sip duration, interval duration

Adjusting for the effects of gender on log mean sip size (B_{Male}=0.15, $p < .0001$), sips were 11.1% larger from the outward-sloped glass than the straight glass, however the data were also consistent with smaller sips (95%CI: -2.8%, 27.0%), $p = .123$). Larger sips were associated with faster total drinking times, $r(198) = -.50$, $p < .0001$; see Figure 4.3). Gender did not significantly predict mean sip duration or mean interval duration, so was not included in these models. Sip durations did not differ between glass shapes (8.1% longer from outward-sloped glasses, 95%CI: -3.8%, 21.6%, $p = .190$). Interval durations did not differ between glass shapes (10.7% longer from outward-sloped glasses, 95%CI: -9.1%, 34.7%), $p = .312$).
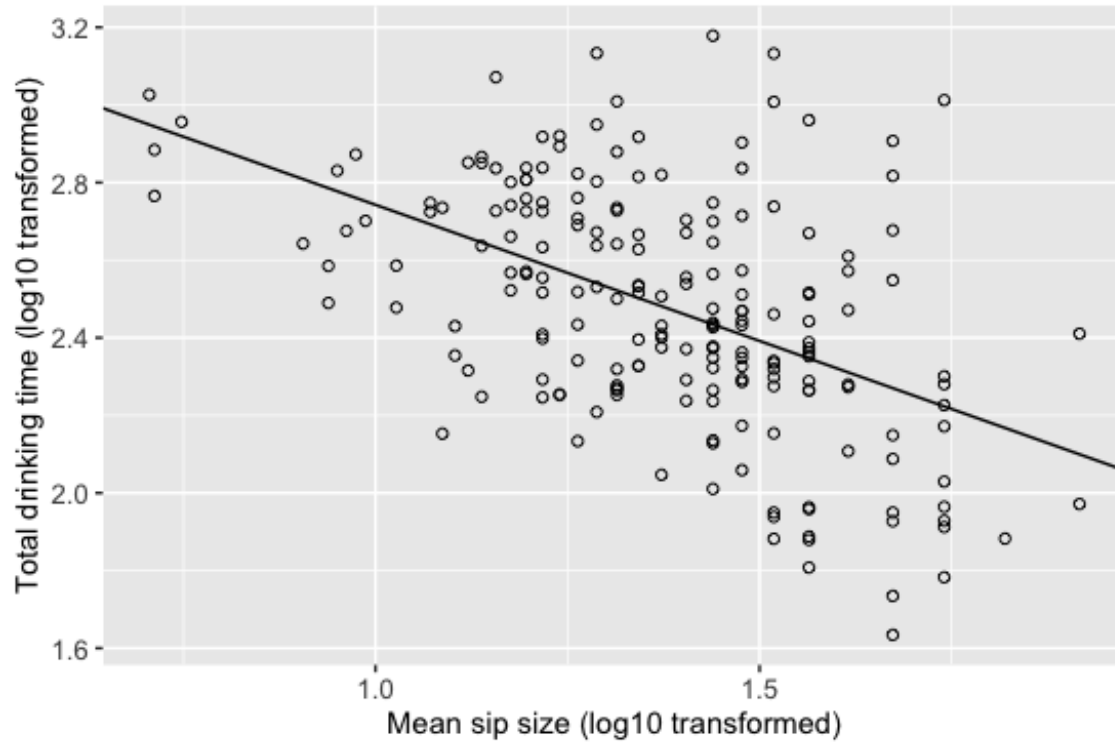
Figure 4.3. Relationship between mean sip size and total drinking time.

Impact of glass shape on midpoint bias

Midpoints were underestimated from both glasses, consistent with under-filling the glass when estimating the halfway point. Individuals under-estimated the midpoints of outward-sloped glasses to a greater degree (mean difference = 14.1ml, 95%CI: 9.5ml, 18.7ml), $t(196) = 6.1$, $p < .0001$). Midpoint bias was not associated with total drinking time, $r(198) = -.09$, $p = .196$).
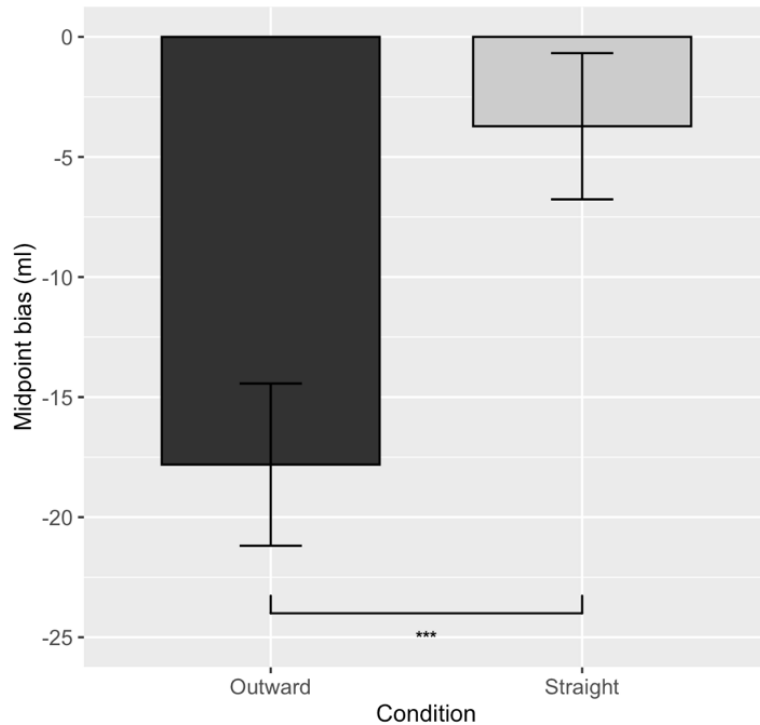
Figure 4.4. Mean bias in midpoint estimation and glass shape.

{Error bars reflect 95% CIs. Negative numbers reflect under filling of glass when estimating midpoint. ***
reflects significance at *p* < .001 level.}

Sensitivity analyses

Individuals who correctly guessed the purpose of the study (n = 2) and/or the aim of the drinking task (n = 7; to measure drinking speed) were excluded from the analysis. Removing these data had no impact on results from the primary or secondary analyses.

Reliability analyses

Video coding was assessed for reliability, for all video data (total drinking time, mean sip size, mean sip duration, mean interval duration, and volume over time data). For volume over time data (drinking trajectories and AUC), an independent coder measured glass:drink height ratios from the videos of 10 participants (40 observations). The 40 height ratios produced by the coder were then compared with the equivalent height ratios extracted for the primary data. For all other video data, 20 videos were assessed by an independent coder.

71

Video coding was consistent across video coders, with high inter-rater reliability, assessed using single measures intra-class correlation. Strong positive associations were observed for total drinking time (20) > 0.99, $p < .0001$, mean sip size (20) = 1.00, $p < .0001$, mean sip duration (20) = .97, $p <.0001$, mean interval duration (20) > 0.99, $p < .0001$, and height ratios (40) > 0.99, $p < .0001$.

Discussion

The present study provides a more robust test of whether glass shape (straight-sided vs. outward-sloped) influences total time taken to consume a soft drink than previous studies. Using a larger sample and fewer comparisons than in our previous study (Study 1) and previous research (Attwood et al., 2012), Study 2 failed to find evidence that total drinking time differed, when drinks were consumed from straight-sided vs. outward-sloped glasses. However, examining the micro-drinking behaviours further, there was evidence that drinking trajectory – the pattern of cumulative intake over time – did differ. In particular, drinking from straight-sided glasses was more linear in pace, while drinking from outward-sloped glasses was more decelerated (characterised by more consumed in the early stages of the drinking episode). This finding is compatible with the idea that when tilted, outward-sloped glasses appear to spill more easily than straight-sided glasses, which may lead people to take larger initial sips from these glasses to avoid spillage. We have shown this mathematically (for more detail on the affordance of volume poured by angle of tilt, see Chapter 2; see also Figure 2.2 and Appendix 2.4). This finding is also consistent with the exploratory analyses in Study 1, which considered sip durations over time. In particular, Study 1 demonstrated longer sip durations at the start and shorter sip durations at the end from outward-sloped glasses (and the reverse pattern from straight-sided ones), which, we hypothesised, might have been a proxy for a more decelerated drinking trajectory from outward-sloped glasses.

Several other effects found in Study 2 were consistent with Study 1. Again, there were trends to suggest larger average sip sizes from outward-sloped glasses than straight-sided ones, and evidence that mean sip size was associated with total drinking time (with larger average sip sizes associated with shorter total drinking times). Further, there was evidence of more midpoint bias from outward-sloped glasses than straight-sided ones, consistent with underfilling outward-sloped glasses when estimating the true midpoint. However, again, there was no evidence that the degree of this perceptual bias was associated with time spent drinking in this study. Consistent with Study 1, Study 2 showed evidence that gender influenced drinking behaviours, with males consuming more quickly and with larger sips than females.

Despite these findings, it remains unclear why the primary analysis – relating to total drinking time – failed to replicate our previous study (Study 1). One possibility is that, in line with Attwood et al. (2012), glass shape does not influence total drinking time for soft drinks, and our previous finding was spurious. Thus more research is warranted to explore the role of drink type (alcoholic vs. non-alcoholic) in moderating these effects. An additional (not mutually exclusive) possibility is that the task used in these studies, which requires participants to drink at their own pace while watching a documentary, may be susceptible to

extraneous influences which could mask true differences. For example, total drinking time, the primary outcome measure, may be influenced by a desire to finish the experiment more quickly, and/or interest in the documentary, which may operate regardless of the glass being drunk from. Given this, and that the link between total drinking time and amount consumed remains untested, future studies may benefit from using measures of *ad libitum* consumption, rather than total drinking time used as a proxy.

Strengths and Limitations

Given that this study was largely a replication of Study 1, several of the strengths and limitations of this study overlap with those discussed in the previous chapter. However, there were also some strengths specific to this study. First, Study 2 used a statistically more powerful design, with a larger sample size based on the effect size found in Study 1. Second, Study 2 utilised a more granular approach to measuring drinking behaviours by measuring cumulative intake over time, based on detecting volume consumed from images (a similar method to Cliceri et al., 2018). While Cliceri and colleagues assumed a quadratic model for characterising patterns of cumulative intake over time (and, indeed, this is often cited as the best characterisation of cumulative intake for food, see Kissileff et al., 1982), when calculating the best model fit of the data, we found that it was better represented by a cubic (S-shaped) model, for both straight-sided and outward-sloped glasses. Further research is warranted to attempt to characterise the dynamic patterns of drinking in other samples and in other scenarios.

One limitation specific to Study 2 relates to the loss of data for drinking trajectory – intake over time. Given the nature of the task, there was often occlusion of liquid in the images of participants drinking, sometimes due to participants holding the glass at an angle, or covering the liquid with their hands. This occlusion in the images prevented the accurate measurement of the liquid:glass heights and thus the calculation of volumes. This might have been avoided by asking participants to place their drink on the table between each sip, without holding the glass or occluding the liquid with their hands. However, this would have likely signposted to the participants that their drinking behaviours were of key interest, possibly leading to 'unnatural' drinking. As a result of missing data due to occlusion, there were only sixteen participants for whom all sips were recorded as volumes (Subset A). Excluding participants for whom <50% of sips were recorded as volumes (Subset B) showed similar patterns of findings, though the effects were smaller. Future research may benefit from hidden weighing scales or other methods to detect cumulative intake over time, though similar issues may be present there, with research on eating behaviours showing that up to a quarter of data can be lost due to errors with ingestive intake monitors (e.g., from leaving cutlery on the plate;

Thomas, Dourish & Higgs, 2015). Overall, this study indicates that detecting cumulative intake over time is possible from images alone.

Future directions

As discussed, there are several options for future studies to extend these findings. One aim will be to verify these preliminary findings relating to drinking trajectory, assessing cumulative intake over time from images or using concealed scales. Second, while these findings have the potential to inform interventions designed to reduce consumption of sugary drinks and alcohol, it should be noted that inferring reductions in amount consumed from slower drinking speeds, different drinking trajectories, or smaller sip sizes requires some assumptions to be made (namely, that these drinking behaviours are good 'proxies' for consumption, or are associated with reduced intake). As such, additional studies with measures of *amount* consumed (in addition to other drinking behaviours) are warranted. Finally, research should assess the robustness of these effects, in particular to changes in the specific glassware used (e.g., tumblers, tall glasses, stemmed glasses, etc.), as well as to changes in the drink served (e.g., different soft drinks, alcohol).

Conclusion and next steps

Study 2 provided no evidence that total drinking time for a soft drink differed depending on the glass being drunk from (failing to replicate Study 1). However, there was some evidence that drinking trajectories differed, with more decelerated drinking from outward-sloped glasses – characterised by a greater amount consumed in the first half of the drinking episode – and more linear drinking from straight-sided glasses. While this indicates that outward-sloped glasses may lead to a different trajectory of consumption, with more consumed in the early stages of drinking, it remains to be seen whether glass shape influences the amount that is consumed *overall*. As in Study 1 and previous research (e.g., Attwood et al., 2012; Troy et al., 2018), Study 2 provided further evidence that midpoints are underestimated more from outward-sloped glasses than straight-sided ones. However, as in Study 1, there was no evidence that this bias in perception of drink midpoints was associated with total drinking time.

Study 3 builds on Studies 1 and 2 by examining the impact of glass shape (straight-sided vs. outward-sloped) on amount consumed, using a bogus taste test to measure *ad libitum* intake of soft drinks. Study 3 also uses a different soft drink (i.e., non-carbonated), as well as different glassware (i.e., stemmed flutes and coupes), to assess the robustness (or specificity) of the effects found thus far.

<u>Chapter 5</u>: Study 3 - Impact of glass shape on consumption of a soft drink during a bogus taste test

Summary

Background

Drinking may be influenced by cues in the physical environment including glassware design. Consumption of carbonated soft drinks from straight-sided tumblers may be slower overall (Study 1, but see Study 2), and more linear in trajectory (Study 2), than from outward-sloped tumblers. The aim of Study 3 was to assess the impact of glass shape (straight-sided vs. outward-sloped) on volume of non-carbonated soft drinks consumed during a bogus taste test. This study used stemmed glasses (wine flutes vs martini coupes), and non-carbonated soft drinks, to assess the robustness (or specificity) of the effects found thus far.

Methods

In a between-subjects adaptive design, participants (N = 72) drank soft drinks from four straight-sided flutes (n = 36) or four outward-sloped coupes (n = 36), during a bogus 'taste test'. The primary outcome was total volume consumed (ml). This pre-registered adaptive design allowed for early stopping rules for recruitment after an internal pilot, based on futility and utility.

Results

The trial was stopped after the internal pilot (N = 72) based on utility, and no further recruitment was required. When adjusting for pre-specified covariates (thirst, maximum oral capacity (ml), gender, and drink enjoyment), 72.1ml (95%CI 11.7ml, 132.6ml) less was consumed from straight-sided glasses than from outward-sloped glasses ($p = .02$).

Discussion

Less was consumed from straight-sided glasses than outward-sloped ones, when participants tasted and rated identical soft drinks. Study 3 adds to a growing evidence-base suggesting that cues in the environment (in this case, glassware design) influence drinking behaviour, and in this case, amount consumed.

Note. The protocol for this study was pre-registered online on the Open Science Framework (see Appendix 5.1.).

Publication status: the studies reported in Chapters 4, 5, and 6 have been combined into one paper and published in Scientific Reports (Langfield, Pechey, Gilchrist, Pilling & Marteau, 2020; see Appendix 4.2. for author-approved manuscript).

Introduction

There is increasing evidence on the impact of glass shape – i.e., straight-sided vs. outward-sloped – on total time spent drinking, although results to date are mixed. Two studies show slower drinking from straight-sided glasses than outward-sloped ones, for beer glasses (Attwood et al., 2012), and tumblers (Study 1), though a third study failed to find evidence of a difference in total drinking time for tumblers (Study 2).

One limitation common to these three studies is the potentially 'noisy' measure of 'total drinking time', reflecting drinking speed. Typically, participants are asked to consume a single drink of a pre-specified volume while watching a documentary. Total time spent drinking thus may be influenced by a number of variables (including interest in the documentary, a desire to finish the experiment more quickly, and so on). Further, it is as yet unclear how predictive drinking time is of amount consumed, the critical measure for assessing whether glassware design can be used to reduce consumption of health-harming drinks.

Beyond 'total drinking time', there is evidence that glass shape may influence patterns of other micro-drinking behaviours. As discussed in Chapter 4, Study 2 showed that drinking trajectories within a standardised period may differ between glass shapes, with a more decelerated pattern from outward-sloped glasses than straight-sided ones, a pattern that has also been found for wide-rimmed vs. narrow-rimmed straight-sided glasses (Cliceri et al., 2018). Sipping behaviours may differ, with trends suggesting larger average sip sizes (i.e., lower number of sips from identical portions) from outward-sloped glasses than straight-sided ones, in Study 1 and 2, supporting the findings of Attwood et al. (2012), which found evidence of a higher number of sips from straight-sided vs. outward-sloped beer glasses, when combining data for full and half-full portions, and beer and lemonade.

Glass shape also appears to influence perception of drink volumes, with greater bias in midpoint estimation for outward-sloped glasses than straight-sided ones, as found in Study 1 and Study 2, as well as in previous studies (e.g., Attwood et al., 2012; Troy et al., 2018). These findings suggest that individuals underestimate the true midpoint of drinks to a greater degree from outward-sloped glasses than from straight-sided ones, consistent with using height as a cue for volume, or an 'elongation effect' (e.g., Raghubir & Krishna, 1999). However, thus far only one study has found an association between midpoint bias and drinking speed (Attwood et al., 2012), with two studies finding no association (Study 1 and Study 2). It remains unclear whether midpoint bias is an important mechanism determining drinking behaviours, including amount consumed.

Uncertainty also remains as to the specificity of the previously-reported effects of glass shape (straight-sided vs. outward-sloped) on drinking behaviours, including total drinking time. Attwood and colleagues (2012) found the effect only for full portions of beer, but not lemonade (Attwood et al., 2012). Study 1 and Study 2 used a carbonated apple drink served in short tumblers, with mixed findings (evidence of an effect, Study 1; no evidence of an effect, Study 2). It remains unclear whether other glasses (i.e., straight-sided vs. outward-sloped glasses with stems), and different soft drinks (i.e., non-carbonated) would show similar patterns.

Building on the existing evidence, Study 3 explores the effect of glass shape on *ad libitum* consumption in a laboratory setting, using another set of glass shapes – narrow-rimmed, straight-sided wine flutes and wide-rimmed, outward-sloped martini-style coupes. Importantly, there is some evidence that carbonation – "fizz" – dissipates more quickly from coupes (e.g., stemmed outward-sloped martini glasses) than flutes (e.g., stemmed straight-sided wine flutes) (Liger-Belair et al., 2009). As a result, to ensure carbonation was not a confound in studies using coupes and flutes, Study 3 used a non-carbonated soft drink. In this study, participants were asked to taste and rate non-carbonated soft drinks while intake was covertly measured. The 'bogus taste test' is a validated paradigm, with consumption during these tests correlating with other measures of intake (e.g., Jones et al., 2016 for alcohol; Robinson et al., 2017 for food). The present study also explored two possible mechanisms, namely micro-drinking behaviours (number of sips) and perceptual judgments (midpoint bias).

Research questions

1. Does glass shape (straight-sided vs. outward-sloped) affect amount consumed (ml)?
2. Does glass shape (straight-sided vs. outward-sloped) affect:
    a. Number of sips?
    b. Midpoint bias?
3. Do number of sips and midpoint bias predict amount consumed?

Methods

Participants

Eligibility and recruitment

Between February – March 2019, participants were recruited from the students and staff at the University of Cambridge (UK), as well as the general population. Potential participants were informed about the study through mailing lists, flyers, and word of mouth (see Appendix 5.2 for recruitment ads).

Eligibility criteria were as follows, requiring that individuals:
- Had not taken part in my previous two experiments (Study 1 and Study 2);
- Were over 18 years old;
- Were prepared to consume drinks that contain sugar;
- Had no known allergies to any of the following ingredients:
  - Fruit Juices from Concentrate 38% (20% Passion Fruit, 18% Lemon)
  - Glucose-Fructose Syrup
  - Flavourings
  - Colours: Lutein, Paprika Extract
  - Stabiliser: E445

Sample size determination

A convenience sample of 72 (50% female) participants was sought. The study sample size of N = 72 – pre-specified in the study protocol (https://osf.io/j9hqu/) – was primarily driven by pragmatic considerations i.e., time and cost, and is in line with convention (Lancaster, Dodd & Williamson, 2004) for an 'internal pilot', forming part of an adaptive design (see Wittes & Brittain, 1990; Kairalla, Coffey, Thomann & Muller, 2012). Given that previous studies have largely focused on the effects of glass shape on speed rather than consumption, the effect size for consumption was unknown. As such, this internal pilot provided the necessary parameters (effect size and p value) for a sample size calculation.

This adaptive design used stopping rules for recruitment at the interim analysis stage after outcome data had been collected on 72 participants, as follows.

1. If the effect of glass shape is significant at $p < 0.3\%$ for the primary interim analysis, or if no additional recruitment was required to achieve $p < 4.7\%$ for the primary final analysis, further recruitment would not be required. This is the *efficacy (utility) stopping criterion* (O'Brien-Fleming boundary).

2. If the sample size required to demonstrate $p < 4.7\%$ at the primary final analysis is unfeasible (with feasibility based on time and cost, being set at n >150 additional participants required) the trial will be stopped. This is the *futility stopping criterion*.

Study setting

The study took place in a testing room in central Cambridge (Behavioural and Clinical Neuroscience Institute, Department of Psychology, Cambridge, CB2 3EB, UK).

Study design

In a between-subjects experiment employing a bogus taste test paradigm (e.g., Maynard et al., 2018; Vasiljevic et al., 2018), participants were randomised to one of two conditions (stratified by gender). Participants received four drinks to taste and rate, served in either straight-sided wine flutes or outward-sloped martini coupes (see Figure 5.1 for images of the glasses). Participants were served a total of 660ml (divided into four 165ml portions) of a sugar-sweetened passion fruit drink to taste and rate.

The primary outcome measure was total volume consumed (ml) within a 10-minute period. Secondary outcome measures were micro-drinking behaviours (number of sips) and perceptual judgments (midpoint bias – assessed after the taste test).

Additional measures obtained included gender, thirst (1-10), maximum oral capacity (ml), and drink enjoyment, which were included to be adjusted for in the main analysis, as specified in our pre-registered analysis plan.

Figure 5.1. Image showing each glass type - (A) straight-sided wine flute; (B) outward-sloped martini coupe.

Materials and Measures

Drinks

The passion fruit drink was Teisseire ® passion fruit le sirop, diluted 1 part syrup, 7 parts water (12.5ml syrup per 100ml served). The syrup ingredients are listed as follows: Sugar, Fruit Juices from Concentrate 38% (20% Passion Fruit, 18% Lemon), Glucose-Fructose Syrup, Water, Flavourings, Colours: Lutein, Paprika Extract, Stabiliser: E445). The syrup contains 80g sugar/100ml undiluted.

The straight-sided wine flute is the "Olympia Modale", supplied by Nisbets (https://www.nisbets.co.uk/olympia-modale-crystal-champagne-flutes-215ml/gf728), (height: 23cm, weight: 145g, capacity: 210ml, rim diameter: 4.5cm). The outward-sloped martini coupe is the "Olympia Campana", also supplied by Nisbets (https://www.nisbets.co.uk/olympia-campana-one-piece-crystal-martini-glass-260ml/cs497), (height: 18cm, weight: 165g, capacity: 260ml, rim diameter: 12cm). See Figure 5.1 for images of the glasses, each containing 165ml portions of prepared passion fruit drink).

Primary outcome measure

Total amount consumed (ml) was measured by weighing the four identical glasses before and after the 10-minute taste test, using high precision scales. Each glass (labelled A, B, C, and D) was weighed with 165ml inside, to provide a total in grams (i.e., 165 + glass weight, to account for minor variation between glasses).

To determine volume consumed after the taste test, the weights of the glasses after consumption were subtracted from the initial weights. Volume consumed was collated across the four glasses – i.e., individual glass consumption data, though recorded, was not analysed.

Secondary outcome measures

Micro-drinking behaviours (i.e., number of sips) were measured by coding the video recordings taken during the drinking sessions (with each sip initiation and endpoint coded by a key press, as in Studies 1 and 2). Poured midpoint estimates were also assessed in the same way as Studies 1 and 2 (but with the true midpoint of these drinks being 82.5ml, rather than 165ml).

Other measures

Maximum oral capacity was calculated by asking participants to fill their mouth to full capacity from a cup filled with room temperature water, before spitting into an empty jug (weighed before and after to gauge volume – the maximum oral capacity). This task completed twice (with the total observed volume divided by two), and was disguised as a 'palate cleanser'.

Drink enjoyment was measured from ratings given during the taste test. Scores for 'tasty' and 'pleasant' (given from 1-10) were averaged across all four rated drinks.

Additional measures obtained included demographic information (age and gender), baseline thirst (1-10), and BMI (kg/m^2), calculated from self-reported height and weight.

Awareness of the purpose of the study was assessed at the end, using open-ended question. Answers were coded as "aware" or "unaware".

Procedure

The study was approved by the University of Cambridge Psychology Research Ethics Committee (reference: PRE.2018.122). Eligible participants were invited to attend a single session between 8 am and 8 pm, Monday to Friday, to take part in a study ostensibly investigating 'taste preferences'. On arrival, participants completed eligibility screening and provided written informed consent (see Appendix 5.3 for participant information sheet and consent form). After this, they answered demographic questions, including age, gender, level of education, handedness, height, weight, and thirst (1-10). All questions were administered using the Qualtrics platform on the computer (see Appendix 5.4 for online questionnaire).

83

Next, participants completed the 'palate cleanser' – twice filling their mouth with water and spitting into a jug to determine oral capacity.

For the taste test, the experimenter prepared four drinks (each with 165ml of the passion fruit drink), and placed them on mats labelled A, B, C, and D. Participants were told to taste and rate the drinks according to 10 descriptors (fruity, smooth, sweet, refreshing, bitter, strong-tasting, gassy, pleasant, light, and tasty) (e.g., Maynard et al., 2018), for 10 minutes. As well as completing these ratings, participants were be asked to indicate their order of preference from 1(favourite) - 4(least favourite), and to what extent they could taste differences in the drinks (Not at all; Somewhat; Extremely; Unsure), to reinforce the cover story (the data were not analysed). They were told to drink as much or as little of the drinks as they would like, to assist their ratings. Video recordings were taken during the taste test.

After the 10-minute taste test, the experimenter returned, switched off the camera, and asked the participant to complete the midpoint pouring task (involving six poured estimates of 82.5ml). The procedure was the same as for Studies 1 and 2. Finally, the participant was asked to guess the purpose of the study, using an open-ended question presented on screen. Participants were given an initial debrief, which was followed by a full debrief sent via email, once all participants had taken part (see Appendix 5.5). Participants were paid £7 cash for taking part. After the participant had left, the experimenter weighed the glasses to determine total volume consumed.

Data analysis

Analyses were pre-registered (https://osf.io/j9hqu/). The primary analysis predicted the amount consumed (ml) from glass shape, adjusting for pre-specified covariates (gender, baseline thirst, maximum oral capacity, and drink enjoyment). Secondary analyses predicted number of sips and midpoint bias from glass shape, and the relationships between amount consumed and number of sips/midpoint bias were also examined.

Although not pre-specified, mean sip size (calculated by dividing total volume consumed by number of sips) was also explored in analyses as an additional micro-drinking behaviour.

Results

Baseline characteristics

At the internal pilot stage of the adaptive design, further recruitment was not required as the initial sample (N = 72) immediately met the final analysis stage threshold of $p < 4.7\%$ (utility stopping criterion). Participants were predominantly students and staff at the University of Cambridge (UK). Baseline characteristics, split by condition, are shown in Table 5.1.

Table 5.1. Baseline characteristics of participants by condition, and overall

	Straight-sided (n = 36)	Outward-sloped (n = 36)	Overall (N = 72)
Gender (N)			
Female	18	18	36
Male	18	18	36
Highest Educational Qualification (%)			
GCSE/O Level	2	1	3
AS/A Level	13	20	33
Undergraduate	9	11	20
Postgraduate	12	4	16
Age (years)	23.50 (19.75, 27)	20 (19, 22)	21.50 (19, 25.25)
Thirst (1-10)	5.94 (1.26)	5.42 (1.54)	5.68 (1.42)
BMI (kg/m^2)	23.19 (3.06)	21.58 (2.86)	22.38 (3.05)
Max oral capacity (ml)	68.99 (20.09)	65.93 (19.28)	67.44 (19.60)

Notes. Thirst was rated from 1 ("Not at all") to 10 ("Extremely"). Age is median (IQR); Thirst, BMI and max oral capacity are mean (SD). One participant omitted to complete the max oral capacity measure, in the straight-sided condition.

Primary analysis

Visual inspection indicated no evidence of skew in the primary outcome measure: volume consumed (ml) or the secondary outcome measures: number of sips, and midpoint bias. For a summary of key outcome measures, see Table 5.2.

Unadjusted models predicting volume consumed from pre-specified covariates (gender, thirst, drink enjoyment and maximum oral capacity) are given in Table 5.3. These univariate analyses suggested that males consumed 64.92ml more than females, (95% CI: 1.09ml to 128.76ml), $p = .046$, and that for each unit increase in rated thirstiness, there was a concurrent increase in consumption by 27.46ml (95% CI: 5.15ml to 49.77ml), $p = .017$.

The adjusted model indicated that 72.1ml less was consumed from straight-sided glasses than outward-sloped glasses (95% CI: -11.7ml, -132.6ml), $p = .022$ (see Table 5.3 for full unadjusted and adjusted linear models).

Table 5.2. Summary of key outcomes, split by condition

		Glass Shape	
		Straight-sided (n = 36)	Outward-sloped (n = 36)
PRIMARY	Amount consumed (ml)	242.79 (113.60)	298.49 (156.69)
SECONDARY	Midpoint bias (ml)	-4.60 (8.33)	-6.00 (10.35)
	Number of sips	28.97 (12.53)	27.39 (11.15)
	Mean sip size (ml)	8.75 (3.47)	11.40 (5.45)

Note. Values are unadjusted M (SD). The camera malfunctioned for one participant (straight-sided condition), giving n = 35 and n = 36, for number of sips/mean sip size, for straight-sided and outward-sloped respectively.

Table 5.3. Unadjusted (univariate) and adjusted (multivariate) regression, predicting amount consumed (ml).

Independent variable	Unadjusted regression analyses				Adjusted regression analyses		
	B	95% CI (B)	p-value	R^2	B	95% CI (B)	p-value
(Intercept)	-	-	-	-	-49.45	-279.51 to 180.61	.675
Glass shape				.027			
Straight-sided	-55.70	-120.03 to 8.64	.089		-72.13	-132.56 to -11.69	.022
Gender				.042			
Male	64.92	1.09 to 128.76	.046		52.94	-19.15 to 125.02	.155
Thirst (1-10)	27.46	5.15 to 49.77	.017	.066	32.97	11.71 to 54.23	.003
Drink enjoyment (1-10)	18.82	-5.97 to 43.60	.135	.018	15.75	-7.07 to 38.57	.181
Max oral capacity (ml)	1.18	-0.51 to 2.87	.168	.013	0.513	-1.33 to 2.36	.588

Notes. Reference for Glass shape is Outward-sloped. Reference for Gender is Female. Thirst was rated from 1 ("Not at all") to 10 ("Extremely"). Drink enjoyment was an average of "pleasant" and "tasty" ratings, which were rated from 1 ("Not at all") to 10 ("Extremely"). Adjusted analyses: $F(5,65) = 3.928$, $p = .0036$, $R^2 = .173$.

Secondary analysis

Number of sips

Total number of sips did not differ between glass shapes (mean difference = -1.6 sips from the outward-sloped glass, 95% CI: -7.2, 4.0), $p = .58$. Number of sips was positively associated with total amount consumed, with fewer sips associated with less being consumed overall, $r(71) = .48$, $p < .0001$.

Midpoint bias

Drink midpoints were underestimated for both glasses. Though outward-sloped glasses led to lower midpoint estimates, there was no evidence that the difference in midpoint bias was meaningful (mean difference for outward-sloped vs. straight-sided= -1.4ml, 95% CI: -5.8ml, 3.0ml), $t(68) = -0.63$, $p = .531$). Midpoint bias was not associated with amount consumed, $r(72) = -.03$, $p = .827$.

Exploratory analysis

Mean sip size was also explored, calculated by dividing total volume consumed by number of sips. Mean sip sizes were 2.7ml smaller from straight-sided glasses than from outward-sloped glasses (95% CI: 0.48ml, 4.8ml), $p = .017$. Mean sip size was strongly and positively associated with total amount consumed, with smaller mean sips associated with less consumed overall, $r(71) = .67$, $p < .0001$.

Sensitivity analysis

Removing individuals (n = 5) who correctly guessed the purpose of the taste test (i.e., to measure volume consumed) had no impact on the primary or secondary analyses.

Reliability analysis

Inter-rater video coding reliability was assessed for 10 videos. The recorded number of sips coded from each of the 10 participants was identical.

Discussion

The present study examined the impact of glass shape (straight-sided vs. outward-sloped) on *ad libitum* consumption of soft drinks. Using a bogus taste test paradigm, when tasting and rating four identical drinks, participants consumed nearly half a glass less overall, when the drinks were served in straight-sided flutes. This study is the first – to our knowledge – to assess the impact of glass shape (straight-sided vs. outward-sloped) on amount consumed, with previous studies typically measuring proxies for it (e.g., total drinking time, amount purchased, and other micro-drinking behaviours; see Appendix 2.3). This study thus contributes to a growing evidence base suggesting that targeting the properties of cues in environments – 'choice architecture' – may be a promising way to reduce consumption of health-harming products (e.g., Hollands et al., 2013; Hollands et al., 2017).

When micro-drinking behaviours were analysed, there was limited evidence that number of sips differed by glass shape. However, when adjusting for overall amount consumed (by calculating mean sip size), sips were smaller from straight-sided glasses, in exploratory analyses. Both number of sips and mean sip size were associated with amount consumed, with a smaller number of sips and smaller average sip sizes associated with less overall consumed. These findings are consistent with Study 1 and 2, though it is worth noting that sips were generally smaller in this study. This is possibly due to the nature of the task: in Study 3, a bogus taste test paradigm was employed, which required participants to taste each of the four drinks while rating them along various criteria. By contrast, in Study 1 and 2, participants were free to consume the drink while watching a nature documentary. The rating element may have encouraged participants to taste the drinks more often, and with smaller sips, to ensure there was enough remaining to answer the upcoming questions. Mean sip size was larger for males than females, which is consistent with Study 1 and 2, as well as previous research (e.g., Lawless et al., 2003).

In contrast to Study 1 and 2, while the results were in the same direction, there was no evidence that outward-sloped glasses led to more midpoint bias than straight-sided ones, when estimating the drink's halfway point. There are several possible explanations for this finding. First, the present study may have been underpowered to detect small effects. Second, bias in visual perception of drink midpoints may be less pronounced, as compared to Studies 1 and 2, from this set of glasses (i.e., stemmed flutes and coupes vs. tumblers), drinks (i.e., non-carbonated vs. carbonated), levels of glass fullness (i.e., less full vs. full), or portion sizes (i.e., smaller vs. larger portions). While there are a number of studies demonstrating midpoint bias from outward-sloped vs. straight-sided glasses (e.g., Troy et al., 2018; Attwood et al., 2012; Study 1; Study 2; Study 3), further research is warranted to assess the potential parameters and limits of the effects.

89

Importantly, as in Study 1 and 2, there was no evidence of an association between midpoint bias and the primary outcome of interest (in this case, amount consumed).

Strengths and Limitations

The present study had a number of strengths. Many of the findings were consistent with the previous two studies, using different glasses, a different soft drink, and a different paradigm to measure drinking behaviour. This suggests that the findings may be robust to changes in the exact methods, measures, and materials used. Further, self-reported thirst was found to predict amount consumed in the taste test, which suggests that this task may have been a valid measure of desire to consume (unlike Study 1 and 2, where thirst was not found to predict total drinking time). The amount served (660ml) appeared to be sufficient to avoid ceiling effects, with no one consuming 100% of the available drinks. There are also a number of limitations to consider when interpreting these findings. First, as with Study 1 and 2, drinking behaviour was measured in the laboratory, which limits the ecological validity of the findings. While the bogus taste test paradigm has been shown to be a valid measure of intake (e.g., Jones et al., 2016), it remains a 'proxy' for real-life drinking, and further studies are required to assess whether the effects are present in real-life drinking environments. Second, the study was single-blind, rather than double-blind, which can introduce bias. However, a script was used to ensure the experimenter used consistent language when explaining the nature of the taste test. Third, while we used a pre-registered adaptive design to estimate effect size and required sample size, given the limited existing evidence, further studies are warranted to establish the accuracy of this effect size estimate. Finally, though rim diameter might confound the effects of glass shape for all studies reported in this thesis, this is particularly the case for Studies 3 and 4, given more marked differences in rim aperture between coupes and flutes.

Conclusion and next steps

Study 3 provided evidence that *ad libitum* consumption of soft drinks may differ depending on the glass drinks are served in. In particular, straight-sided wine flutes led to less soft drink consumed than outward-sloped martini coupes. These findings are consistent with the findings from Study 1 and 2, that drinking may be *slower* or more *steady* (less decelerated) from straight-sided glasses (with drinking time and trajectory being possible proxies for, or predictors of, measures of consumption). In Study 3 there was no statistical evidence that midpoint bias was greater from outward-sloped glasses (failing to replicate Study 1 and 2). There was also no evidence that bias in perception of drink midpoints was associated with amount

consumed (consistent with Study 1 and 2, which found no evidence of associations between midpoint bias and total drinking time). Study 4 builds on Studies 1 – 3 by examining a novel potential mechanism for slower and/or reduced consumption from straight-sided glasses. Namely, affordance of lip embouchures – the position of the lips during sipping – measured using surface electromyography.

Chapter 6: Study 4 - Impact of glass shape on amplitude of activity in *orbicularis oris* and sip size: an electromyography study

Summary

Background

Drinking behaviour may be influenced by cues in physical environments including glassware design. In particular, growing evidence suggests slower paced drinking, and less overall consumed, from straight-sided vs. outward-sloped glasses. The aim of this study was to assess a novel potential mechanism for these effects – namely, degree of lip pursing, or embouchure, during sipping.

Methods

In a within-subjects crossover design, using an adapted bogus taste test, participants (N = 40) tasted non-carbonated soft drinks from two straight-sided wine flutes and two outward-sloped martini coupes (order counterbalanced), with surface electromyography (EMG) detecting muscle activity in the upper and lower lips (*orbicularis oris*). The primary outcome was embouchure – percentage of lip muscle activity used, as a proportion of maximum voluntary activity (i.e., when pursed as much as possible). The secondary outcome was sip size (ml).

Results

Adjusting for standard crossover design variables, and with participant as a fixed effect, participants used 20% more lower lip muscle activity, 95%CI[14.7, 25.6], *p* < .0001, and 9% more upper lip muscle activity 95%CI[3.3, 14.8], *p* = .0017, when sipping from straight-sided glasses, indicative of more pursed embouchures. Adjusting for the same variables, as well as gender, thirst, maximum oral capacity, and glass shape (all pre-specified), sips were 16% smaller from straight-sided glasses, 95%CI[12.2, 20.8], *p* < .0001.

Discussion

This preliminary study provides evidence to support the hypothesis that when drinking from straight-sided glasses, lips may be more pursed, and sips may be smaller. Lip embouchure may thus be one of several potential mechanisms underlying reduced intake from straight-sided glasses. Broadly, this research adds to a growing evidence base suggesting that targeting the shape of glassware may be a promising, novel intervention to reduce consumption of health-harming drinks.

Note. The protocol for this study was pre-registered online on the Open Science Framework (see Appendix 6.1.).

Publication status: the studies reported in Chapters 4, 5, and 6 have been combined into one paper and published in Scientific Reports (Langfield, Pechey, Gilchrist, Pilling & Marteau, 2020; see Appendix 4.2.).

Introduction

There is a growing evidence base investigating the effect of glass shape and size on drinking behaviours. The shape of a glass (i.e., whether it is straight-sided or outward-sloped) may influence drinking speed for alcohol served in beer glasses (Attwood et al., 2012) and a soft drink served in tumblers (Study 1), though a follow up study failed to replicate this latter effect (Study 2). As discussed in the previous chapter, in Study 3, glass shape was found to influence amount consumed of a soft drink in a bogus taste test paradigm. Those drinking from outward-sloped glasses consumed around 70ml more – nearly half a glass – than those drinking from straight-sided glasses.

Micro-drinking behaviours may be important indicators of or proxies for consumption, and provide insights on potential underlying mechanisms. These behaviours may also be influenced by glass design. In Study 1 and 2, there were trends suggesting smaller average sip sizes (i.e., a greater number of sips for a given portion), from straight-sided tumblers than outward-sloped ones. In Study 3, where amount consumed varied, there was evidence that mean sip size differed, with smaller sips taken from straight-sided flutes (though the total number of sips did not differ). In all three studies, mean sip size was associated with the primary drinking behaviour of interest (total drinking time in Study 1 and 2, and amount consumed in Study 3). Sip sizes may also change dynamically, with a more decelerated pattern, characterised by consuming a higher volume in the first half of the drinking episode, from outward-sloped tumblers compared with straight-sided ones, as found in Study 2.

Several mechanisms have been suggested to explain the effects of glassware design on drinking behaviours. These include effects of glassware on perception of the drink (including ability to judge volumes consumed and volumes remaining, and titration of drinking rates based on these judgments), and a cueing or 'affordance' of sip sizes and other micro-drinking behaviours based on the physical characteristics of the container (see Chapter 2 for a review of these mechanisms). Taking the latter of these two proposed mechanisms, one possibility is that certain glasses may afford larger sips (and/or increased consumption) due to the nature of liquid flow from the rim when the glass is tilted. For outward-sloped glasses, when these are tilted into the mouth to extract a sip, more liquid is poured than when a straight-sided glass is tilted to the same degree (see Figure 2.2 and Appendix 2.4 for further detail). Thus the physical characteristics of the glassware's design could potentially influence drinking behaviours via the affordance of liquid flowing from the rim.

Another potential affordance of glass shape on drinking may be the position of the lips, and in particular, the extent the lips are pursed, during sipping. One method to measure this is electromyography (EMG), which detects electrophysiological activity of muscles. EMG allows researchers to detect the initiation of muscle activity (i.e., when they are being used), as well as the strength of that activity (i.e., how much they are being used). Several studies have explored the facial muscles involved in drinking, often in the context of swallowing disorders. The facial muscles involved in the normal functioning of swallowing include the orbicularis oris (upper and lower lips), masseter (jaw), submental-submandibular region (below the chin), infrahyoid (neck), and patalaryngeal regions (e.g., Vaiman, Eviatar & Segal, 2004; Vaiman & Eviatar, 2009; Vaiman, Nahlieli & Eliav, 2006; Zaretsky et al., 2017; Murray et al., 1998).

The orbicularis oris is responsible for compressing the lips and protruding them forward into a pucker (e.g., Fridlund & Cacioppo, 1986). The activity of these muscles is therefore potentially important for characterising the position of the lips – or embouchures – during drinking. Indeed, there is some evidence that EMG measurement of orbicularis oris activity can distinguish subtle differences in the embouchures of musicians playing brass and wind instruments (e.g., White & Basmajian, 1973, Basmajian & White, 1973; Gotouda et al., 2007). To our knowledge, only one study has investigated the impact of the receptacle from which a drink is consumed on activity in the orbicularis oris. Murray and colleagues (1998) found greater activity (indicative of a more pursed embouchure) when sips were taken via a straw, as compared to those taken from a cup or spoon. However, there is a lack of evidence characterising the embouchures associated with drinking from glasses of different shapes, and the relationship between embouchure and sip size. It is possible that glasses of different shapes may afford certain embouchures, which may, in turn, cue differences in sip sizes. A more pursed, closed embouchure may be associated with smaller sips, though this hypothesis awaits testing.

The present study will use facial EMG to explore the effect of glass shape (straight-sided wine flute vs. outward-sloped martini coupe, as in Study 3) on embouchure (the amplitude of activity in the lips, expressed as a percentage of maximum activity), during consumption of a soft drink using an adapted bogus taste test.

Bogus taste tests typically covertly measure *ad libitum* consumption while participants are asked to taste and rate products at their own pace, consuming as much or as little as they would like (e.g., Jones et al., 2016). Given the addition of psychophysiological measurements in the present study, an adapted procedure was used. Participants were asked to taste each drink in clearly-defined stages, in response to cues flashed on the screen (as in Murray et al., 1998; Cannon, Li & Grigor, 2017), prior to rating each drink.

95

Research questions

1. Does glass shape (straight-sided vs. outward-sloped) affect lip embouchure (i.e., amplitude of activity in the orbicularis oris)?
2. Does embouchure predict sip size (ml)?

Methods

Participants

Between June – July 2019, a convenience sample of 40 females was recruited from the students and staff at Macquarie University (Australia), using the same recruitment methods as Studies 1 and 2 (see Appendix 6.2). The sample size – stipulated in the pre-registered study protocol (https://osf.io/75b89/) – was based on pragmatic constraints, and was in line with previous studies (e.g., Carr, Winkielman, & Oveis, 2013; Larsen, Norris, & Cacioppo, 2003; Wu et al., 2015).

Eligibility criteria was more stringent for this study (given the additional use of facial electromyography). To take part, it was required that individuals:
- were female (given difficulty detecting lip muscle activity in males with extensive facial hair, discovered during pilot testing);
- were over 18 years old;
- had not eaten, drunk (including water), or smoked anything for 30 minutes prior to the test session;
- had had no surgical procedures performed on the lips (e.g., cleft lip surgery or cosmetic reconstruction);
- did not have highly sensitive skin (as the skin would be gently exfoliated with abrasive gel and an abrasive pad, which might have irritated highly sensitive skin);
- were prepared to remove facial make up prior to the task;
- were prepared to consume drinks that contain sugar;
- had no known allergies to any of the following ingredients:
  - Fruit Juices from Concentrate 38% (20% Passion Fruit, 18% Lemon),
  - Glucose-Fructose Syrup,
  - Flavourings,
  - Colours: Lutein, Paprika Extract, Stabiliser: E445.

Study setting

The study took place in the Bar Laboratory testing room at the Simulation Hub, 10 Hadenfeld Ave, Macquarie University, NSW 2109, Australia.

Study design

In a within-subjects crossover design, using an adapted bogus taste test, participants were presented with four soft drinks (165ml portions) to taste, served in two straight-sided wine flutes (A) and two outward-sloped martini coupes (B) (see Figure 5.1 for an image of each glass shape), in the sequence ABAB or BABA, with order randomised. An adapted version of the bogus taste test was used to allow more precise measurement of embouchures. In this task, participants were asked to sip three times from each of four drinks, following cues on the screen, before rating the taste of each drink.

The primary outcome measure was embouchure - the mean amplitude of muscular activity (mV) in the left orbicularis oris (upper and lower) detected during sipping, expressed as a percentage of maximal voluntary contraction (%MVC). Maximal voluntary contraction was measured by asking participants to protrude their lips forward as firmly as possible.

Other measures included sip size (ml), baseline thirst (1-10), and maximum oral capacity (ml). Thirst and maximum oral capacity were measured to be included as covariates for analyses involving sip size.

Materials and Measures

Drinks

As in Study 3, participants were served a total of 660ml (divided into four 165ml portions) of Teisseire ® passion fruit le sirop, diluted 1 part syrup, 7 parts water (12.5ml syrup per 100ml served), to taste and rate. The syrup ingredients are listed as follows: Sugar, Fruit Juices from Concentrate 38% (20% Passion Fruit, 18% Lemon), Glucose-Fructose Syrup, Water, Flavourings, Colours: Lutein, Paprika Extract, Stabiliser: E445). The syrup contains 80g sugar/100ml undiluted.

The straight-sided wine flute is the "Olympia Modale", supplied by Nisbets (https://www.nisbets.co.uk/olympia-modale-crystal-champagne-flutes-215ml/gf728), (height: 23cm,

97

weight: 145g, capacity: 210ml, rim diameter: 4.5cm). The outward-sloped martini coupe is the "Olympia Campana", also supplied by Nisbets (https://www.nisbets.co.uk/olympia-campana-one-piece-crystal-martini-glass-260ml/cs497), (height: 18cm, weight: 165g, capacity: 260ml, rim diameter: 12cm). See Figure 5.1 for images of each glass type, each containing 165ml portions of prepared passion fruit drink).

Primary outcome measure - embouchure

The primary outcome measure in this study was embouchure. Embouchure was measured using surface electrodes which detect the amplitude of activity in the upper and lower lips. Higher amplitudes of lip muscle activity are a proxy for a more 'pursed' embouchure. Lip muscle activity was measured for all twelve sips (three measurements, corresponding to three sips, for each of the four glasses).

Four surface electrodes were used, attached to the upper and lower lips on the left side of the face (see Figure 6.2). For the lower left quadrant, one electrode was placed 1cm below the cheilion (corner of mouth), and the paired electrode placed 1cm medial and slightly below (corresponding to the edge of the mouth). The upper left quadrant followed the same pattern (see Fridlund & Cacioppo, 1986 & van Boxtel, 2010 for recommended placement of electrodes for facial EMG). The ground electrode was placed on the temple.

Figure 6.1. Placement of surface electrodes on the upper and lower lip, with the ground electrode on the temple.

A two-channel Biopac MP160 system was used for continuous electromyographic (EMG) signal acquisition, and data inputs were recorded and processed using *AcqKnowledge* 5.0 software (BIOPAC

systems Inc., USA). Raw amplitudes of activity were transformed using a script which generates a rectified and integrated copy of the data over a period of 250ms and then rescales the channel so that this runs from 0-100%, with an individual's maximum voluntary contraction (MVC) representing 100%. Standardising activity in this way has been recommended for facial EMG measurement (van Boxtel, 2010).

To determine each individual's MVC, maximal lip compression trials were run, involving participants protruding their lips as hard as possible three times (as in Murray et al., 1998). The signal with the highest amplitude (from the three maximum lip compression attempts) was selected for each participant, and used to standardise their EMG activity. The amplitudes selected for MVC were chosen for each lip site (upper/lower).

Secondary outcome measure – sip size

Individual sip sizes (ml) were measured in real time, for each of the three sips taken from each of the four glasses. Sip sizes were noted by the experimenter after each sip, when the glass was placed on concealed weighing scales (see Figure 6.2 for layout of testing room). The weight of each glass was measured before consumption (i.e., with 165ml drink inside) and subsequently after each sip was taken during the adapted taste test.
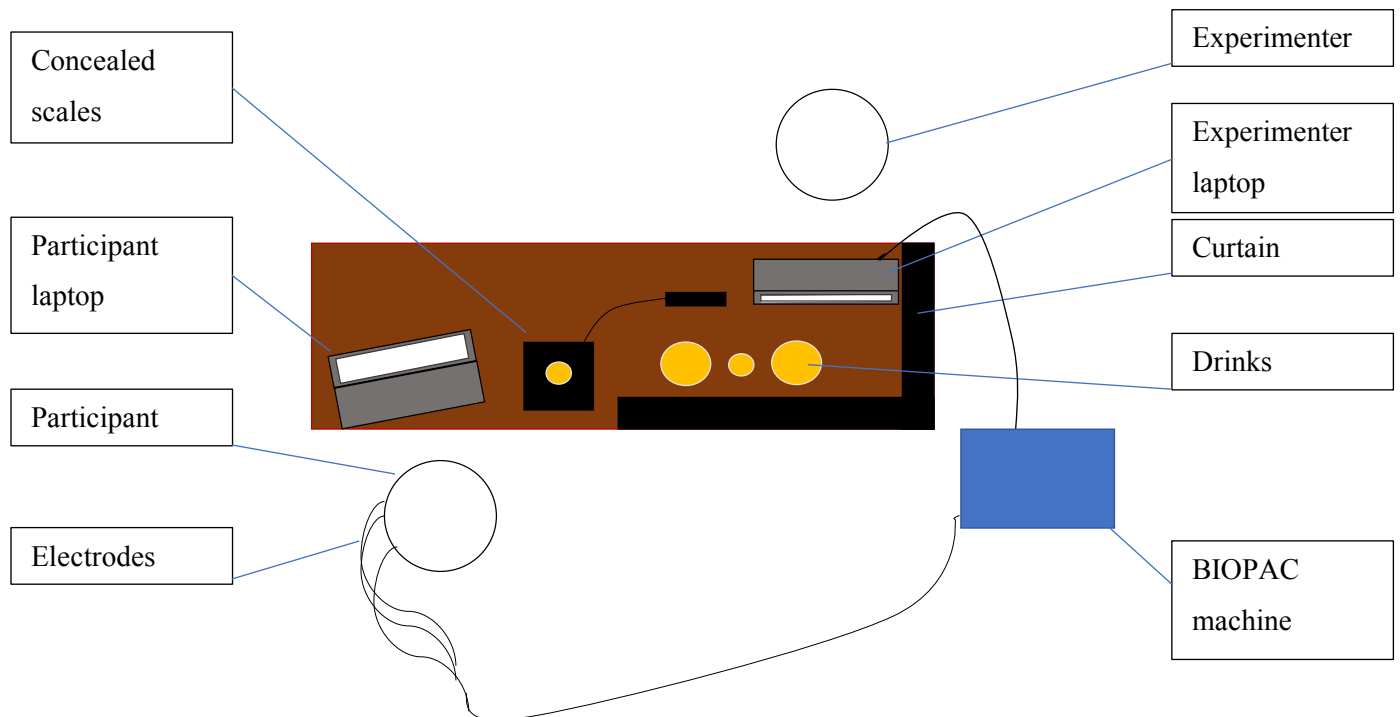
Figure 6.2. Layout of testing room in the 'bar laboratory'

Other measures

Maximum oral capacity was measured – disguised as a palate cleanser – in the same way as Study 3. As in Study 3, awareness of the purpose of the study was assessed at the end, using an open-ended question. Answers were coded as "aware" or "unaware".

Procedure

The study was approved by the University of Cambridge Psychology Research Ethics Committee (reference: PRE.2019.030), and the Macquarie University Research Ethics Committee (reference: 5201954159069). Eligible participants attended a single session at the 'bar-laboratory' on Macquarie University campus between 8 am and 7 pm, Monday to Friday. They were invited to take part in a study ostensibly investigating 'reactions to drinks served in different containers'. The testing room is designed to mimic a bar, with bar stools and a service counter, coupled with easy access to equipment for electrophysiological measurement.

On arrival, participants were given information about the study and were provided the opportunity to ask questions. After giving written informed consent and completing eligibility screening (see Appendix 6.3 for information sheet and consent form), participants completed the 'palate cleanser' – filling their mouth with water and spitting into a jug, twice. Next, the participants answered baseline demographic questions, including age, gender, level of education, and nationality, and rated their baseline thirst (1-10). All questions were administered using the Qualtrics platform on the computer (see Appendix 6.4 for online questionnaire).

To prepare the skin for electrode placement, any make up or surface oils around the lips and temple was removed using a make-up remover wipe. The skin was brushed with an exfoliative pad, and then brushed with a small amount of abrasive gel (NuPrep ®) on the end of a cotton bud.

The surface electrodes were then filled with electrode gel (SignaGel ®) to encourage signal conductivity and reduce artifacts, prior to being affixed to skin (upper and lower lips, and temple) with adhesive discs. Once the electrodes were attached, the trailing wires were clipped behind the ear. An Impedance checker assessed signal conductivity for each electrode prior to beginning the taste test. If impedance was high (i.e., greater than 30 kO) the relevant electrodes were removed and re-affixed.

Participants were instructed to taste the four drinks, one by one (i.e., from two straight-sided glasses and two outward-sloped glasses) in the order assigned to them (i.e., ABAB or BABA). Participants took three sips from each drink. Each sip was divided into four stages. The initiation of each of the four stages was demarcated by words on the screen ("Relax", "Prepare", "Remove", "Swallow"; adapted from Murray et al., 1998). The action to be elicited for each word was explained, as follows:

Step 1 – "Relax": "Please relax, keeping your lips at rest"
Step 2 – "Prepare": "Please lift the glass and hold it in front of your mouth"
Step 3 – "Remove": "Now raise the glass to your lips and take a sip"
Step 4 – "Swallow": "Remove the glass from your lips and swallow the sip in a single swallow"

Participants first practised these stages by sipping from a glass of water. Once they were confident with the steps, they would then begin the taste test, taking sips from each glass three times (with 15 second gap to follow the "swallow" stage, and prior to the initiation of the next sip). After tasting each drink three times, the participant was shown a 10-item questionnaire. The questions were used in previous studies using bogus taste tests (e.g., Maynard et al., 2018). Participants were asked to rate the drink, from 1(Not at all) to 10 (Extremely), on 10 descriptors, included as filler questions ("fruity", "smooth", "sweet", "refreshing", "bitter", "strong-tasting", "gassy", "pleasant", "light", and "tasty"). They were also asked to rate, from 1-10, how much they enjoyed the experience of consuming their drink from that glass. All of these questions were filler questions, to add to the cover story and disguise the true aim of the study, and the results of these ratings were not analysed. Once all four drinks had been tasted and rated, participants were asked to complete the maximal lip compression tasks (which was used to standardise amplitude of activity into a percentage of maximum activity). They were asked to "squeeze your lips together as hard as you can, so they protrude as far as possible". They did this 3 times, as prompted by the on-screen instructions.

After electrodes were removed from the participant, and make-up remover wipes and tissues offered, participants were asked to indicate what they believed to be the purpose of the study, by typing their answers into the online questionnaire. They were finally debriefed, and told a full debrief would be emailed to them after all participants had taken part (see Appendix 6.5). They were paid 10AUD for taking part.

Data analysis

Analyses were pre-registered (https://osf.io/75b89/). The primary analysis predicted embouchure (% muscle activity used in upper and lower lips) from glass shape, adjusting for order effects, using a linear mixed effects model.

The secondary analysis predicted sip size (ml) from embouchure (% MVC for muscle activity used in upper and lower lips), adjusting for pre-specified covariates (order effects, baseline thirst, maximum oral capacity), and with glass shape as a fixed effect, in a linear mixed effects model.

Results

Baseline characteristics

Forty females participated in the experiment, which took place on campus at Macquarie University, Australia, between June and July 2019. Participants were predominantly students and staff at Macquarie University (Australia). Further demographic and study-relevant information – including baseline thirst and maximum oral capacities – is shown in Table 6.1.

Table 6.1. Baseline demographics and characteristics of participants (N = 40)

Gender (%)	
Female	100
Nationality (%)	
Australian	62.5
Chinese	10.0
Bangladeshi	5.0
British	5.0
Other	17.5
Highest Educational Qualification (%)	
School Certificate (GCSE equivalent)	2.5
Higher School Certificate (AS/A Level equivalent)	60.0
Bachelors or Associate Degree	22.5
Postgraduate Degree	15.0
Age (years)	20 (19, 24.3)
Thirst (1-10)	5.48 (2.10)
BMI (kg/m^2)	23.06 (4.68)
Max Oral Capacity (ml)	52.46 (15.30)

Notes. Thirst was rated from 1 ("Not at all") to 10 ("Extremely"). Age is median (IQR); BMI, thirst, and maximum oral capacity are mean (SD).

Table 6.2. Summary of key outcomes, split by condition

	Glass shape	
	Straight-sided	**Outward-sloped**
Lip pursing (%MVC) – upper	14.06 (13.33, 14.83)	12.91 (10.69, 15.59)
Lip pursing (%MVC) – lower	14.03 (13.40, 14.68)	11.68 (9.60, 14.20)
Sip size (ml)	10.07 (9.60, 10.56)	12.16 (10.65, 13.89)

Note. Values are back transformed from log (Geometric mean and 95% CI), from models adjusting only for repeated-measures. MVC is maximum voluntary contraction.

Primary analysis

Visual inspection of distributions indicated positive skew for embouchure (% MVC upper, % MVC lower) and sip size (ml). All three variables were thus transformed using a log function, improving the shapes of the distributions. Back-transformed geomeans with 95% CIs are thus reported in Table 6.2. for these outcome measures, adjusting only for repeated-measures.

Two linear mixed effects models were used, predicting the co-primary endpoints of i) upper and ii) lower lip muscle activity (log %MVC) from glass shape, adjusting for standard crossover design variables (treatment = glass shape, sequence = ABAB/BABA, and time period = drink number) as well as sip number (1ˢᵗ, 2ⁿᵈ, 3ʳᵈ) and with participant as a random effect. These models indicated that, when sipping from straight-sided glasses, participants used 8.9% more upper lip muscle activity than when sipping from outward-sloped glasses (95% CI: 3.3% to 14.8%), $p = .0017$, and 20.03% more lower lip muscle activity than when sipping from outward-sloped glasses (95% CI: 14.7%, 25.6%) $p < .0001$. Findings were significant after adjusting for co-primary endpoints (i.e., significance when alpha < 2.5% using Bonferroni adjustment). See Table 6.3 for full models.

Given the absence of existing evidence prior to this study to inform a sample size calculation (and the pragmatic constraints), effect sizes have been calculated to inform future research. Using lme.descore function in R, effect sizes (Cohen's d) were determined from the mixed model. Straight-sided glasses led to an increase in lower lip muscle activity with an effect size of $d = .7$, and an increase in upper lip muscle activity with an effect size of $d = .3$.

Table 6.3. Linear mixed effects models predicting log(% MVC) upper, and log(%MVC) lower, from glass shape, adjusting for order effects.

	Upper Lip				Lower Lip			
	B	Exp(B)	95% CI Exp(B)	p-value	B	Exp(B)	95% CI Exp(B)	p-value
(Intercept)	2.632	13.91	10.61 to 18.22	< .0001***	2.487	12.02	9.11 to 15.86	< .0001***
Glass shape								
Straight-sided	0.086	1.089	1.033 to 1.148	.00168**	0.183	1.200	1.147 to 1.256	< .0001***
Sequence								
BABA	-0.097	0.908	0.625 to 1.318	.614	0.118	1.125	0.764 to 1.657	.555
Drink number (1-4)	0.0035	1.003	0.980 to 1.027	.773	-0.0269	0.973	0.954 to 0.993	.009**
Sip number								
2nd sip	-0.043	0.958	0.898 to 1.022	.198	-0.0199	0.980	0.928 to 1.036	.482
3rd sip	-0.065	0.937	0.878 to 1.000	.051	-0.0357	0.965	0.913 to 1.020	.207

Notes. % MVC is percentage of muscle activity used, as a proportion of maximum voluntary contraction (MVC). Participant ID was included as a random effect. Reference for Glass shape is Outward-sloped. Reference for Sequence is ABAB. Drink number is 1st, 2nd, 3rd, 4th. Reference for Sip number is 1st sip. Exp(B) = eB.

Secondary analysis

Two linear mixed effects models were used, predicting log sip size from (i) upper and (ii) lower muscle activity (% MVC), adjusting for the same variables as above, as well as baseline thirst and maximum oral capacity (ml).

These models indicated that glass shape meaningfully predicted sip size, with sips that were 17.3% smaller and 16.6% smaller from straight-sided glasses than outward-sloped glasses, when adjusting for upper %MVC (95% CI 13.3%, 21.3%, p < .0001) and lower %MVC (95% CI 12.2%, 20.8%, p < .0001), respectively, see Table 6.4. However, there was no evidence that muscle activity predicted sip size in these models: for every 1% increase in upper lip muscle activity used, there was a 0.19% decrease in sip size (95% CI: -0.56, 0.2), *p* = .337, and for every 1% increase in lower lip muscle activity used, there was a 0.36% decrease in sip size (95% CI: -0.95, 0.3), *p* = .251. See Table 6.4 for full models.

Exploratory analysis

In exploratory analyses, we removed glass shape from these models to determine whether lip muscle activity predicted sip size for upper and lower %MVC respectively, without adjusting for the effects of glass shape on sip size. In this analysis, lower lip muscle activity (%MVC lower) did predict sip size, such that for every 1% increase in lower lip muscle activity used, there was a 1.13% decrease in sip size (95% CI: -1.70, -0.51), *p* = .0002. There was no evidence that upper lip muscle activity (%MVC upper) predicted sip size; for every 1% increase in upper lip activity used, there was a 0.27% decrease in sip size (95% CI: -0.66, 0.14), *p* = .191.

Sensitivity analysis

Removing individuals (n = 3) who correctly guessed the true aims of the study did not impact the primary or secondary analyses.

Table 6.4. Linear mixed effects models predicting log (sip size) from %MVC upper, and %MVC lower, adjusting for order effects, glass shape, thirst, and maximum oral capacity.

	Upper Lip				Lower Lip			
	B	Exp(*B*)	95% CI Exp(*B*)	*p*-value	B	Exp(*B*)	95% CI Exp(*B*)	*p*-value
(Intercept)	2.652	14.18	7.60 to 26.43	< .0001***	2.686	14.68	7.80 to 27.61	< .0001***
%MVC	-0.0019	0.998	0.994 to 1.002	.337	-0.0036	0.996	0.991 to 1.003	.251
Glass shape								
Straight-sided	-0.191	0.826	0.787 to 0.867	< .0001***	-0.182	0.834	0.792 to 0.878	< .0001***
Sequence								
BABA	-0.061	0.941	0.720 to 1.230	.669	-0.055	0.947	0.725 to 1.237	.701
Drink number (1-4)	-0.034	0.967	0.946 to 0.988	.0022**	-0.036	0.965	0.944 to 0.986	.0013**
Sip number								
2nd sip	0.017	1.017	0.959 to 1.079	.580	0.017	1.017	0.959 to 1.078	.580
3rd sip	0.024	1.024	0.965 to 1.086	.434	0.024	1.024	0.966 to 1.086	.426
Thirst (1-10)	-0.022	0.979	0.918 to 1.043	.524	-0.025	0.975	0.915 to 1.040	.468
Max oral capacity (ml)	0.002	1.002	0.993 to 1.011	.676	0.002	1.002	0.993 to 1.011	.661

Notes. % MVC is percentage of muscle activity used, as a proportion of maximum voluntary contraction (MVC). Participant ID was included as a random effect. Reference for Glass shape is Outward-sloped. Reference for Sequence is ABAB. Drink number is 1st, 2nd, 3rd, 4th. Reference for Sip number is 1st sip. Thirst was rated from 1 ("Not at all") to 10 ("Extremely"). Exp(*B*) = e^{B}.

107

Discussion

The present study aimed to explore a potential mechanism for reduced intake from straight-sided glasses: namely, the pursing of lips during sipping, and its impact on sip size. Study 4 revealed that lips may be more pursed when sipping from straight-sided glasses, as compared to outward-sloped glasses. In particular, around 10% more upper lip muscle activity, and 20% more lower lip muscle activity, was observed when participants sipped from straight-sided glasses. Correspondingly, the study showed that sips were smaller from straight-sided glasses, and there was some evidence of an association between lip muscle activity and sip size (with smaller sips associated with more pursed lower lips).

Taken together, these findings suggest that affordance of lip embouchures may be one candidate mechanism for understanding why straight-sided glasses may lead to reduced intake of soft drinks, relative to outward-sloped glasses. It is worth noting that average sip sizes in this study were consistent with those found in Study 3, which used the same glasses and drinks, and a bogus taste test paradigm. The sip sizes observed in these latter studies were generally smaller than those found in Study 1 and 2, which used tumblers and carbonated drinks, and a different study paradigm to measure drinking behaviour.

Strengths and Limitations

There are a number of strengths and limitations to this study that warrant consideration. First, the main strength of this research is that it applied a novel technique to study a previously-unstudied mechanism – namely, extent of lip pursing (embouchure) during sipping from glasses of different shapes. Amplitude of lip muscle activity appears to be a valid measure of embouchure, with more pursed lips reflecting higher levels of activity (as demonstrated in the maximum compression trials). Second, though neither the experimenter nor the participant were blind to the condition, an independent coder who was blind to condition extracted the physiological data. Third, participants were also found to be generally unaware of the study aims, with only three identified as aware. Fourth, though the sample size was small (due to pragmatic concerns, given my limited time in Australia), a within-subjects design was used to minimise the impact of between-subject variation in lip embouchures and sip sizes. Fifth, it is important to note that the study was limited to females (given difficulty measuring embouchures when substantial facial hair was present), which reduces generalisability across genders. Sixth, as in Studies 1 – 3, and to allow for the detailed study of mechanism which is less feasible in more ecologically valid settings, Study 4 was

108

conducted in an artificial laboratory setting. While the testing room was a 'bar-laboratory', which mimicked some of the features of a real-life drinking environment, drinking remained artificial in nature, and lacked many of the features which mark real-life drinking scenarios, such as the presence of drinking companions, and the absence of facial electrodes. Finally, as in Study 3, it is possible that effects on embouchure and sip size were driven by rim diameter (i.e., the width of the glass aperture), rather than glass shape overall.

Future directions

Given that this study is the first of its kind, more research is warranted to verify these preliminary findings on glass shape and lip embouchures. Studies might seek to extend the findings with a sample that includes males, as well as consider other drink types (e.g., alcoholic) and glasses (e.g., tumblers, beer glasses, etc.).

Conclusion and next steps

Study 4 provides evidence for a novel potential mechanism that may contribute to the effects found in Studies 1 - 3, namely, that lip embouchures may be more pursed when drinking from straight-sided glasses, as compared with outward-sloped ones. A corresponding effect on sip size was also found, with smaller sips taken from straight-sided glasses, though embouchure was not found to mediate this effect in this preliminary study. These findings await verification in a larger-scale study. However, given limited evidence from Studies 1 – 3 that midpoint bias is an important driver of the effects of glass shape on drinking behaviours, affordance of micro-drinking behaviours via embouchures may be one promising candidate mechanism that underlies some of the effects of glassware design on drinking behaviours.

109

Chapter 7: Thesis summary and conclusions

Overview

This thesis addressed three main aims, as follows.

1) To review evidence on the impacts of glassware design (size, shape, and/or resulting fullness) on consumption of alcoholic and non-alcoholic drinks

2) To conduct experiments investigating the impact of glass shape (straight-sided vs sloped) on consumption of soft drinks, and to characterise the 'mechanics' of that consumption

3) To develop and test hypotheses about mechanisms that may underlie effects of glassware design on drinking behaviours

Chapter 2 in this thesis addresses the first aim, by systematically reviewing and evaluating existing evidence on glassware design and drinking behaviours for alcoholic and non-alcoholic drinks. Addressing the second aim, Chapters 3 – 6 present four laboratory studies designed to test the impact of a specific set of glass shapes (i.e., straight-sided vs. sloped-glasses) on the consumption of soft drinks, including 'macro' drinking outcomes (e.g., measures of consumption), as well as 'micro' drinking behaviours (e.g., sip size). In relation to the final aim, throughout the thesis, two potential mechanisms – neither exhaustive nor exclusive – are examined, namely: perceptual effects (including hedonic ratings and visual perception) and affordance of drinking behaviours (including via lip embouchures and via the angle the glass is tilted). An integrated summary of key thesis findings is found below, with findings discussed in relation to the existing literature reviewed in Chapter 2. The extent to which findings are consistent across studies will also be examined. Possible moderators of interventions involving glassware design will be discussed, and the strengths and limitations of this set of studies assessed. Finally, implications for future research and implementation will be described.

Integrated summary of findings
Impact of glass shape on total drinking time

A previous laboratory study found that individuals consumed beer 60% more slowly from straight-sided beer glasses than outward-sloped ones, though no evidence that total drinking time differed for lemonade (Attwood et al., 2012). While it is possible that glass shape does not influence drinking rates in the same way for alcoholic and non-alcoholic drinks, lemonade is not matched visually to beer (clear vs. amber liquid). This may be important, in particular because differences in consumption rate were hypothesised to be affected by perception of visual cues to volume remaining (i.e., midpoint bias), and clear (vs amber) liquid may change or reduce the effect of glass shape on ability to perceive drink midpoints.

Study 1 investigated the effect of glass shape on total drinking time of a soft drink. This study used outward-sloped, straight-sided, and inward-sloped tumblers, and an amber liquid more visually similar to beer (i.e., Appletiser). In contrast to Attwood and colleagues' findings (2012), there was evidence that total drinking time differed for this soft drink, with drinking about 20% slower from the straight-sided glass than the outward-sloped glass. Although drinking from the inward-sloped glass was also faster than from the straight-sided glass, wide confidence intervals suggested no meaningful difference. The aim of Study 2 was to verify these initial findings with a larger sample and fewer comparisons, and compared drinking time for a soft drink (using the same procedures as Study 1), between outward-sloped and straight-sided tumblers. In this second study, there was no evidence or trend to suggest a difference in overall drinking time, though evidence suggested more *decelerated* drinking rates from outward-sloped glasses (characterised by a greater amount consumed in the first half of consumption – see later section on additional micro-drinking behaviours).

Total drinking time, the primary outcome measure in Studies 1 and 2, may have been susceptible to extraneous influences from the nature of the experimental procedure. For example, in the experimental tasks used in Studies 1 and 2 (and in previous studies, e.g., Attwood et al., 2012; Troy et al., 2017), total time spent drinking may have been driven by a desire to finish the experiment more quickly, and/or interest in the documentary, which may operate regardless of the glass being drunk from (i.e., representing noise, potentially masking true differences). While it was initially considered that total time spent drinking could be a predictor or proxy of consumption, given these issues, and the fact that amount consumed is the critical measure for assessing reduction in consumption of health-harming drinks, it was clear that more studies were needed measuring the impact of glassware design on amount consumed.

Impact of glass shape on amount consumed

As identified in the review in Chapter 2, only 3 published studies have measured amount consumed directly (with many more measuring amount purchased or poured, possible proxies for consumption), with 2 on

glass size and 1 on glass shape. Building on Studies 1 and 2 and the existing literature, Study 3 examined the impact of glass shape on *ad libitum* consumption in a laboratory setting. This study also used stemmed glasses, rather than tumblers (Studies 1 and 2), or beer glasses (Attwood et al., 2012), to assess how robust the effects of glassware design were, to changes in the exact glass specifications. The study glasses were narrow-rimmed, straight-sided wine flutes and wide-rimmed, outward-sloped martini-style coupes. Given some evidence that carbonation dissipates more quickly from coupes than flutes (Liger-Belair et al., 2009), Study 3 also used a non-carbonated soft drink. In a 10 minute bogus taste test (a validated measure of ad libitum consumption for food and alcohol; Robinson et al., 2017; Jones et al., 2016), when tasting and rating drinks served in straight-sided flutes, participants consumed 72ml (~30%) less overall than when sipping from outward-sloped flutes. This was the equivalent of around half a glass less consumed, when tasting four drinks. As in Jones et al. (2016), amount consumed was positively associated with self-reported baseline thirst, speaking to the validity of this task and measure. The amount served in this study (660ml) appeared to be sufficient to avoid ceiling effects, with no one consuming 100% of the available drinks (unlike some previous research using a taste test paradigm, e.g., Maynard et al., 2018).

Glass shape and micro-drinking behaviours

Sip size

Previous evidence suggested that larger cups may lead to larger sips, though confounds in the experimental design of these studies meant effects may have been driven by portion size, or nature of drinking instructions (Lawless et al., 2003; Bennett et al., 2009). All four studies presented in this thesis measured the impact of glass shape on sip size. In Studies 1 and 2, participants drank a fixed portion (330ml) at their own pace, and video recordings enabled coding of sips (i.e., number of sips). Mean sip size was calculated by dividing total amount consumed (330ml) by number of sips. Though trends suggested smaller sips from straight-sided glasses than outward-sloped (Study 1 and 2) and inward-sloped (Study 1) glasses, there was no statistical evidence that mean sip size differed. In Study 3 participants tasted and rated four drinks served in identical glasses during a bogus taste test, and sips were subsequently coded from video recordings. While total number of sips did not differ, mean sip size – calculated by dividing total amount consumed (primary outcome) by number of sips – differed. Sips were around 30% smaller from straight-sided glasses than outward-sloped ones. Finally, Study 4 recorded sip sizes taken from straight-sided wine flutes and outward-sloped martini coupes, with the primary aim being to measure lip muscle activity (see mechanisms section). Participants placed their drink on concealed weighing scales in between sips, allowing for covert measurement of individual sip sizes. Sips were 17% smaller when taken from straight-sided glasses vs. outward-sloped ones.

In Studies 1 – 3, relationships between sip size and the primary drinking outcome for each study was assessed. Mean sip size was negatively associated with total drinking time (Studies 1 and 2), indicating that smaller sips were associated with longer time spent drinking. Mean sip size was positively associated with amount consumed (Study 3), indicating that smaller sips were associated with a reduction in amount consumed.

Overall, the findings were broadly consistent. Each study showed trends (Studies 1 and 2) or effects (Studies 3 and 4) in the same direction, indicating smaller sips were taken from straight-sided glasses, regardless of the exact glassware used (i.e., tumblers in Studies 1 and 2, stemmed glasses in Studies 3 and 4). Smaller sips were associated with longer drinking times (Studies 1 and 2) and reduced amount consumed (Study 3). While the patterns were consistent, sips recorded in Studies 3 and 4 were generally smaller than those recorded in Studies 1 and 2. There are several possible explanations for this, which may have operated synergistically. For example, differences in rim diameter were more extreme in the latter two studies, which may have led to more marked differences in sip size (glasses with narrow apertures 'afford' less liquid flow, given the same tilt – see Figure 2.2 and mechanisms section below for further discussion). Further, differences in the study paradigms may have contributed to differences in sip sizes: the first two studies involved participants drinking while watching a documentary, while the latter two studies involved bogus taste tests. Taste tests require individuals to take several sips, to allow them to make informed ratings about the drink's taste.

Sip and Interval duration
There was no evidence that glass shape predicted mean sip or interval duration, for 330ml soft drink served in straight-sided vs. outward-sloped glasses (Studies 1 and 2) or straight-sided vs. inward-sloped glasses (Study 1). In exploratory analyses involving plotting sip durations over time, Study 1 found longer initial, and shorter final, sip durations from the outward-sloped glass, which contrasted with the straight-sided glass, for which the opposite pattern was true. This pattern of findings might could indicate large initial gulps due to the relatively full, outward-sloped glass, though it is not possible to determine the dynamic changes in sip sizes (~ drinking trajectory) from sip and interval durations alone.

Drinking trajectory
Study 2 extended findings from Study 1 (suggesting longer initial and shorter final sips from outward-sloped glasses), by measuring drinking trajectory (cumulative intake plotted over time). One published study has explored drinking trajectory previously, measuring intake from video recordings, and comparing tall-narrow vs short-wide glasses (Cliceri et al., 2018). While there was no evidence that total drinking time

113

of an alcoholic drink differed by glass shape, drinking trajectory differed, with more decelerated drinking from the short-wide glass. Similarly, Study 2 found a difference in drinking trajectory between glass shapes during consumption of a soft drink: a more decelerated pattern of consumption was observed from outward-sloped glasses, as compared to straight-sided ones. It is also worth noting that while Cliceri et al. (2018) assumed a quadratic model fitted the cumulative intake curves (as in studies on eating; Kissileff et al., 1982), Study 2 demonstrated that a cubic ("S"-shaped) model was the best fit of the cumulative intake curves, for both straight-sided and outward-sloped glasses. Further research is warranted to characterise the dynamic patterns of drinking in other samples, for other drinks, and in other settings.

Possible mechanisms

This thesis has developed and tested hypotheses about potential mechanisms that might underlie some of the effects of glassware design on drinking. These mechanisms were first discussed in the review of existing literature (Chapter 2), and tested in the experiments (Chapters 3 – 6). This thesis proposes two possibilities – neither exclusive nor exhaustive – namely, perceptions (including volume judgments such as midpoint bias) and affordance (including affordance of lip embouchure and of liquid flow via angle of tilt), see Figure 2.1 for a logic model of these mechanisms.

When evaluating these proposed mechanisms, it is important to identify *i.* how glassware design influences perceptions of a drink and *ii.* how these perceptions influence drinking behaviour, as well as *iii.* how glassware design affords certain behaviours such as liquid flow and embouchures and *iv.* how these in turn influence drinking behaviour. This thesis begins to address these questions. There is, for example, much evidence for *i.* but less for *ii.* There is little evidence for *iii.* and *iv.* but what evidence there is appears promising.

Perceptual effects – midpoint bias

Ability to estimate the volume remaining in the glass may be one mechanism underlying some of the effects of glassware design on drinking behaviours. One reason is that titration of consumption (i.e., keeping track of pace) relies on accurate perception of amount remaining. Previous research identified in the review indicates that when estimating the half-way point on a glass (i.e., half of the drink remaining), participants tend to underfill for outward-sloped glasses to a greater degree than for straight-sided ones. This midpoint bias has been assessed using physical pouring exercises (Troy et al., 2018) and virtual pours (Attwood et al., 2012; Troy et al., 2018), with participants estimating midpoints on pint glasses (i.e., 284ml) and midpoints on 355ml glasses (i.e., 178ml). Findings indicate that glass midpoints are underestimated by

between 22-30% for outward-sloped glasses, 5-7% for straight-sided ones, and 5% for inward-sloped ones (Attwood et al., 2012; Troy et al., 2018).

Building on the existing evidence, using tumblers and stemmed glasses, and physical pouring tasks, three studies measured the impact of glass shape on midpoint bias. In Studies 1 and 2, when asked to pour to the glass midpoint (165ml for a 330ml capacity glass), participants poured ~14ml less into outward-sloped tumblers than straight-sided ones, though there was no evidence of a difference between inward-sloped and straight-sided glasses in Study 1. In Study 3, using stemmed 165ml glasses, there was no evidence of a difference in estimates of the midpoint (82.5ml) poured into straight-sided wine flutes and outward-sloped martini coupes, though the direction of the effect was the same. Importantly, no association was found between midpoint bias and drinking time ($r = 0.01, -0.09$), or midpoint bias and amount consumed ($r = -0.03$), in Studies 1, 2 and 3 respectively. Thus while the evidence was somewhat consistent, suggesting that glassware design does indeed influence perceptions of the drink (in this case, perception of volume), with effects and trends in the same direction, it remains to be seen whether midpoint bias is an important mechanism explaining differences in drinking behaviours.

Perceptual effects – drink enjoyment

Substantial evidence reported in the review suggested that glassware design may influence subjective ratings about the drink, for example, how much it is enjoyed, its flavour, or how appropriate the glass is considered to be (e.g., see Spence & Wan, 2015). One study in this thesis investigated the impact of glass shape on drink enjoyment, finding no evidence that enjoyment differed by glass shape (Study 1). Drink enjoyment was also not found to be associated with total drinking time in this study. Given the possibility that drink enjoyment affects amount consumed (perhaps over and above drinking speed), Study 3 also measured drink enjoyment and adjusted for it in the model predicting amount consumed from glass shape. While there was no evidence that drink enjoyment predicted amount consumed in this model, the direction of effect suggested a trend that increased drink enjoyment was associated with increased intake. Overall, there was limited empirical evidence in this thesis to support the hypothesis that drink enjoyment is a mechanism underlying differences in drinking behaviours when drinking from different glass shapes, though more research is warranted to explore this further.

Affordance via liquid flow

As discussed in Chapter 2, the flow of liquid when a glass is tilted differs depending on the shape of the glass. Taking straight-sided and outward-sloped glasses for comparison, when full, outward-sloped glasses (~cones) appear to spill easily, and require relatively less tilt than full straight-sided glasses (~cylinders) to

afford the same liquid flow. That is, amount poured is less from straight-sided glasses, given the same angle of tilt (see Figure 2.2). This affordance of liquid pouring by pouring angle from different glass shapes might shed light on some of the findings on glass shape and drinking behaviours. For example, tilting a full outward-sloped (conical) glass towards the lips to extract a sip may afford a larger initial sip, when compared to tilting a full straight-sided (cylindrical) glass. This might contribute to a more decelerated pattern of consumption – characterised by a larger amount consumed in the first half of consumption from outward-sloped glasses – as found in Study 2. However, it is important to note that these are patterns which may not be linked – that is, decelerated trajectories from outward-sloped glasses may be caused by a factor – or indeed a number of factors – other than affordance of liquid flow.

Affordance via embouchure

An additional affordance proposed in this thesis is affordance of lip embouchures – the extent of lip pursing – which might also differ by glass shape. One previous study identified in the review investigated lip muscle activity during sipping from different implements (spoon, straw and cup; Murray et al., 1998). Study 4 involved a laboratory experiment to assess extent of lip muscle activity – an indicator of embouchure - during sipping from glasses of different shapes. Facial electrodes were attached to the upper and lower lips, while participants sipped from straight-sided flutes and outward-sloped coupes. This study found upper lip and lower lip muscle activity increased by 9% and 20% respectively, indicative of more pursed embouchures, when participants sipped from straight-sided flutes than from outward-sloped coupes.

One limitation that warrants particular consideration when evaluating Study 4 is that it remains unclear whether embouchure *causes* smaller sips, and, in turn, reductions in amount consumed. This preliminary study provided evidence that glass shape influences lip embouchures, and that glass shape influenced sip size (with smaller sips taken from straight-sided flutes vs outward-sloped coupes). It is not yet clear whether embouchure mediates the effect of glass shape on sip size, and further testing is warranted to examine this relationship further. One option for future research might be to manipulate embouchure through training, and to observe whether sip sizes change, regardless of glass shape. However, in the context of behaviour change research, exploring mechanism may only be "fundamentally a means to an end" (p. 390; Hollands, Marteau, et al., 2016).

Moderators of effects

Alcoholic vs non-alcoholic drinks

While several of the effects found in Chapters 3 - 6 seem to be robust to changes in the drink served (as discussed in the previous section), additional research is warranted to examine whether these findings apply beyond the two soft drinks used in these studies, and perhaps even more importantly, whether they apply to alcohol (note that while studies on alcohol were included in the literature review, all four empirical experiments used soft drinks). It is useful to consider whether and how the empirical findings reported in this thesis (i.e., Studies 1 – 4), might generalise to alcohol.

There are potential differences between these drink types, including motivations behind consumption, with quantity of alcohol consumed likely more salient than quantity of soft drinks consumed. When drinking alcohol, people may be less influenced by contextual cues such as glass size or shape, due to motivations around intoxication, though this hypothesis is speculative. The social and physical context of alcohol consumption also likely differs from that of soft drink consumption, with alcohol consumption more commonly associated with social gatherings and out-of-home settings such as bars, pubs, and restaurants. Further, this thesis presented several findings on midpoint bias – ability to estimate the half-way point of a drink – which indicated no evidence that it was associated with drinking speed (Studies 1 and 2) or amount consumed (Study 3). However, it is possible that the impact of midpoint bias might be more influential during alcohol intake. As suggested by Attwood and colleagues (2012), individuals may be less motivated to titrate consumption of soft drinks (in the absence of expected intoxication), and thus (biased) perceptual cues to volume may be less salient in this context.

The intoxicating effect of alcohol consumption is also important to consider in relation to effects and proposed mechanisms. Some findings, if replicated with alcohol, may have additional implications. For example, Study 2 (Chapter 4) demonstrated more decelerated consumption from outward-sloped glasses (characterised by a greater amount consumed in the first half of the drinking episode), relative to straight-sided glasses. Given that alcohol consumption leads to intoxication, the physiological effects of drinking at a decelerated rate may be more concerning. Further, in Chapter 2, a mechanism of affordance by angle of tilt was presented, proposing that outward-sloped glasses lead to a greater flow of liquid when tilted to the same degree as straight-sided glasses. Affordance of liquid flow might be one mechanism contributing to the effect of glass shape on amount consumed or micro-drinking behaviours such as sip size. However, the affordance by tilt effect suggests a degree of motor control that might be compromised as people become intoxicated. As a result, it may be less influential in driving effects of glass shape on consumption for alcohol, particularly when several drinks are consumed. Given the possible differences discussed, further research on the moderating effect of drink type (i.e., alcohol vs soft drinks) would be particularly beneficial.

117

Other contextual effects

There are also further contextual factors that might moderate effects of glassware design on drinking behaviours. Drinking in real-world drinking settings may differ from drinking in a laboratory setting, due to contextual effects which are hard to reproduce (Giboreau, 2018). There are a number of features of real-life drinking scenarios are not reflected in laboratory studies of drinking (e.g., the absence of facial electrodes). Further, the studies reported in this thesis (i.e., Studies 1 - 4) and many laboratory studies in the published literature (e.g., Attwood et al., 2012; Troy et al., 2017; Zupan, Pechey, et al., 2017) involve solitary drinking. This fails to reflect social nature of drinking, especially for the consumption of alcohol, where individuals may be influenced by social cues and signals of consumption from companions. Indeed, in an early observational study on contextual factors influencing drinking, individuals drinking in groups were found to drink more than when with one companion (Rosenbluth et al., 1978). Thus drinking with companions (vs solitary) might moderate (i.e., reduce) the impact of glassware design on behaviour. It is possible that this moderation would be stronger for alcohol (vs soft drinks), as cues to others' consumption are likely more salient in settings involving alcohol intake. Evidence supporting these hypotheses is awaited, though some experimental research has measured consumption of alcohol – manipulating portion/glass size – and found clustering based on the pairs participants drank in (Kersbergen et al., 2018).

A further contextual effect that might moderate the impact of glassware design on drinking is whether drinks are free-poured by consumers or served in fixed portions. For wine, larger wine glasses increase amount of wine purchased (and presumably consumed), though the effect is stronger in restaurants than in bars (Pilling et al., 2020). One hypothesis offered by the authors was that wine sold in restaurants is more likely to be sold by the bottle/carafe, requiring free-pouring by consumers (as opposed to bars, where it is more likely to be sold by the glass, in fixed portions). Thus the impact of increasing glass size is more potent when consumers are able to fill their glasses themselves. Nature of pouring thus might moderate the impact of glassware design on drinking (for wine, at least), with stronger effects when drinks are freely-poured.

Strengths of the thesis

Elucidating mechanism

This thesis includes the investigation of novel mechanisms that may underlie the effects of glassware design on drinking behaviours. As outlined in the literature review, while there is a wealth of evidence on the impacts of glassware design on how a drink is perceived (including perception of drink volumes, and

hedonic ratings), there is relatively less evidence linking these perceptions with drinking behaviours. In three studies, this thesis examined the relationship between perceptual bias in midpoint estimation and drinking behaviours, finding no evidence that midpoint bias was associated with total drinking time (Study 1 and Study 2) or amount consumed (Study 3). This thesis presented an additional promising but – as yet – relatively unstudied possibility, that glassware may cue or afford micro-drinking behaviours via i) angle of tilt and volume poured, and/or ii) lip embouchures. Taking the first of these possibilities, as described in Chapter 2, when glasses of different shapes are tipped, the flow of liquid from the rim differs. Taking straight-sided vs. outward-sloped glasses as an example, this is because for the same angle of tilt, straight-sided glasses afford relatively less flow of liquid than outward-sloped glasses do (see Figure 2.2 and Appendix 2.4). These findings are supported by Study 2 findings, that outward-sloped glasses lead to a more decelerated pattern of consumption (with more consumed in the early stages of the drinking episode), relative to straight-sided ones. However, this is a post-hoc hypothesis, and it is important to note that decelerated consumption may not have been driven by affordance of volumes poured from angles of tilt. Taking the second of these possibilities, we found evidence in a preliminary study that lip embouchures differ by glass shape (Study 4). The affordance of these embouchures may, in turn, influence drinking behaviour, but this hypothesis awaits further investigation. One strength of this thesis was the novelty in exploring this previously-unstudied phenomenon: it was the first to use facial EMG to measure lip muscle activity – an indicator of embouchure – during sipping from glasses of different shapes (Study 4). Lip muscle activity appears to be a valid measure for embouchure, as maximum voluntary contraction trials (asking participants to protrude their lips as hard as possible) led to the highest amplitudes of activity.

Future studies could attempt to isolate each mechanism, to determine whether the effect on drinking behaviour remains. For example, opaque glasses with different shapes, sizes, and fullness could be used, to reduce the impact of visual perception of drink volumes and midpoint bias, which has been found to vary by glass shape (e.g., Studies 1 and 2; Attwood et al., 2012; Troy et al., 2018). To "limit" the role of affordance via lip embouchures, which may vary depending on glass shape (e.g., Study 4), future studies might provide straws (which likely elicit the same lip embouchure regardless of the glass being sipped from). Should the effect of glassware design on measures of consumption remain, this might cast some doubt as to the importance of embouchure as a potential mechanism.

Robustness of findings

Findings demonstrate some consistent patterns across several measures of drinking behaviours (and physiological measures), using different study paradigms (e.g., participants drinking at their own pace, and bogus taste tests), and study designs (i.e., between-subjects in Studies 1 - 3, and within-subjects in Study

119

4). Many of these findings also appear to be consistent regardless of the exact drink served (i.e., carbonated in Studies 1 and 2, and non-carbonated in Studies 3 and 4), and importantly, regardless of the exact glassware used (i.e., tumblers in Studies 1 and 2 and stemmed flutes and coupes in Studies 3 and 4). The reliability of the research is further supported by high scores for inter-rater reliability, for each of the three studies which relied on video-coded drinking data (Studies 1 – 3). Across all four experiments, few participants accurately guessed the aims of the research, and excluding those who did had no impact on any of the analyses. Finally, all studies included the direct observation of drinking behaviours. This reflects a strength of the research, as while it is more labour intensive (and sometimes not feasible), observing behaviour directly is surely a more valid representation of that behaviour than self-reported survey data, which, as Baumeister and colleagues (2007) suggested, may be better described as the action of "finger movements, as in key strokes and pencil marks" (p.397).

Scientific transparency

In the context of growing concerns around the reproducibility of scientific research, and in particular around dissemination of research (e.g., Munafò et al., 2017), this set of studies followed recommendations for promoting open and transparent science, by pre-registering each study protocol (including study design and planned analyses) on a publicly-accessible database prior to data collection. Datasets have since been added, to allow other researchers to run their own analyses on the data (see Appendices 3.1; 4.1; 5.1; 6.1 for links to Open Science Framework repositories).

Limitations of the thesis

Rim diameter vs glass shape

One important limitation to the thesis relates to the difficulty determining which design features were responsible for the effects found in each study. As mentioned in previous chapters, and perhaps most importantly, rim diameter may be a problematic confound in this set of studies. For example, although Study 3 found an effect of glass shape (straight-sided vs. outward-sloped) on amount of soft drink consumed, the effect may have been driven by rim diameter which also varied with glass shape. The glasses used in Studies 3 and 4 were particularly extreme, with very narrow and extreme apertures (flutes and coupes). It is thus possible that the effects reported in this thesis were not driven by overall glass shape (including wall slope), but rather, the width of the glass aperture. This difficulty is common in studies of this nature, where manipulating features of glassware design (e.g., size or shape) often leads to differences

in glass fullness (keeping portion size constant; e.g., Study 3 and 4; Zupan, Pechey et al., 2017), when manipulating portion size (keeping fullness constant), glass size may vary (e.g., Kersbergen et al., 2018; Lawless et al., 2003), or when varying glass shape, in attempting to keep glass capacity constant, glass height can vary (Attwood et al., 2012). Thus, a limitation of this body of research is that it can be difficult to determine the exact feature of a drinks container that influences consumption.

Laboratory setting and Study samples

All four studies reported in this thesis were conducted in laboratory settings which, though advantageous for elucidating mechanism (one of the aims of this project), are unlikely to mimic real-life drinking environments. This is common: based on the studies reviewed in Chapter 2, few studies took place in real-life settings such as pubs and restaurants (but see Pechey et al., 2016; 2017; Troy et al., 2015; Clarke et al., 2019). It should be noted that measuring consumption directly is difficult in field studies – for food and drink - with selection and purchasing data used as a proxy for the amount consumed. Drinking in the laboratory may not reflect natural drinking behaviour, given the absence of drinking companions and other cues which mark real-life drinking settings, and the artificial nature of the tasks, which, at the extreme, involved the presence of facial electrodes. Many laboratory studies on drinking assess consumption of a single drink (e.g., Study 1 and 2; Attwood et al., 2012; Troy et al., 2017; Zupan, Pechey et al., 2017), and it is unclear whether any behaviour changes would persist when consuming multiple drinks. To address this in some way, Study 3 did serve several drinks, though in a bogus taste test paradigm which involved tasting multiple drinks. It remains to be seen how consumption during a bogus taste test would reflect drinking over a longer period when multiple drinks might be consumed in full (rather than tasted).

The studies were all conducted in testing rooms on campuses at the University of Cambridge, Cambridge, UK (Studies 1 – 3) and Macquarie University, North Ryde, Australia (Study 4). Given that recruitment was also conducted in these settings (i.e., through university mailing lists, posters and flyers on campus, etc.), the studies generally attracted undergraduate and postgraduate students and staff at these institutions. As a result, the samples may not be representative of the general population (UK or Australia), so it is unclear whether these findings would apply beyond the demographic reported in these studies.

Validity of measures

As discussed previously, it is possible that some of the measures used in these studies may lack validity. Study 1 and 2 measured total drinking time, while participants drank at their own pace while watching a documentary. While this paradigm has been used in several previous studies to assess total drinking time (e.g., Attwood et al., 2012; Troy et al., 2017; Zupan, Pechey et al., 2017), unlike bogus taste tests, which

have been found to be predictive of other measures of intake (e.g., Jones et al., 2016; Robinson et al., 2017), the validity of this measure as a proxy for consumption remains unstudied. Measuring total drinking time (i.e., by calculating the time elapsed from the start of the first sip until the end of the last sip) may also fail to capture important differences in drinking behaviours. This became apparent in Study 2, which failed to find an effect of glass shape on total drinking time, but did show evidence of differences in drinking, when the pattern of consumption was examined in more detail (i.e., when cumulative intake was plotted over time).

Studies 1 – 3 measured the impact of glass shape on midpoint bias – the ability to estimate a drink's midpoint. While these studies extend prior findings by using physical (as in Troy et al, 2018), rather than virtual (as in Troy et al., 2018; Attwood et al., 2012; Pechey et al., 2015) pours, there are some limitations to these findings that are worth noting. Ability to pour accurate drink volumes may vary, depending on the angle that glasses are observed from (Chen et al., 2017), as well as whether the glass is in the hand or on the table (Walker et al., 2014). Studies 1 – 3 obtained poured midpoint estimates without controlling for these factors, so estimates for midpoint bias may have been influenced by either or both of these factors (though, importantly, any effects were unlikely to have varied systematically with the intended manipulation of glass shape).

Implications for future research

The work presented in this thesis aids the design of future research studies on glassware design and drinking behaviours in a number of ways. As well as attempting to verify the preliminary empirical findings, further research should explore moderators of the reported effects of glassware design on drinking behaviours. As discussed, this is of particular interest given that there might be important differences in drinking behaviours relating to the type of drink being consumed (e.g., alcohol) and the setting and context of that consumption (e.g., out-of-home vs at home, solitary vs in groups, etc.). Further, rim diameter may confound the effects: there did appear to be some stronger effects in Study 3 (fluted glasses with narrow vs. wide diameters) vs. Study 1 and 2 (tumblers with similar diameters). Given previous evidence that short-wide vs. tall-narrow glasses may influence amount poured (e.g., Wansink & van Ittersum 2003; 2005; Caljouw & van Wijck, 2014), the extent to which the effects are driven by wall-angle (i.e., straight-sided vs. outward-sloped) or rim diameter (i.e., narrow vs. wide) warrants further investigation. As discussed, studies are required in settings which better reflect real-life drinking scenarios. Several studies on wine glass size have been conducted 'in the field', including pubs and restaurants (for summary of these studies see Pilling et al.,

2020). This may be one way to test the external validity of these effects, and enable estimates of the size of effects on amount consumed (or amount purchased, as a proxy for consumption).

On the basis of the evidence reported in the review it is clear that one particular area for future research concerns the extent to which macro-drinking behaviours, such as amount poured, may act as proxies for consumption. Studies might involve measurements of amounts poured, as well as number of drinks, to explore possible compensatory effects. For example, if less is poured into and consumed from smaller glasses, at what size might the use of smaller glasses increase consumption through compensatory behaviour? This is also important as it will aid the design of glassware which strikes the right balance, addressing the issue of when a glass becomes 'too small', such that compensatory behaviours are elicited.

This thesis also has implications for future research through the development of the Typology of micro- and macro- drinking behaviours (Table 2.1). This represents a starting point for characterising and understanding the micro-structure of a drinking episode, and could enable more systematic study and better reporting of these behaviours. By exploring micro-drinking behaviours, future studies might also illuminate *how* an intervention works to reduce intake, and/or give clues to important effects on drinking behaviours that may not translate to an effect on the 'macro' measure of drinking in a given study. Studying the micro-structure of drinking – using the typology presented here as a starting point – has the potential to develop understanding of these effects and in particular whether and how much they link to volume consumed. The Typology – which provides a framework for studying micro-drinking behaviours – as well as the empirical evidence presented in this thesis (Chapters 3 – 6) – suggest that some measures of drinking behaviours may be more informative than others. For example, across four studies, sip size appears to differ by glass shape. There were trends and effects when calculating 'mean sip size' (i.e., amount consumed / number of sips; Studies 1 - 3), and stronger effects when sip sizes were measured directly (Study 4). Studies involving sipping behaviours most often use average sip sizes, or simply count sips (e.g., Studies 1 – 3; Zupan, Pechey et al., 2017; Attwood et al., 2012), and the methods used to measure different micro-drinking behaviours may merit refinement. For example, using a more dynamic approach to studying drinking behaviour – including measuring 'drinking trajectories' or sip sizes over time – appears promising, as it gives a more complete picture of an individual's behaviour. This can be done by extracting volume information from images of the glass at intervals (as in Study 2; Cliceri et al., 2018), or by using a hidden weighing scales that record the weight of the glass after each sip (as in Study 4; Bennett et al., 2009). These approaches provide a more precise estimate of the dynamics of consumption (i.e., the drinking trajectory), illustrating how drinking behaviour might change over time. While eating behaviour has been characterised by a quadratic curve (e.g., Kissileff et al., 1982), the two studies reported here use quadratic (Cliceri et al., 2018)

and cubic (Study 2) curves to characterise drinking over time. The shape of these curves may also differ depending on conditions (such as glass shape). Thus, measuring both micro- and macro- drinking behaviours using both static and dynamic measures will provide a more complete picture of drinking which - in turn - may achieve a greater understanding of the effects of glassware design on consumption, though the significance of these drinking trajectories for overall consumption remains unstudied. While feasibility of measuring micro-drinking behaviours will vary depending on the available resources and key research questions of each study, future research might aim to incorporate measures of sip size, and in particular, obtain real-time estimates of sip size, and drinking trajectory, rather than averages.

Implications for implementation

While sufficient evidence for the impact of glassware upon consumption of drinks that harm health is awaited, it is timely to consider the routes by which any intervention might be implemented. There are several options including voluntary action, regulation, and legislation. Given possible barriers to change, including public acceptability of interventions and potential cost, researchers should continue to strive for evidence of the effectiveness and likely parameters for any given intervention involving glassware design. Such parameters include drink-type (e.g., alcoholic vs. non-alcoholic), drinking context (e.g., bar, restaurant, or home, with drinks pre-served or self-served), and drinking pattern when multiple drinks are consumed. Effect size estimates, generated from multiple studies, are also required to make predictions about the possible impact of an intervention at a population level. Together, these factors would help to form a robust evidence base which is required for any regulation-based policies. Further work is also required to assess feasibility for mass scale change, including evaluating the views of glass manufacturers, drinks manufacturers, publicans, parents, and consumers.

Importantly, to inform discussions around interventions and policy, the potential 'reach' of the intervention must be considered, including where and how implementation would take place, and the feasibility of achieving implementation. There are potential conflicts of interest with pubs, bars, and restaurants (i.e., out-of-home drinking settings): the financial and business interests of the hospitality and drinks industries are unlikely to align with public health interests, and voluntary pledges as part of public-private partnerships have previously been ineffective at reducing alcohol consumption (e.g., Knai et al., 2015). Mass voluntary adoption of glassware designed to reduce intake might therefore be unlikely. Policies may also be resisted by producers and retailers of the drinks targeted by the policy (Freudenberg, 2014; Pomeranz & Brownell, 2014). If regulation is the goal, further work is required to determine the exact specifications of glassware

that could be effective at reducing intake of health-harming drinks. Evidence-based glassware design specifications would then need to be communicated to relevant parties to ensure successful adoption, and potential loopholes should be considered, given the conflict of interests. Further, it is important to consider the proportion of consumption that *could* be targeted by an intervention. If the focus of the intervention is out-of-home drinking settings, the proportion of drinking that takes place in these settings would need quantifying, to inform how effective an intervention could be at a population level. Survey evidence quantifying alcohol consumption in Great Britain in 2009-11 indicates that the most common alcohol consumption practice was 'light drinking at home with a partner' (accounting for 20% of occasions), with up to 70% of drinking occasions taking place in home settings (Ally et al., 2016).

Routes to implementation may also be influenced by whether an intervention is constrained by drink type (e.g., alcoholic and non-alcoholic beverages with high levels of sugar). As well as determining which drinks should or could be targeted, the feasibility of implementing this – including how it would be regulated and implemented in out-of-home settings – warrants careful consideration. If glassware was substituted without consideration of drink type, there could be unintended effects. An intervention which reduces water consumption would not confer any benefit to health; it would likely achieve the opposite given the importance of water for hydration (e.g., Jéquier & Constant, 2010; Benelam & Wyness, 2010). Relatedly, an intervention designed to reduce intake of soft drinks may have unintended consequences for overall fluid intake. While global reduction is beneficial for alcohol intake, for soft drinks, the picture is somewhat less clear. Certain groups might not benefit from an intervention designed to reduce intake of sugary drinks, as global reduction in fluid intake (even for high-sugar beverages) could have unintended consequences. Older adults, for example, are more likely to be dehydrated, and it is sometimes necessary to encourage consumption of sugary drinks to achieve sufficient liquid intake (e.g., Ferry, 2005). Reducing fluid intake in this population might therefore have negative consequences for their health. Thus the benefits of any intervention focussed on reducing consumption of soft drinks must be balanced against possible harms, and these considerations must inform discussion around feasibility and population-level implementation.

In summary, the first step towards a policy involving standardised or regulated glassware is developing a robust evidence base, including the likely effect size of any given intervention. The likelihood of glassware-design based policies is also dependent on addressing the above concerns and issues surrounding feasibility of implementation. There are several policy options for reducing sugary-drink and/or alcohol intake, including public health campaigns (e.g., provide information about risks), taxation (e.g., soft drinks industry levy introduced in the UK in 2018, commonly known as the "Sugar Tax"), and other physical micro-environment ("nudge") interventions (e.g., regulate portion size or availability of certain products). As

125

discussed in early chapters, one important consideration is public acceptability – i.e., how popular/acceptable an intervention is. This appears to differ by intervention type, with less intrusive – possibly less effective – interventions (e.g., dietary counselling) rated as more acceptable (Diepeveen, Ling, Suhrcke, Roland & Marteau, 2013; Petrescu, Hollands, Couturier, Ng & Marteau 2016; Reynolds et al., 2019). Communicating evidence that an intervention is effective appears to increase support for that intervention (e.g., Reynolds et al., 2019). While it is possibly too early to discern whether government would (or, indeed, should) regulate glassware, perhaps one of the key challenges to implementation is to "change minds" about changing behaviour, with a focus on changing *environments* not *individuals* (Marteau, 2018).

Conclusions

This thesis addressed three aims. First, to review evidence on the impacts of glassware design (size, shape, and/or resulting fullness) on consumption of alcoholic and non-alcoholic drinks, second, to conduct experiments investigating one intervention for soft drink consumption involving glassware design (straight-sided vs sloped), and third, to develop and test hypotheses about mechanisms that may underlie effects of glassware design on drinking behaviours.

These aims were achieved in a series of studies that tested novel hypotheses about potential underlying mechanisms and added robust evidence to a limited evidence base identified through systematic review. The findings provide promising evidence that glassware design influences drinking behaviour, including how much we consume, and the 'mechanics' of that consumption. This thesis provides a base from which research can move forward to further address these aims, which can inform effective, novel interventions contributing to the many needed to reduce consumption of health-harming drinks.

References

Ally, A. K., Lovatt, M., Meier, P. S., Brennan, A., & Holmes, J. (2016). Developing a social practice-based typology of British drinking culture in 2009–2011: implications for alcohol policy analysis. Addiction, 111(9), 1568-1579.

Almiron-Roig, E., Tsiountsioura, M., Lewis, H. B., Wu, J., Solis-Trapala, I., & Jebb, S. A. (2015). Large portion sizes increase bite size and eating rate in overweight women. *Physiology & behavior*, *139*, 297-302.

Andrade, A. M., Greene, G. W., & Melanson, K. J. (2008). Eating slowly led to decreases in energy intake within meals in healthy women. *Journal of the American Dietetic Association, 108*(7), 1186-1191.

Attwood, A. S., Scott-Samuel, N. E., Stothart, G., & Munafò, M. R. (2012). Glass shape influences consumption rate for alcoholic beverages. *PLOS ONE*, *7*(8), e43007.

Basmajian, J. V., & White, E. R. (1973). Neuromuscular control of trumpeters' lips. *Nature, 241*(5384), 70.

Bellisle, F., & Le Magnen, J. (1981). The structure of meals in humans: eating and drinking patterns in lean and obese subjects. *Physiology & Behavior*, *27*(4), 649-658.

Benelam, B., & Wyness, L. (2010). Hydration and health: a review. Nutrition Bulletin, 35(1), 3-25.

Bennett, J. W., Van Lieshout, P. H., Pelletier, C. A., & Steele, C. M. (2009). Sip-sizing behaviors in natural drinking conditions compared to instructed experimental conditions. *Dysphagia*, *24*(2), 152-158.

Blackman, D. E. (1985). Contemporary Behaviourism: A Brief Overview. In C. F. Lowe, M. Richelle, D. E. Blackman, C. M. Bradshaw (Eds.), *Behaviour Analysis and Contemporary Psychology* (pp. 259-281). London: Lawrence Erlbaum Associates Ltd.

Bland, J. M., & Altman, D. G. (1996). Transformations, means, and confidence intervals. *BMJ, 312*(7038), 1079.

Bolhuis, D. P., Lakemond, C. M., de Wijk, R. A., Luning, P. A., & de Graaf, C. (2013). Consumption with large sip sizes increases food intake and leads to underestimation of the amount consumed. *PLOS ONE*, *8*(1), e53288.

British wine glasses have got bigger over the years. (2017, December 23). *The Economist*. Retrieved from https://www.economist.com/science-and-technology/2017/12/23/british-wine-glasses-have-got-bigger-over-the-years.

Brocklebank, L (2019). Straight-sided glasses for alcohol reduction. *ISRCTN*. https://doi.org/10.1186/ISRCTN10456720

Brunstrom, J. M., Tribbeck, P. M., & MacRae, A. W. (2000). The role of mouth state in the termination of drinking behavior in humans. *Physiology & behavior*, *68*(4), 579-583.

Caljouw, S. R., & van Wijck, R. (2014). Is the glass half full or half empty? How to reverse the effect of glass elongation on the volume poured. *PLOS ONE*, *9*(10), e109374.

Cannon, P. R., Li, B., & Grigor, J. M. (2017). Predicting subjective liking of bitter and sweet liquid solutions using facial electromyography during emptying, swirling, and while thinking about the taste.

Carr, E. W., Winkielman, P., & Oveis, C. (2014). Transforming the mirror: Power fundamentally changes facial responding to emotional expressions. *Journal of Experimental Psychology: General*, *143*(3), 997.

Chandon, P., & Ordabayeva, N. (2009). Supersize in one dimension, downsize in three dimensions: Effects of spatial dimensionality on size perceptions and preferences. *Journal of Marketing Research*, *46*(6), 739-753.

Chandon, P., & Ordabayeva, N. (2017). The accuracy of less: Natural bounds explain why quantity decreases are estimated more accurately than quantity increases. *Journal of Experimental Psychology: General*, *146*(2), 250.

Chazelas, E., Srour, B., Desmetz, E., Kesse-Guyot, E., Julia, C., Deschamps, V., ... & Deschasaux, M. (2019). Sugary drink consumption and risk of cancer: results from NutriNet-Santé prospective cohort. *BMJ*, *366*, l2408.

Chen, Y. L., & Lee, Y. C. (2019). Effects of lighting, liquid color, and drink container type on volume perception. *i-Perception*, *10*(5), 2041669519880916.

Chen, Y. L., Lee, Y. C., Lee, T. Y., & Chen, M. Z. (2017). Effect of Viewing Angle on Volume Perceptions for Paired Tumblers. *i-Perception*, *8*(4), 2041669517719296.

Clarke, N., Pechey, R., Pilling, M., Hollands, G. J., Mantzari, E., & Marteau, T. M. (2019). Wine glass size and wine sales: four replication studies in one restaurant and two bars. *BMC research notes*, *12*(1), 426.

Cliceri, D., Petit, E., Garrel, C., Monteleone, E., & Giboreau, A. (2018). Effect of glass shape on subjective and behavioral consumer responses in a real-life context of drinking consumption. *Food Quality and Preference*, *64*, 187-191.

Cliff, M. A. (2001). Influence of wine glass shape on perceived aroma and colour intensity in wines. Journal of Wine Research, 12(1), 39-46.

de Graaf, C. (2011). Why liquid energy results in overconsumption. *Proceedings of the Nutrition Society*, *70*(2), 162-170.

De Visser, R. O., & Birch, J. D. (2012). My cup runneth over: Young people's lack of knowledge of low-risk drinking guidelines. *Drug and alcohol review*, *31*(2), 206-212.

Department of Health. (2016a). Childhood Obesity: A Plan for Action. Available from: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/546588/Childhood_obesity_2016__2__acc.pdf

Department of Health. (2016b). UK Chief Medical Officers' Alcohol Guidelines Review. Summary of the Proposed New Guidelines. Available from:

https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/489795/summary.pdf

Department of Health. (2010). Healthy lives, healthy people: Our strategy for public health in England. Available from: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/216096/dh_127424.pdf

Diepeveen, S., Ling, T., Suhrcke, M., Roland, M., & Marteau, T. M. (2013). Public acceptability of government intervention to change health-related behaviours: a systematic review and narrative synthesis. *BMC Public Health*, *13*(1), 756.

Doulah, A., Farooq, M., Yang, X., Parton, J., McCrory, M. A., Higgins, J. A., & Sazonov, E. (2017). Meal microstructure characterization from sensor-based food intake detection. *Frontiers in nutrition*, *4*, 31.

Ferriday, D., Bosworth, M. L., Godinot, N., Martin, N., Forde, C. G., Van Den Heuvel, E., ... & Brunstrom, J. M. (2016). Variation in the oral processing of everyday meals is associated with fullness and meal size; a potential nudge to reduce energy intake?. *Nutrients*, *8*(5), 315.

Ferry, M. (2005). Strategies for ensuring good hydration in the elderly. *Nutrition Reviews*, *63*(6), S22-9.

Foy, D. W., & Simon, S. J. (1978). Alcoholic drinking topography as a function of solitary versus social context. *Addictive Behaviors*, *3*(1), 39-41.

French, D. P., Cameron, E., Benton, J. S., Deaton, C., & Harvie, M. (2017). Can communicating personalised disease risk promote healthy behaviour change? A systematic review of systematic reviews. *Annals of Behavioral Medicine*, *51*(5), 718-729.

Freudenberg, N. (2014). Lethal but legal: corporations, consumption, and protecting public health. Oxford University Press.

Fridlund, A. J., & Cacioppo, J. T. (1986). Guidelines for human electromyographic research. *Psychophysiology, 23*(5), 567-589.

Gakidou, E., Afshin, A., Abajobir, A. A., Abate, K. H., Abbafati, C., Abbas, K. M., ... & Abu-Raddad, L. J. (2017). Global, regional, and national comparative risk assessment of 84 behavioural, environmental and occupational, and metabolic risks or clusters of risks, 1990–2016: a systematic analysis for the Global Burden of Disease Study 2016. *The Lancet*, *390*(10100), 1345-1422.

Giboreau (2018). Situational Factors and the Design of In Situ Evaluations. In G. Ares, P. Varela (Eds.), *Methods in Consumer Research, Volume 2: Alternative Approaches and Special Applications* (pp. 109-116). Woodhead Publishing.

Gibson, J.J. (1979). *The Ecological Approach to Visual Perception*. Boston: Houghton Mifflin.

Gotouda, A., Yamaguchi, T., Okada, K., Matsuki, T., Gotouda, S., & Inoue, N. (2007). Influence of playing wind instruments on activity of masticatory muscles. *Journal of oral rehabilitation*, *34*(9), 645-651.

Grech, A., & Allman-Farinelli, M. (2015). A systematic literature review of nutrition interventions in vending machines that encourage consumers to make healthier choices. *Obesity reviews*, *16*(12), 1030-1041.

Hagger, M. S. (2016). Non-conscious processes and dual-process theories in health psychology. *Health psychology review, 10*(4), 375.

Hill, K. M., Foxcroft, D. R., & Pilling, M. (2018). "Everything is telling you to drink": understanding the functional significance of alcogenic environments for young adult drinkers. *Addiction Research & Theory*, *26*(6), 457-464.

Hill, K. M., Pilling, M., & Foxcroft, D. R. (2018). Alcohol-related affordances and group subjectivities: A Q-Methodology study. *Drugs: Education, Prevention and Policy*, *25*(5), 376-385.

Hollands, G. J., Bignardi, G., Johnston, M., Kelly, M. P., Ogilvie, D., Petticrew, M., ... & Marteau, T. M. (2017). The TIPPME intervention typology for changing environments to change behaviour. *Nature Human Behaviour*, *1*(8), 0140.

131

Hollands, G. J., French, D. P., Griffin, S. J., Prevost, A. T., Sutton, S., King, S., & Marteau, T. M. (2016). The impact of communicating genetic risks of disease on risk-reducing health behaviour: systematic review with meta-analysis. *BMJ*, *352*, i1102.

Hollands, G. J., Marteau, T. M., & Fletcher, P. C. (2016). Non-conscious processes in changing health-related behaviour: a conceptual analysis and framework. *Health Psychology Review*, *10*(4), 381-394.

Hollands, G. J., Shemilt, I., Marteau, T. M., Jebb, S. A., Kelly, M. P., Nakamura, R., ... & Ogilvie, D. (2013). Altering micro-environments to change population health behaviour: towards an evidence base for choice architecture interventions. *BMC public health*, *13*(1), 1218.

Hollands, G. J., Shemilt, I., Marteau, T. M., Jebb, S. A., Lewis, H. B., Wei, Y., ... & Ogilvie, D. (2015). Portion, package or tableware size for changing selection and consumption of food, alcohol and tobacco. *The Cochrane database of systematic reviews*, (9).

Iborra-Bernad, C., Wathelet, O., & Giboreau, A. (2012) Measuring bread use in a French restaurant. A naturalistic approach: Grid analysis for the French culture. In A. Spink, F. Grieco, O. Krips, L. Loijens, L. Noldus, P. Zimmerman (Eds.) *Measuring behaviour 2012, 8th International Conference on Methods and Techniques in Behavioural Research,* pp. 434-438. Available from: http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.388.1603&rep=rep1&type=pdf#page=434

James, W. (1899). Talks to Teachers on Psychology: And to Students on Some of Life's Ideals (New York, NY: Henry Holt), 65.

Jéquier, E., & Constant, F. (2010).Water as an essential nutrient: the physiological basis of hydration. *Eur J Clin Nutr* 64, 115–123.

Jones, A., Button, E., Rose, A. K., Robinson, E., Christiansen, P., Di Lemma, L., & Field, M. (2016). The ad-libitum alcohol 'taste test': secondary analyses of potential confounds and construct validity. *Psychopharmacology*, *233*(5), 917-924.

Kairalla, J. A., Coffey, C. S., Thomann, M. A., & Muller, K. E. (2012). Adaptive trial designs: a review of barriers and opportunities. *Trials*, *13*(1), 145.

Kampfer, K., Leischnig, A., Ivens, B. S., & Spence, C. (2017). Touch-flavor transference: Assessing the effect of packaging weight on gustatory evaluations, desire for food and beverages, and willingness to pay. *PLOS ONE*, *12*(10).

Kersbergen, I., Oldham, M., Jones, A., Field, M., Angus, C., & Robinson, E. (2018). Reducing the standard serving size of alcoholic beverages prompts reductions in alcohol consumption. *Addiction*.

Kissileff, H. R., Klingsberg, G., & Van Itallie, T. B. (1980). Universal eating monitor for continuous recording of solid or liquid consumption in man. *American Journal of Physiology-Regulatory, Integrative and Comparative Physiology*, *238*(1), R14-R22.

Kissileff, H. R., Thornton, J., & Becker, E. (1982). A quadratic equation adequately describes the cumulative food intake curve in man. *Appetite*, *3*(3), 255-272.

Knai, C., Petticrew, M., Durand, M. A., Eastmure, E., & Mays, N. (2015). Are the Public Health Responsibility Deal alcohol pledges likely to improve public health? An evidence synthesis. *Addiction*, *110*(8), 1232-1246.

Knibb, G., Jones, A., & Christiansen, P. (2018). Pour Guess: The Effect of Glass Shape and an Ice Substitute on Alcohol Pouring and Estimation. *Alcoholism: Clinical and Experimental Research*, *42*(7), 1228-1236.

Krider, R. E., Raghubir, P., & Krishna, A. (2001). Pizzas: π or square? Psychophysical biases in area comparisons. *Marketing Science*, *20*(4), 405-425.

Krop, E. M., Hetherington, M. M., Nekitsing, C., Miquel, S., Postelnicu, L., & Sarkar, A. (2018). Influence of oral processing on appetite and food intake–A systematic review and meta-analysis. *Appetite*, *125*, 253-269.

Lancaster, G.A., Dodd, S., & Williamson, P.R. (2004). Design and analysis of pilot studies: recommendations for good practice. *J Eval Clin Pract*, 10, 307–312.

Langfield, T., Pechey, R., Pilling, M., & Marteau, T. M. (2018). Impact of glass shape on time taken to drink a soft drink: A laboratory-based experiment. *PLOS ONE*, *13*(8), e0202793.

Langfield, T., Pechey, R., Pilling, M., & Marteau, T. M. (under review). Glassware design and drinking behaviours: a review of impact and mechanisms using a new typology of drinking behaviours. *Health Psychology Review*.

Langfield, T., Pechey, R., Gilchrist, P. T., Pilling, M. A., & Marteau, T. M. (2020). Glass shape influences drinking behaviours in three laboratory experiments. *Scientific Reports, 10*(1), 1-11.

Larsen, J. T., Norris, C. J., & Cacioppo, J. T. (2003). Effects of positive and negative affect on electromyographic activity over zygomaticus major and corrugator supercilii. *Psychophysiology, 40*(5), 776-785.

Lawless, H. T., Bender, S., Oman, C., & Pelletier, C. (2003). Gender, age, vessel size, cup vs.. straw sipping, and sequence effects on sip volume. *Dysphagia*, *18*(3), 196-202.

Liger-Belair, G., Cilindre, C., Gougeon, R. D., Lucio, M., Gebefügi, I., Jeandet, P., & Schmitt-Kopplin, P. (2009). Unraveling different chemical fingerprints between a champagne wine and its aerosols. *Proceedings of the National Academy of Sciences*, *106*(39), 16545-16549.

Maggioni, E., Risso, P., Olivero, N., & Gallace, A. (2015). The effect of a container's weight on the perception of mineral water. *Journal of sensory studies*, *30*(5), 395-403.

Malik, V. S., Popkin, B. M., Bray, G. A., Després, J. P., & Hu, F. B. (2010). Sugar-sweetened beverages, obesity, type 2 diabetes mellitus, and cardiovascular disease risk. *Circulation*, *121*(11), 1356-1364.

Marchiori, D. R., Adriaanse, M. A., & De Ridder, D. T. (2017). Unresolved questions in nudging research: Putting the psychology back in nudging. *Social and Personality Psychology Compass*, *11*(1), e12297.

Marteau, T. M. (2018). Changing minds about changing behaviour. *The Lancet*, *391*(10116), 116-117.

Marteau, T. M., Hollands, G. J., & Fletcher, P. C. (2012). Changing human behavior to prevent disease: the importance of targeting automatic processes. *science*, *337*(6101), 1492-1495.

Maynard, O. M., Langfield, T., Attwood, A. S., Allen, E., Drew, I., Votier, A., & Munafò, M. R. (2018). No impact of calorie or unit information on ad libitum alcohol consumption. *Alcohol and Alcoholism*, *53*(1), 12-19.

McGill, R., Anwar, E., Orton, L., Bromley, H., Lloyd-Williams, F., O'Flaherty, M., ... & Allen, K. (2015). Are interventions to promote healthy eating equally effective for all? Systematic review of socioeconomic inequalities in impact. *BMC public health*, *15*(1), 457.

McGowan, J. G., Petticrew, M. Rutter, H., Pearson-Stuttard, J., White, M., Marteau, T. M. (2018) Changing behaviour for a healthier population. In J. Pearson-Stuttard (Ed.), *Annual Report of the Chief Medical Officer: Health 2040 – Better Health Within Reach*, pp. 1-28. Available from: https://www.gov.uk/government/publications/chief-medical-officer-annual-report-2018-better-health-within-reach

McGrenere, J., & Ho, W. (2000). Affordances: Clarifying and evolving a concept. In *Graphics interface*, 179-186.

Michie, S., Carey, R., Johnston, M., Rothman, A. J., Kelly, M., Davidson, K., & de Bruin, M. (2016). From theory-inspired to theory-based interventions: linking behaviour change techniques to their mechanisms of action. *Eur Health Psychol*, *18*, 395.

Mirabito, A., Oliphant, M., Van Doorn, G., Watson, S., & Spence, C. (2017). Glass shape influences the flavour of beer. *Food Quality and Preference*, *62*, 257-261.

Murray, K. A., Larson, C. R., & Logemann, J. A. (1998). Electromyographic response of the labial muscles during normal liquid swallows using a spoon, a straw, and a cup. *Dysphagia*, *13*(3), 160-166.

Norman, D. (1988). *The psychology of everyday things*. New York: Basic Books.

Norman, D. (2013). *The design of everyday things*. MIT Press.

135

Ohkuma, T., Hirakawa, Y., Nakamura, U., Kiyohara, Y., Kitazono, T., & Ninomiya, T. (2015). Association between eating rate and obesity: a systematic review and meta-analysis. *International journal of obesity*, *39*(11), 1589-1596.

Olivier, J., Johnson, W. D., & Marshall, G. D. (2008). The logarithmic transformation and the geometric mean in reporting experimental IgE results: what are they and when and why to use them?. *Annals of Allergy, Asthma & Immunology*, *100*(4), 333-337.

Pechey, R., Attwood, A. S., Couturier, D. L., Munafò, M. R., Scott-Samuel, N. E., Woods, A., & Marteau, T. M. (2015). Does glass size and shape influence judgements of the volume of wine?. *PLOS ONE*, *10*(12), e0144536.

Pechey, R., Couturier, D. L., Hollands, G. J., Mantzari, E., Munafò, M. R., & Marteau, T. M. (2016). Does wine glass size influence sales for on-site consumption? A multiple treatment reversal design. *BMC public health*, *16*(1), 390.

Pechey, R., Couturier, D. L., Hollands, G. J., Mantzari, E., Zupan, Z., & Marteau, T. M. (2017). Wine glass size and wine sales: a replication study in two bars. *BMC research notes*, *10*(1), 287.

Petrescu, D. C., Hollands, G. J., Couturier, D. L., Ng, Y. L., & Marteau, T. M. (2016). Public acceptability in the UK and USA of nudging to reduce obesity: the example of reducing sugar-sweetened beverages consumption. *PLOS ONE*, *11*(6), e0155995.

Piaget, J. (1967) *Six Psychological Studies*. New York: Random House.

Pilling, M., Clarke, N., Pechey, R., Hollands, G. J., & Marteau, T. M. (2020). The effect of wine glass size on volume of wine sold: A mega-analysis of studies in bars and restaurants. *Addiction*.

Pomeranz, J. L., & Brownell, K. D. (2014). Can government regulate portion sizes?. *The New England journal of medicine*, *371*(21), 1956.

Pudel, V. (1971). Food-Dispenser eine Methode zur Untersuchung des ,spontanen 'Appetitverhaltens. *Zeitschrift für Ernährungswissenschaft, 10*(4), 382-393.

Raghubir, P., & Krishna, A. (1999). Vital dimensions in volume perception: Can the eye fool the stomach?. *Journal of Marketing research*, 313-326.

Raudenbush, B., Meyer, B., Eppich, W., Corley, N., & Petterson, S. (2002). Ratings of pleasantness and intensity for beverages served in containers congruent and incongruent with expectancy. *Perceptual and motor skills*, *94*(2), 671-674.

Reynolds, J. P., Archer, S., Pilling, M., Kenny, M., Hollands, G. J., & Marteau, T. M. (2019). Public acceptability of nudging and taxing to reduce consumption of alcohol, tobacco, and food: A population-based survey experiment. *Social Science & Medicine*, *236*, 112395.

Robinson, E., Almiron-Roig, E., Rutters, F., de Graaf, C., Forde, C. G., Tudur Smith, C., ... & Jebb, S. A. (2014). A systematic review and meta-analysis examining the effect of eating rate on energy intake and hunger. *The American journal of clinical nutrition*, *100*(1), 123-151.

Robinson, E., Haynes, A., Hardman, C. A., Kemps, E., Higgs, S., & Jones, A. (2017). The bogus taste test: Validity as a measure of laboratory food intake. *Appetite*, *116*, 223-231.

Room, R., Babor, T., & Rehm, J. (2005). Alcohol and public health. *The Lancet*, *365*(9458), 519-530.

Rosenbluth, J., Nathan, P. E., & Lawson, D. M. (1978). Environmental influences on drinking by college students in a college pub: Behavioral observation in the natural environment. *Addictive Behaviors*, *3*(2), 117-121.

Rozin, P., Scott, S., Dingley, M., Urbanek, J. K., Jiang, H., & Kaltenbach, M. (2011) Nudge to nobesity I: Minor changes in accessibility decrease food intake. *Judgment and Decision Making, 6,* 323–332.

Scientific Advisory Committee on Nutrition. (2015). *Draft Carbohydrates and Health Report*. Available from https://www.gov.uk/government/publications/sacn-carbohydrates-and-health-report.

Shah, M., Schroeder, R., Winn, W., & Adams-Huet, B. (2011). A pilot study to investigate the effect of plate size on meal energy intake in normal weight and overweight/obese women. *Journal of Human Nutrition and Dietetics*, *24*(6), 612-615.

137

Sheeran, P., Klein, W. M., & Rothman, A. J. (2017). Health behavior change: Moving from observation to intervention. *Annual review of psychology*, *68*, 573-600.

Singh, G. M., Micha, R., Khatibzadeh, S., Lim, S., Ezzati, M., & Mozaffarian, D. (2015). Estimated global, regional, and national disease burdens related to sugar-sweetened beverage consumption in 2010. *Circulation*, *132*(8): 639–66. Available from: https://doi.org/10.1161/CIRCULATIONAHA.114.010636.

Skinner, B. F. (1974). *About behaviorism*. New York: Knopf.

Spence, C. (2011). Crystal clear or gobbletigook. *World of Fine Wine*, *33*, 96-101.

Spence, C., & Van Doorn, G. (2017). Does the shape of the drinking receptacle influence taste/flavour perception? A review. *Beverages*, *3*(3), 33.

Spence, C., & Wan, X. (2015). Beverage perception and consumption: The influence of the container on the perception of the contents. *Food quality and preference*, *39*, 131-140.

Stafford, L. D., & Salmon, J. (2017). Alcohol health warnings can influence the speed of consumption. *Journal of Public Health, 25*(2), 147-154.

Stanaway, J. D., Afshin, A., Gakidou, E., Lim, S. S., Abate, D., Abate, K. H., ... & Abdela, J. (2018). Global, regional, and national comparative risk assessment of 84 behavioural, environmental and occupational, and metabolic risks or clusters of risks for 195 countries and territories, 1990–2017: a systematic analysis for the Global Burden of Disease Study 2017. *The Lancet*, *392*(10159), 1923-1994.

Stead, M., Angus, K., Macdonald, L., & Bauld, L. (2014). Looking into the glass: Glassware as an alcohol marketing tool, and the implications for policy. *Alcohol and alcoholism*, *49*(3), 317-320.

Strack, F., & Deutsch, R. (2004). Reflective and impulsive determinants of social behavior. *Personality and social psychology review, 8*(3), 220-247.

Te Morenga, L., Mallard, S., & Mann, J. (2013). Dietary sugars and body weight: systematic review and meta-analyses of randomised controlled trials and cohort studies. *BMJ*, *346*, e7492.

Thaler, R. & Sunstein, C.R. (2008). *Nudge: Improving decisions about health, wealth, and happiness*. New Haven: Yale University Press.

Thomas, J. M., Dourish, C. T., & Higgs, S. (2015). Effects of awareness that food intake is being measured by a universal eating monitor on the consumption of a pasta lunch and a cookie snack in healthy female volunteers. Appetite, 92, 247-251.

Tomaszewski, R. J., Strickler, D. P., & Maxwell, W. A. (1980). Influence of social setting and social drinking stimuli on drinking behavior. *Addictive behaviors*, *5*(3), 235-240.

Troy, D. M., Attwood, A. S., Maynard, O. M., Scott-Samuel, N. E., Hickman, M., Marteau, T. M., & Munafò, M. R. (2017). Effect of glass markings on drinking rate in social alcohol drinkers. *European journal of public health*, *27*(2), 352-356.

Troy, D. M., Attwood, A. S., Maynard, O. M., Scott-Samuel, N. E., Hickman, M., Woods, A., & Munafò, M. R. (2018). Effect of glass shape on the pouring accuracy of liquid volume. *PLOS ONE*, *13*(10), e0204562.

Troy, D. M., Maynard, O. M., Hickman, M., Attwood, A. S., & Munafò, M. R. (2015). The effect of glass shape on alcohol consumption in a naturalistic setting: a feasibility study. *Pilot and feasibility studies*, *1*(1), 27.

U.S. Department of Health and Human Services and U.S. Department of Agriculture. 2015–2020. (2015). Dietary Guidelines for Americans. 8th Edition. December 2015. Available from: http://health.gov/dietaryguidelines/2015/guidelines/

Vaiman, M., & Eviatar, E. (2009). Surface electromyography as a screening method for evaluation of dysphagia and odynophagia. *Head & face medicine*, *5*(1), 9.

Vaiman, M., Eviatar, E., & Segal, S. (2004). Surface electromyographic studies of swallowing in normal subjects: a review of 440 adults. Report 1. Quantitative data: timing measures. *Otolaryngology-Head and Neck Surgery, 131*(4), 548-555.

Vaiman, M., Nahlieli, O., & Eliav, E. (2006). Oynophagia in patients after dental extraction: surface electromyography study. *Head & face medicine*, *2*(1), 34.

Van Boxtel, A. (2010). "Facial EMG as a tool for inferring affective states" in *Proceedings of Measuring Behaviour 2010* (Eindhoven, Measuring Behaviour), 104–108.

Van Doorn, G., Woods, A., Levitan, C. A., Wan, X., Velasco, C., Bernal-Torres, C., & Spence, C. (2017). Does the shape of a cup influence coffee taste expectations? A cross-cultural, online study. *Food Quality and Preference*, *56*, 201-211.

Vasiljevic, M., Couturier, D. L., Frings, D., Moss, A. C., Albery, I. P., & Marteau, T. M. (2018). Impact of lower strength alcohol labeling on consumption: A randomized controlled trial. *Health Psychology*.

Wakefield, M. A., Loken, B., & Hornik, R. C. (2010). Use of mass media campaigns to change health behaviour. *The Lancet*, *376*(9748), 1261-1271.

Walker, D., Smarandescu, L., & Wansink, B. (2014). Half full or empty: Cues that lead wine drinkers to unintentionally overpour. *Substance Use & Misuse*, *49*(3), 295-302.

Wan, X., Zhou, X., Woods, A. T., & Spence, C. (2015). Influence of the glassware on the perception of alcoholic drinks. *Food quality and preference*, *44*, 101-110.

Wansink, B., & Van Ittersum, K. (2003). Bottoms up! The influence of elongation on pouring and consumption volume. *Journal of consumer research*, *30*(3), 455-463.

Wansink, B., & Van Ittersum, K. (2005). Shape of glass and amount of alcohol poured: comparative study of effect of practice and concentration. *BMJ*, *331*(7531), 1512-1514.

Warner, K. E., & Balagura, S. (1975). Intrameal eating patterns of obese and nonobese humans. *Journal of comparative and physiological psychology, 89*(7), 778.

Webb, T. L., & Sheeran, P. (2006). Does changing behavioral intentions engender behavior change? A meta-analysis of the experimental evidence. *Psychological bulletin*, *132*(2), 249.

Weijzen, P. L., Smeets, P. A., & de Graaf, C. (2009). Sip size of orangeade: effects on intake and sensory-specific satiation. *British Journal of Nutrition*, *102*(7), 1091-1097.

Westerterp-Plantenga, M. S., Wouters, L., & Ten Hoor, F. (1991). Restrained eating, obesity, and cumulative food intake curves during four-course meals. *Appetite*, *16*(2), 149-158.

White, A. M., Kraus, C. L., Flom, J. D., Kestenbaum, L. A., Mitchell, J. R., Shah, K., & Swartzwelder, H. S. (2005). College students lack knowledge of standard drink volumes: implications for definitions of risky drinking based on survey data. *Alcoholism: Clinical and Experimental Research*, *29*(4), 631-638.

White, A. M., Kraus, C. L., McCracken, L. A., & Swartzwelder, H. S. (2003). Do college students drink more than they think? Use of a free-pour paradigm to determine how college students define standard drinks. *Alcoholism: Clinical and Experimental Research*, *27*(11), 1750-1756.

White, E. R., & Basmajian, J. V. (1973). Electromyography of lip muscles and their role in trumpet playing. *Journal of Applied Physiology*, *35*(6), 892-897.

Wittes, J., & Brittain, E. (1990). The role of internal pilot studies in increasing the efficiency of clinical trials. *Statistics in Medicine*, *9*(1-2), 65-72.

World Health Organization. (2015). *Guideline: sugars intake for adults and children*. World Health Organization. Available from: https://apps.who.int/iris/bitstream/handle/10665/149782/9789241549028_eng.pdf?sequence=1

World Health Organization. (2018). WHO Global Status Report on Alcohol and Health. Available from: https://apps.who.int/iris/bitstream/handle/10665/274603/9789241565639-eng.pdf

World Health Organization. (2014). Global status report on alcohol and health, 2014. Available from: https://apps.who.int/iris/bitstream/handle/10665/112736/9789240692763_eng.pdf;jsessionid=B1E0309B7E9DAD93D88B3E9C3B20A334?sequence=1

Wu, Y., van Dijk, E., & Clark, L. (2015). Near-wins and near-losses in gambling: a behavioral and facial EMG study. *Psychophysiology*, *52*(3), 359-366.

Zandian, M., Ioakimidis, I., Bergh, C., Brodin, U., & Södersten, P. (2009). Decelerated and linear eaters: effect of eating rate on food intake and satiety. *Physiology & behavior*, *96*(2), 270-275.

Zandian, M., Ioakimidis, I., Bergström, J., Brodin, U., Bergh, C., Leon, M., ... & Södersten, P. (2012). Children eat their school lunch too quickly: an exploratory study of the effect on food intake. *BMC Public Health*, *12*(1), 351.

Zandy, S. L., Pang, J. S., Ho, M. H. R., & Matthews, D. B. (2013). Singaporean college students overpour drinks similar to western populations: Influence of peer presence in a simulated alcohol-pouring task. *Alcoholism: clinical and experimental research*, *37*(11), 1963-1970.

Zaretsky, E., Pluschinski, P., Sader, R., Birkholz, P., Neuschaefer-Rube, C., & Hey, C. (2017). Identification of the most significant electrode positions in electromyographic evaluation of swallowing-related movements in humans. *European Archives of Oto-Rhino-Laryngology*, *274*(2), 989-995.

Zlatevska, N., Dubelaar, C., & Holden, S. S. (2014). Sizing up the effect of portion size on consumption: a meta-analytic review. *Journal of Marketing*, *78*(3), 140-154.

Zupan, Z., Evans, A., Couturier, D. L., & Marteau, T. M. (2017). Wine glass size in England from 1700 to 2017: a measure of our time. *BMJ*, *359*, j5623.

Zupan, Z., Pechey, R., Couturier, D. L., Hollands, G. J., & Marteau, T. M. (2017). Micro-drinking behaviours and consumption of wine in different wine glass sizes: a laboratory study. *BMC psychology*, *5*(1), 17.

Appendices

Appendix for Chapter 2

2.1. Review article

Langfield, T., Pechey, R., Pilling, M., & Marteau, T. M. (revised and resubmitted 11.09.2020). Glassware design and drinking behaviours: a review of impact and mechanisms using a new typology of drinking behaviours. *Health Psychology Review*.

Glassware design and drinking behaviours: a review of impact and mechanisms using a new typology of drinking behaviours

Tess Langfield, Rachel Pechey, Mark A. Pilling, Theresa M. Marteau

University of Cambridge

Much of the global burden of disease is attributable to unhealthy behaviour, including excessive consumption of alcohol and sugar-sweetened beverages. Developing effective methods to change these drinking behaviours could inform policies to improve population health. In line with an increasing interest in environmental-level interventions – *i.e.,* changing the environment in which a behaviour occurs in order to change the behaviour of interest – this review first describes the existing evidence of the impact of glassware design (including capacity and shape) on drinking behaviours (*e.g.,* at the 'micro' level – including sip size, as well as at the macro level – including amount consumed). The roles of two sets of possible underlying mechanisms – perception and affordance – are also explored. Finally, this review sets out a provisional typology of drinking behaviours to enable more systematic approaches to the study of these behaviours. While there is a paucity of evidence – in particular on measures of consumption – this growing evidence base suggests promising targets for novel interventions involving glassware design to reduce the consumption of drinks that harm health.

Keywords: Choice architecture; glassware design; drinking; micro-drinking behaviours; drinking topography; affordance; perceptual effects; visual perception..

Changing drinking behaviour to prevent disease

Much of the global burden of disease is attributable to several unhealthy behaviours, including excessive consumption of alcohol and sugar-sweetened beverages (Stanaway et al., 2019; Chazelas et al., 2019; WHO Global Status Report on Alcohol and Health, 2018; Singh et al., 2015). Alcohol alone is linked to over sixty different health conditions (Room et al., 2005), and the consumption of sugar-sweetened beverages is associated with obesity, type 2 diabetes, cardiovascular disease, and a number of other health conditions (*e.g.,* Malik et al., 2010; Te Morenga et al. 2013; Scientific Advisory Committee on Nutrition, 2015). Measures aimed at reducing the intake of alcohol and sugary drinks are thus high on national and international government agendas (*e.g.,* Department of Health, 2016a; 2016b; World Health Organisation, 2015; U.S. Department of Health and Human Services and U.S. Department of Agriculture, 2015).

Changing behaviour by changing cues in physical environments

It has been suggested that effective interventions for changing routine or habitual behaviours should acknowledge the important role of automatic, non-conscious processes in shaping these behaviours (*e.g.,* Marteau et al., 2012; Hollands, Marteau & Fletcher, 2016; Hagger, 2016; Marteau, 2018). One approach to changing behaviour which is thought to target these automatic processes is *choice architecture,* also known as *nudging.* Here, choices, environments, or cues within environments are designed to elicit a change in behaviour, often outside of awareness. The concept of "nudging" was popularised by Richard Thaler and co-author Cass Sunstein in their 2008 book 'Nudge: Improving decisions about health, wealth and happiness' (Thaler & Sunstein, 2008). Though this approach has gained traction among researchers and policymakers in recent years, similar ideas about human behaviour can be traced to the end of the 19th century, when William James (1899) wrote that "ninety-nine hundredths, or possibly, nine hundred and ninety-nine thousandths of our activity is purely automatic and habitual" (p.65). Later, the Behaviourism paradigm that dominated mid-20th century Psychology held the environment or situation as central in determining behaviour (*e.g.,* Skinner, 1974), and couched behaviour in its environmental context (Blackman, 1985). Indeed, in an early semi-naturalistic study investigating factors influencing drinking, Rosenbluth and colleagues (1978) found that the setting in which drinking takes place (including the characteristics and numbers of companion drinkers) influenced drinking behaviours including amount consumed and drinking rate. The authors suggested that contextual factors were at least as important in driving drinking as the characteristics of the drinker and their drinking history, in line with the "widespread behavioural view" (p.120).

With the recent popularisation of interventions to change behaviours via changing cues in environments or *nudging*, a lack of clarity in the definitions of key concepts and terms has become apparent (*e.g.,* Marchiori et al., 2017). In response to this lack of clarity, a Typology of Interventions in Physical and

Proximal Micro-Environments (TIPPME) has been developed (Hollands et al., 2013) and refined (Hollands et al., 2017) for use as a framework for conceptualising physical environment interventions. Such interventions include altering the placement or properties of products, associated objects, and the wider environment in which the products exist, in order to change behaviours.

Glassware as a cue to consume

One property of the physical, proximal micro-environment that may influence consumption is the drinks container. Although many foods can be consumed directly – such as fruit, biscuits, and sandwiches – drinks are almost always consumed from some form of drinking vessel. Thus, the drinks container can be seen as a mediator of drinking (Spence & Wan, 2015). Drinks containers take many forms, varying with type of drink – *e.g.,* beer *vs* coffee – and drinking context – *e.g.,* picnic *vs* formal banquet. The focus of this review is on both alcoholic and non-alcoholic drinks, and glassware in the form of glasses and cups – but not cans or bottles – consumed in any drinking context.

Glassware can take many different forms and designs including different capacities and shapes. It has been suggested that design of a glass – including its size and shape – has become "an integral part of marketing activity", warranting careful consideration to maximise sales (Stead et al., 2014, p.318). Indeed, wine glasses have increased in capacity over the last three hundred years and particularly since the 1990s when their size has almost doubled, likely contributing to the increase in wine consumed over the last thirty years (Zupan, Evans, Couturier & Marteau, 2017). Given that the number of people drinking wine was roughly constant over this period, increased wine glass size is a good candidate for understanding the increase in consumption ("British wine glasses have got bigger over the years", 2017, para 4), though changes in number of drinks consumed and the amount consumed per drinking occasion could also play a role. Due to the potential impact of glassware design on drinking behaviour and outcomes, glassware design is a target for reducing consumption of health-harming drinks. The primary aim of this review is therefore to examine the existing evidence on the impact of glassware design on drinking behaviours and outcomes.

Potential Mechanisms: Perception and Affordance

To further understand and optimise any potential effects of glassware design on drinking, and to facilitate the design of effective interventions, it is helpful to conceptualise potential 'mechanisms of action' (Michie et al., 2016). This is related to the 'experimental medicine' approach, which highlights the importance of understanding not only *whether* a behaviour change intervention is effective, but how it works to change behaviour (*e.g.,* Scheeran, Klein & Rothman, 2017). Figure 1 illustrates two – neither exhaustive nor exclusive – potential mechanisms which have been highlighted by research to date as factors that may mediate or contribute to the effects of glassware design on drinking behaviours. First,

there may be *perceptual effects* of glassware design. In this review, as in previous papers (*e.g.,* Spence & Wan, 2015), perceptual effects of glassware design will include subjective judgments (*e.g.,* liking for drinks and other subjective responses), as well as visual judgments (e.g., visual perceptions of liquid volume). Second, there may be *affordance* by glassware design. This relates to the observation that some glasses, by dint of some feature of their design, appear to invite or afford faster drinking rates, larger gulps, or other patterns of behaviours that may, in turn, influence how much is drunk from them. The penultimate aim of this paper is to outline and evaluate evidence in support of these proposed mechanisms.

Defining drinking behaviours

'Drinking behaviour' is a broad term, encompassing a number of behaviours. The primary aim of this paper is to review the effects of glassware design on measures of consumption – the key outcome of interest to researchers and policymakers interested in reducing consumption of health-harming drinks and increasing consumption of healthy drinks. When organising and discussing the evidence in relation to the primary aim, it is important to distinguish between larger-scale (*macro*) drinking behaviours – amount consumed and proxies for it – and smaller-scale (*micro*) drinking behaviours – the micro-structure of drinking behaviours such as sip size, and the evidence is organised as such. On one level, micro-drinking behaviours are a fundamental feature of drinking: any drinking episode can be characterised by different micro-drinking elements, for example, how large the sips were, how many sips were taken, and whether pace of consumption was consistent over time. On another level, these micro-drinking behaviours might be seen as proxies for, or predictors of, larger-scale 'macro' drinking behaviours such as volume consumed. Thus delineating drinking behaviours by contrasting micro- with macro- behaviours can uncover the mechanics of *how* effects on consumption might work, which may yield new insights beyond what is captured from studying consumption outcomes alone. In the absence of an existing typology, the final aim of this paper will be to present a provisional typology of micro- and macro- drinking behaviours on the basis of the existing evidence, to enable more systematic study and better reporting of these behaviours in future studies.

Aims

I. To summarise evidence of the impact of glassware design – notably size, shape, and resulting fullness – on macro-drinking behaviours.

II. To summarise evidence of the impact of glassware design – notably size, shape, and resulting fullness – on micro-drinking behaviours.

III. To describe two potential mechanisms through which glassware design might impact on drinking behaviours, namely perception and affordance.

IV. To develop a preliminary typology of drinking behaviours

Search strategy

An electronic literature search was completed on 2 Sep 2020, to source relevant papers on the impact of glassware design (size, shape, fullness) on macro- and micro- drinking behaviours (i.e., aims I and II). MEDLINE and PsycInfo databases were used. Eligibility criteria included: experimental design (non-observational or literature reviews), measuring human drinking behaviour (not measured virtually, online, or using self-reported drinking), with researcher assignment to condition (e.g., glassware design features manipulated, not participant self-selected, for between-subject designs) or presentation order (for within-subject designs).

The following search terms were used for each database: (drink* OR drunk* OR consum* OR sale* OR sold OR purchas* OR sip* OR taste* OR pour* OR drink frequency OR drink number OR number of drinks) AND (glass* OR drinkware OR cup OR container) AND (size* OR capacit* OR portion* OR volume* OR shape* OR fullness).

Electronic database searching returned 671 papers (607 after removing duplicates). 23 papers met the eligibility criteria. Snowball searching and personal communications revealed an additional 4 papers, providing a total of 27 papers included for review. For details of all included studies, see Supplementary Information.

I. Impacts of glassware design on macro-drinking behaviours

Searches were conducted for experimental studies manipulating glassware (size, shape, and fullness) and measuring human drinking behaviour (amount consumed, amount purchased, amount poured, and number of drinks), for alcoholic and non-alcoholic drinks. Observational studies and literature reviews were excluded. Studies were only included if they measured drinking behaviours (not online or via self-report).

Amount consumed

Four studies have examined the impact of glassware design on amount consumed. Kersbergen and colleagues (2018) investigated whether reducing the serving size of alcohol could reduce alcohol consumed (measured in UK units) in a semi-naturalistic laboratory setting. Pairs of participants were offered beer, cider, or wine in either standard or reduced serving sizes. Findings suggested that by reducing the serving size of alcohol by 25%, alcohol units consumed were reduced by ~20%. However, though the intended manipulation was portion size, in order to keep glass fullness constant, glass sizes also varied with portion size. As a result, the reduced consumption which was observed may have been caused by reduced portion size, reduced glass size, or a combination of the two variables.

In a follow up study, Kersbergen et al. (2018) investigated whether reducing the serving size of alcohol reduced the volume of alcohol consumed – expressed in units (UK definition) of alcohol – in a bar setting. Again, participants were offered beer, cider, or wine in either standard or reduced serving sizes, with the price of drinks proportional to the serving size. The primary outcome measure was amount of alcohol consumed (expressed in UK units) within 3 hours of observation. Consumption was measured through covert observation of drinking in the bar by researchers – in particular by counting the number of beverages consumed at each table (given known serving sizes), and through counting the number of beverages sold (minus wastage). Findings suggested that by reducing the serving size of alcohol, by ~30%, alcohol units consumed were reduced by ~35%. As before, given that glass size varied with serving size, it is possible that the reduction in intake found was in part due to the reduction in glass size.

Two studies have reported on the impact of glass shape on amount consumed. Raghubir & Krishna (1999) compared amount of a soft drink consumed when served in a taller and wider glass of identical capacities, finding more was consumed from the taller glasses. More recently, Langfield and colleagues (2020) compared consumption of soft drinks served in straight-sided wine flutes and outward-sloped martini coupes, during a 10 minute bogus taste test. They found that when tasting and rating drinks served in straight-sided flutes, participants consumed 72ml less overall than when sipping from outward-sloped flutes.

Amount purchased

Nine studies report on the impact of glassware design on amount of drinks purchased. In the first of a series of studies, Pechey and colleagues (2016) investigated the impact of wine glass size on sales of wine in a bar/restaurant setting. In this study, as in all the following studies in this section, drinking was not directly measured, with purchasing of wine for immediate consumption used as a proxy for actual consumption. Wine sales increased by 9.4% when sold using larger glasses (370ml), as compared with standard glasses (300ml), with no differences in sales observed when using smaller (250ml) glasses compared with standard glasses (300ml). Six follow up studies have been conducted in bars and restaurants (Pechey et al., 2017; Clarke et al., 2019), summarised in a mega-analysis by Pilling and colleagues (2020), the results of which will be reported here (but see Supplementary Information for further details on each study). This analysis indicated that, when combining all data, there were no effects of wine glass size on sales of wine in bars. However, in restaurants, compared with the 300ml glass, wine sales were 7% higher when 370ml glasses were used. There was also a trend to suggest that wine sales decreased by around 10% from smaller (250ml) glasses, though this was not significant.

Using a similar design, Troy et al. (2015) compared pub sales between weekends when straight-sided *vs* outward-sloped beer glasses were used. Though the primary aim of this field study was to assess feasibility, the authors noted that sales were 24% lower when beer was served using straight compared with curved glasses. This finding awaits replication in a larger field study, currently underway in 24 bars (see Brocklebank, 2019 for trial pre-registration).

Amount poured

Another possible proxy for consumption, particularly for drinking at home where drinks are typically self-served rather than served by staff as in a commercial establishment, is amount poured. Nineteen studies have investigated the effect of glassware design (size and shape) on amount poured, including 4 which measure the free pouring of self-defined drinks (*e.g.,* "typical serving"), 14 which stipulate an exact amount to be poured (*e.g.,* a "standard drink" serving of alcohol), and 1 which measures both.

In two field studies measuring volume poured in freely poured self-servings for subsequent consumption, Wansink and van Ittersum (2003) found between 19-74% more juice was poured into short-wide glasses than tall-narrow ones (capacity both 659ml). In a laboratory study measuring self-defined pours of alcohol (not for consumption), Knibb et al. (2018) found no evidence that short-wide *vs* tall-narrow glasses differed in terms of amount poured. It is worth noting here that variation in "self-defined" servings might contribute to the absence of an effect of glass shape on poured volumes in between-subjects designs (such as Knibb et al., 2018). Walker et al. (2014) compared amount of wine poured into wine glasses of different shapes and sizes, for self-defined typical servings, and found 12% more wine was poured into wider glasses than narrower ones of the same capacity, but no difference for wine glasses of different sizes. De Visser & Birch (2012) found that increasing cup size for wine (150ml *vs* 250ml) and beer (340ml *vs* 570ml) led to increased alcohol units poured for both self-defined usual servings and alcohol units ("standard drinks").

Six further studies measure the effect of glassware design on "standard drink" pours. Three studies by Wansink and van Ittersum (2003; 2005) measured pours of single shots of spirits, finding pours were 3-30% larger in short-wide *vs* tall-narrow glasses (capacity both 355ml). White and colleagues (2003) investigated amount of alcohol poured among college students, for "standard drinks" of beer, straight shots - *i.e.,* single serving of spirits - and mixed drinks - *i.e.,* spirit served with a mixer. Participants poured each standard drink into glasses of different sizes. The amount poured was generally higher than a "standard drink", an effect that increased in magnitude with increasing cup size, for all drink and glass types. In a follow up study, White et al. (2005) asked participants to pour standard drinks (beer, straight shots, mixed drinks, and wine) into cups of various sizes (three per drink type). Increasing cup size led to increased volume poured for beer, mixed drinks, and wine. There was an effect of cup size on volume

poured for shots in shot glasses, though it was non-linear: there was a U shaped relationship, with less poured into the middle-sized cup. Extending these findings to a Singaporean sample, Zandy and colleagues (2013) found that increasing cup size led to increased volume pours of "standard drinks" (30ml and 220ml, for shots and beer respectively, based on Singapore Health Promotion Board), for both beer and liquor.

Five studies report the impact of glass design on set volumes (i.e., not standard-drinks or self-defined servings). Chen and Lee (2019) found between 7-27% more was poured into larger *vs* smaller glasses of different shapes, and that between 10-17% more was poured into tall-slender *vs* short-wide glasses, when participants were asked to pour either 100ml or 200ml. Four studies report on glass shape and pouring to drink midpoints. In two studies, when asked to pour to the glass midpoint (165ml for a 330ml capacity glass), participants poured ~14ml less into outward-sloped tumblers than straight-sided ones (Langfield et al., 2018; Langfield et al., 2020), though there was no evidence of a difference between inward-sloped and straight-sided glasses in the former study (Langfield et al., 2018). In a follow up study using stemmed 165ml glasses, there was no evidence of a difference in estimates of the midpoint (82.5ml) poured into straight-sided wine flutes and outward-sloped martini coupes, though the direction of the effect was the same (Langfield et al., 2020). Troy and colleagues also found that when estimating midpoints (284ml) for pint glasses (568ml), ~45ml less was poured into outward-sloped and ~15ml less into tulip glasses than straight-sided ones, though - as found by Langfield and colleagues (2018) - there was no evidence of a difference between inverted and straight-sided glasses.

Three studies highlight that the effects of glassware design (shape and size) on amount poured for set portions may vary with features of the pouring task and nature of the instructions. Caljouw & van Wijck (2014) measured volume of lemonade poured in "drink" and "shot" portions, poured into glasses of different shapes (short-wide *vs* tall-narrow, both 300ml). There was an interaction between glass shape and drink portion, such that when pouring shots, more was poured in short-wide glasses, but when pouring drinks, more was poured into the tall-narrow glasses. Chen and colleagues (2017) found that while glass size (large *vs* small) and shape (tall-narrow *vs* short-wide) did influence amount poured for a set portion, the direction of these effects depended on viewing angle, with the direction of the effects reversing when poured at 0 and 30 degrees *vs* 60 and 90 degrees. Chandon & Ordabayeva (2009) measured amount of alcoholic and non-alcoholic drinks poured into various outward-sloped and straight-sided glasses. They found that 'supersizing' – pouring three times the volume, *vs* 'downsizing' – pouring a third of the volume, reversed the effect of glass shape on amount poured. In particular, more was poured into outward-sloped glasses when supersizing, but the opposite was true when downsizing.

II. Impacts of glassware design on micro-drinking behaviours

Searches were conducted for experimental studies manipulating glassware (size, shape, and fullness) and measuring human drinking behaviour (total drinking time, sip size, number of sips, sip and interval durations, and drinking trajectory), for alcoholic and non-alcoholic drinks. As for macro-drinking behaviours, observational studies and literature reviews were excluded, and studies were only included if they measured drinking behaviours (not online or via self-report).

Total drinking time

One factor related to the amount consumed, for food at least, is speed of consumption (for a review see Robinson et al., 2014). Quicker eating rates may increase *ad libitum* consumption through one or more of several processes, including lower levels of satiation (*e.g.,* Andrade et al., 2008) and decreased orosensory exposure to the food – the time the food spends in the mouth (de Graaf, 2011). It is plausible that the speed at which drinks are consumed may also influence, or be a proxy for, the total amount consumed. Thus, exploring the conditions under which people consume drinks more quickly – for example, depending on the glass used – may inform why people consume more or less overall. Five studies have investigated the effect of glass shape and size on time taken to consume alcoholic and non-alcoholic drinks, described below.

The effect of glass shape (outward-sloped *vs* straight-sided) on drinking speed has been investigated in three studies. Attwood et al. (2012) found that individuals consumed 340ml of beer 60% more slowly from straight 340ml, compared with outward-sloped 340ml, beer glasses, although no differences were found for a soft drink, or for smaller (170ml) portions. Glass fullness predicted total drinking time, with full glasses (larger portions) consumed more slowly than half-full glasses (smaller portions). These authors attributed their key finding – that glass shape influenced total drinking time for alcohol – to titration of drinking rate based on biased perception of volumes, with greater bias for outward-sloped glasses due to the nonlinear relationship between height and volume. (See later section on perception for more discussion of this perceptual mechanism). A second study investigated the effect of glass shape – outward-sloped, straight-sided, and inward-sloped tumblers – on total drinking time, using a soft drink (Langfield et al., 2018). In contrast to Attwood and colleagues' findings (2012), drinking was about 20% slower from the straight-sided glass than the outward-sloped glass for a soft drink. Although drinking from the inward-sloped glass was also faster than from the straight-sided glass, wide confidence intervals suggested no meaningful difference. A third study compared drinking speed for a soft drink (the same as Langfield et al., 2018) from outward-sloped and straight-sided tumblers. There was no evidence or trend to suggest a difference in overall drinking time (Langfield et al., 2020).

A further study investigated the impact of glass shape on total drinking time of an alcoholic cocktail, using straight-sided glasses of different shapes (narrow/tall *vs* short/wide), and measuring drinking in a semi-naturalistic bar-laboratory setting (Cliceri et al., 2018). Participants consumed the 150ml cocktail about 7% slower from the tall/narrow glass than the short/wide one, although there was no statistical evidence that this difference was meaningful. It is worth noting that straws were used in both conditions, which may have masked differences in drinking afforded by sipping from glasses directly (see section on Affordance).

Glass size has also been investigated in the context of drinking speed. Zupan, Pechey et al. (2017) explored the effect of wine glass capacity on total drinking time in a laboratory setting. Based on previous evidence that larger wine glasses elicited higher sales of wine (Pechey et al., 2016), Zupan and colleagues predicted that wine is consumed more quickly from larger glasses, keeping serving size constant. Contrary to predictions, consumption was 18% slower from larger than smaller wine glasses (370ml, 250ml respectively).

Sip size

There is some evidence from studies on eating behaviour that show that larger portion sizes lead to larger bite sizes (Almiron-Roig et al., 2015) and that eating with large bite sizes increases how much is consumed, alongside an underestimation of the amount consumed – a possible mechanism underlying increased consumption from larger portion sizes (Hollands et al., 2015; Bolhuis et al. 2013). One study has directly manipulated sip size to examine the effect on the amount of a drink that is drunk. Weijzen et al. (2009) investigated the impact of manipulating sip size on the volume of orangeade consumed by giving participants small (5g) and large (20g) sips, delivered via a tube in their mouths. Participants self-administered the drink using a pump to initiate each sip, and decided when to terminate drinking. Although the drinking behaviour was highly artificial in nature, the study showed an increase in volume consumed of 20% and 40% when the drink was delivered in larger sip sizes, for sugar-free and sugar-sweetened beverages respectively. Taken together, this evidence suggests that understanding the conditions under which people consume with smaller sips may be important in understanding why people may consume less overall. Three studies have measured sip sizes for non-alcoholic drinks taken from glasses of different sizes and shapes, described below.

Two studies report effects of glass size on sip size, albeit with some caveats. Lawless, Bender, Oman and Pelletier (2003) found individuals took sips that were about 15% larger from cups with 600ml *vs* 150ml capacity, although cup size was confounded with portion size to keep fullness constant. This means it is not clear which variable(s) – portion size, cup size, or both – drove increased sip size. A second study manipulated the nature of drinking – *i.e.,* whether drinking was "instructed" (participants were given a series of cups and instructed to sip from each) or "natural" (participants were given a glass

of water without explicit instructions while completing a screening interview) – to determine the impact on sip size (Bennett, Van Lieshout, Pelletier & Steele, 2009). The aim of this study was to inform swallowing assessment procedures in clinical settings – which often require patients to take sips – for example, in patients with dysphasia – disordered swallowing. A large effect was found: sip sizes were four times larger in the natural phase compared with the instructed phase (24ml *vs* 6ml). However, portion size, as well as cup size, varied between these conditions (from 20-50ml in the instructed tasks to 200ml in the natural task), meaning larger sips may have been driven by any of these factors - portion size, cup size, instructions - alone or in combination.

A third study reports the effect of glass shape on sip size. Langfield and colleagues (2020) recorded sip sizes taken from straight-sided wine flutes and outward-sloped martini coupes, with the primary aim being to measure lip muscle activity (see later section on Affordance). Participants placed their drink on concealed weighing scales in between sips, allowing for covert measurement of sip size. Sips were 17% smaller when taken from straight-sided glasses *vs* outward-sloped ones.

Number of sips

Number of sips may be a proxy for sip size, especially when a set portion is consumed. That is, a drink drunk in fewer sips can be said to have been consumed with larger gulps – on average – than an identical drink drunk in more sips. Six studies have counted number of sips taken to consume alcoholic and non-alcoholic drinks.

In five studies where participants consumed a set portion of drink at their own pace, numbers of sips were explored. Cliceri et al (2018) compared number of sips taken from a 150ml portion of cocktail served straight-sided glasses of different shapes (narrow/tall *vs* short/wide). While slightly more sips were taken from the tall-narrow glass, there was no statistical evidence to support that the difference was meaningful. Attwood et al. (2012) compared numbers of sips taken from full (340ml) and half-full (170ml) portions of beer and lemonade, served in 340ml outward-sloped and straight-sided glasses. Incorporating all the data, there were main effects of glass shape and fullness, such that more sips were taken from straight-sided glasses than outward-sloped ones, and more sips taken from full portions than half-full portions. In two studies, there was no evidence that mean sip size – calculated by dividing total amount consumed (330ml) by number of sips – differed between straight-sided glasses and outward-sloped glasses (Langfield et al., 2018; Langfield et al., 2020) and between straight-sided and inward-sloped glasses (Langfield et al., 2018). Zupan, Pechey et al (2017) found no evidence that consuming wine in a larger or smaller glass led to differences in number of sips taken to consume a 175ml portion.

In another study, participants tasted and rated four drinks served in identical glasses during a bogus taste test, and sips were subsequently coded from video recordings (Langfield et al., 2020). While total

number of sips did not differ, when expressed as a proportion of total amount consumed (the primary outcome measure, which varied between participants), mean sip size was smaller from straight-sided glasses than outward-sloped ones.

Sip and interval durations

Four studies have examined sip and interval durations from glasses of different sizes, shapes, and fullness. Zupan, Pechey et al. (2017) found shorter average sip durations for wine consumed in larger *vs* smaller capacity wine glasses. Attwood et al. (2012) found that individuals tended to have longer intervals between sips from the straight *vs* outward-sloped glasses – when sipping full (340ml) portions – for beer but not lemonade. These authors also found that glass fullness predicted total sip and interval duration, with longer total sipping and inter-sip time from full (340ml) glasses than half-full (170ml) ones. In two studies, there was no evidence that glass shape predicted sip or interval duration, for 330ml soft drink served in straight-sided *vs* outward-sloped glasses (Langfield et al., 2020; Langfield et al., 2018) or straight-sided *vs* inward-sloped glasses (Langfield et al., 2018).

Drinking trajectory

One further micro-drinking behaviour that may differ by glassware design is drinking trajectory within a standardised period – *i.e.,* the dynamic pattern of drinking over time. Here, instead of comparing summaries of micro-drinking behaviours – for example, mean sip size or total number of sips – these micro-drinking behaviours are considered over time within one drinking episode. Studies on eating behaviour have identified ways to monitor dynamic changes in consumption over time, using covert weighing scales which record weights at regular intervals during eating episodes (*e.g.,* "Universal Eating Monitor"; Kissileff, Klingsberg, & Van Itallie, 1980; "Mandometer ®" (Zandian et al., 2009). This continuous measurement allows researchers to plot participants' cumulative food intake curves, which can be characterised as 'decelerated' or 'linear' (*e.g.,* Pudel, 1971; Kissileff et al., 1982; Westerterp-Plantenga et al., 1991; Zandian et al., 2009; Zandian et al., 2012). Decelerated eating would be characterised by more rapid consumption at the beginning, such that more is consumed in the first half of the eating episode, while a linear trajectory would be characterised by a more constant pace. It is possible that studies on drinking may also distinguish different drinking trajectories, and determining the conditions under which more 'decelerated' or 'linear' patterns are present may be informative. Two studies report on the impact of glassware design on drinking trajectory (cumulative intake over time).

Cliceri et al. (2018) plotted consumption over time, and found that drinking from a short, wide glass was more decelerated than drinking from a tall, narrow glass. This decelerated pattern was characterised by a larger volume consumed in the first half of the drinking period. Although a decelerated pattern of consumption was common in this study - only 30% had an accelerated pattern - a greater proportion of

individuals drinking from the short, wide glass (81%) showed this pattern, as compared to those drinking from the tall, narrow glass (60.4%).

In exploratory analyses, Langfield and colleagues (2018) found longer initial, and shorter final, sip durations from the outward-sloped glass, which contrasted with the straight-sided glass, for which the opposite pattern was true. These long initial sip durations may have been proxies for large initial gulps due to the relatively full, outward-sloped glass, though it is not possible to determine trajectory (consumption over time) from sip and interval durations alone. In a follow up study, Langfield and colleagues (2020) extended these findings by measuring cumulative intake over time (with measures of intake obtained from images of the drinks, as in Cliceri et al., 2018). In this study, there was a difference in drinking trajectory between glass shapes: a more decelerated pattern of consumption was observed from outward-sloped glasses, as compared to straight-sided ones.

III. Hypothesised mechanisms for impacts of glassware design on drinking behaviours

To optimise and better understand effects of glassware design on consumption (micro- and/or macro-drinking behaviours), it is useful to consider plausible underlying mechanisms as targets for such optimisation. In the following sections, two distinct but not exclusive sets of mechanisms are presented: perception and affordance (see Figure 1 for logic model).

Perception

There is a wealth of evidence concerning the effect of a drink's container on how the drink is perceived, including ratings of flavour, liking of the drink, and volume perception (Spence & Wan, 2015; Spence & van Doorn, 2017). Drinks can taste different depending on the shape of a glass. For example, beer may taste fruitier and more intense when served in curved compared with straight-sided glasses (Mirabito, Oliphant, Van Doorn, Watson & Spence, 2017). Identical wines have been perceived to be different wines, depending on the shape of the glass in which they were served (Spence, 2011). Satisfaction with the amount of a drink consumed has been shown to be higher when it was served in a tall-narrow glass than when served in a short-wide one (Cliceri et al. 2018). Perceived appropriateness of a drink's container may also influence liking for the drink (Raudenbush, Meyer, Eppich, Corley & Petterson, 2002), as well as how much people are willing to pay for alcoholic drinks (Wan, Zhou, Woods & Spence, 2015). Container design may also influence volume consumed via perceived unit costs, such that drinks in larger containers might be perceived to be less expensive, per unit of volume, as compared to drinks in smaller containers (Wansink, 1996).

For perception of volume, the ability to judge liquid volumes may vary with glass shape and size for wine glasses (Pechey et al., 2015; Walker et al., 2014), glass shape for tumblers and hi-ball glasses (*e.g.,* Wansink & van Ittersum, 2005; 2003), as well as glass shape (outward-sloped *vs* straight-sided) for both beer glasses (Attwood et al., 2012; Troy et al., 2018) and tumblers (Langfield et al., 2018; Langfield et al., 2020).

Specifically, several studies have explored the effect of glass shape on ability to estimate drink midpoints. When comparing straight-sided *vs* outward-sloped glasses, research shows that individuals underestimate the midpoint for outward-sloped glasses to a greater degree than for straight-sided ones, with midpoints underestimated by between 7% and 30% for outward-sloped glasses and 2% and 6% for straight-sided glasses (Attwood et al., 2012; Troy et al., 2018; Langfield et al., 2018; Langfield et al., 2020; see Figure 2 for example glasses filled half-way, as in Langfield et al., 2018; Langfield et al., 2020).

Bias in midpoint estimation has been examined using both virtual (*e.g.,* Attwood et al., 2012; Troy et al., 2018) and real-life (*e.g.,* Langfield et al., 2018; Langfield et al., 2020; Troy et al., 2018) drink pouring tasks. These biases are consistent with conflating height with volume, or an 'elongation effect', such that volumes that are taller are perceived as greater (*e.g.,* Raghubir & Krishna, 1999). The elongation effect, and differences in perception of volume found for outward-sloped vs straight-sided glassware, may be driven by a failure to assess the multiplicative impact of changing more than one dimension simultaneously (e.g., object height and width). Individuals may focus on one dimension – such as height – and thus fail to adjust for width (e.g., see Krider, Raghubir & Krishna, 2001; Chandon & Ordabayeva, 2009). The elongation effect has also been found to vary with portion size, or relative fullness of the glass, and may be reversed when pouring large drinks, as opposed to shots (Caljouw & van Wijck, 2014). Use of height as a cue to volume begins at a young age. Seminal experiments by Piaget showed that children aged 2-7 were generally unable to 'conserve' the liquid poured from one short-wide container to a tall-narrow one, perceiving the identical volumes differently, depending on the glass shape (*e.g.,* Piaget, 1967).

How a drink is *perceived* – including preferences for drinks, subjective ratings of flavour, and ability to estimate volume – may be one mechanism through which the design of a glass impacts drinking. However, relatively few studies have directly examined whether these *subjective* perceptions of drinks and glassware translate into tangible differences in *objectively* measured drinking behaviours. Indeed, there may be a disconnect between subjective perceptions and objective drinking behaviours. For example, Chandon and Ordabayeva (2017) found participants to be more accurate when estimating decreasing - as opposed to increasing - quantities, although this asymmetry was reduced when pouring quantities, as opposed to estimating numerically. A further study on eating behaviour found self-reported preference for one food item over another predicted selection of that food item, but did not predict the amount consumed – measured using covert video recordings (Iborra-Bernad et al., 2012). Taken together, these studies suggest perceptions, subjective ratings, and even selections, may not always be accurate predictors of behaviour.

As previously discussed, four studies report drinkers underestimate the mid-point of a glass to a greater extent for outward-sloped compared with straight-sided glasses (Attwood et al., 2012; Troy et al., 2018; Langfield et al., 2018; Langfield et al., 2020). Midpoint bias might, in turn, impact drinking behaviour, via titration of consumption based on false information about amount consumed. That is, if midpoints are underestimated, drinkers will have consumed more than half of their drink when they reach their perceived midpoint. This might speed up consumption, if drinking is titrated based on biased midpoints. The relationship between midpoint bias and drinking behaviour has been explored in four studies.

157

Attwood et al (2012) found a trend towards a positive association between the degree of perceptual midpoint bias and rate of consumption ($r = 0.15$). This might reflect an underpowered analysis or other mechanisms contributing to the differences in drinking speed. In three subsequent studies, no association was found between midpoint bias and drinking time ($r = 0.01$, -0.09), or midpoint bias and amount consumed ($r = -0.03$), for consumption of soft drinks (Langfield et al., 2018; Langfield et al., 2020). If midpoint bias is an important determinant of drinking behaviour, clear midpoint labels on outward-sloped glasses may slow consumption relative to unmarked outward-sloped glasses. Troy and colleagues (2017) found a trend suggesting that labelling the half-way point slowed drinking speed relative to unmarked glasses, but the confidence intervals were wide and also consistent with faster drinking. Taken together, these findings suggest that factors other than perception – and in this case volume perception – may be driving effects of glass shape on drinking speed more strongly, at least for outward-sloped and straight-sided glasses.

Thus, although there are many studies on the impact of the drink container on how the drink is perceived, further studies are warranted to determine the extent to which perceptual effects, including bias in volume perception, as well as subjective ratings such as for liking and flavour can explain variation in drinking behaviours.

Affordance

An alternative or additional mechanism that may underlie the effects of glassware design on drinking behaviours is *affordance*, described by Gibson (1979) as "what it (*an object or the environment*) offers to the animal, what it provides or furnishes, either for good or ill" (p.127). These ideas were later popularised by Norman, a student of Gibson's, in 'The Psychology of Everyday Things' (later 'The Design of Everyday Things'), and were applied to objects in our environment that were seemingly poorly designed, failing to *afford* the appropriate behaviour (Norman, 1988; 2013). The primary difference between the two conceptualisations is that, for Norman, the key insight is in how actors can *design* environments that afford behaviours more easily, while Gibson was more interested in how actors perceive existing environments (McGrenere & Ho, 2000). Further, for Norman, affordances can make actions easier or more difficult (rather than simply exist or not exist, as implied by Gibson; McGrenere & Ho, 2000).

In the context of drinking behaviours, there are a number of ways affordance might be a useful concept. Two studies have characterised the ecological affordances of *alcogenic* environments such as pubs, through observation and interviews (Hill, Pilling & Foxcroft, 2018; Hill, Foxcroft & Pilling, 2018). One example of an affordance identified by these researchers was faster drinking rates when individuals could not place their drinks on tables. That is, a pattern of drinking – in this case, increased drinking

rate – was apparently afforded by the wider drinking environment, and in particular by a lack of a "put-on-able" surface (Hill, Foxcroft & Pilling, 2018; p.459).

Glassware design and affordance

Broadly, then, characteristics of a drinking environment might be said to *afford* an increase or a decrease in drinking, for example, by the nature of the room layout. The glass from which a drink is consumed may also afford more or less of this drink being drunk, depending on its design. Indeed, some of the basic properties of the design of a glass, such as its size, shape, and fullness, might afford specific patterns of drinking behaviours. For example, the flow of liquid when a glass is tilted may differ depending on the shape of the glass. This can be observed when comparing the flow of liquid from an outward-sloped compared with a straight-sided glass. When full, outward-sloped glasses – which resemble truncated cones – appear to spill easily. They require relatively less tilt than full straight-sided glasses – which resemble cylinders – to pour out the same volume. Figure 3 plots volume poured by pouring angle, for cones and cylinders, for (a) tumblers with the same dimensions as those used by Langfield and colleagues (Langfield et al., 2018; Study 1, Langfield et al., 2020), and (b) more extreme versions (Study 2 & 3; Langfield et al., 2020). For more information on how these plots were obtained, see Supplementary Information.

When drinking, volume tipped into the mouth can thus be influenced by the simple affordance of different glass shapes. Less tilt – and potentially less effort – is required to tip the same amount of liquid into the mouth from an outward-sloped glass than a straight-sided one (see Figure 3A and 3B). This affordance of liquid pouring by pouring angle from different glass shapes can shed light on some of the findings on glass shape and drinking behaviours. For example, tilting a full outward-sloped (conical) glass to the lips to extract a sip may afford a larger initial sip, when compared to tilting a full straight-sided (cylindrical) glass. This might contribute to a more decelerated pattern of consumption – characterised by a larger amount consumed in the first half of consumption from outward-sloped glasses – as found in a recent study (Langfield et al. 2020).

An additional affordance by glassware design might involve embouchure – the extent of lip pursing – when sipping. Glasses of different designs may afford greater (or less) pursed embouchures, leading to smaller (or greater) sized sips, resulting in less (or more) being consumed. Using facial electromyography, one study found greater muscle activity used in the lips when participants sipped through a straw, as compared to sipping from a spoon or a cup (Murray et al., 1998). Glasses of different shapes and sizes may also cue differences in embouchures. This was explored in a recent study (Langfield et al., 2020). Using facial electrodes attached to the upper and lower lips to measure embouchure, this study found increased lip muscle activity, indicative of more pursed embouchures, when participants sipped from straight-sided wine flutes than from outward-sloped martini coupes. Sips

were also smaller from wine flutes, but there was limited evidence from this preliminary study that embouchures mediated this effect. Thus there is some evidence to support the hypothesis that different glass shapes afford different embouchures, but further studies are required to validate these preliminary findings in a study with greater power to detect smaller effects than was possible in this preliminary study.

A final affordance of glassware design on consumption is the affordance of volume poured from larger *vs* smaller glasses. Larger glasses afford larger pours, by nature of the maximum capacity of the container, and this may contribute to increased consumption from larger glasses. Indeed, in their analysis of the effects of wine glass size on wine sales from bars and restaurants, Pilling et al. (2020) found that larger wine glasses led to increased purchasing of wine in the restaurants settings but not in bars. One explanation that is offered by the authors is that wine is more commonly served by the bottle in restaurants, which allows consumers to free-pour their wine, so larger wine glasses may have afforded larger pours, and thus, increased consumption.

IV. Typology of drinking behaviours

Table I. Typology of macro- and micro- drinking behaviours

	Behaviour	*Definition*	*Measurement*	*Example references*
Macro	Amount consumed	Amount that is consumed (e.g., ml). Also referred to as *ad libitum consumption, total intake, volume ingested, volume consumed etc.*	Measure the volume consumed (ml), for example by weighing the drink(s) before and after consumption.	*Kersbergen et al. (2018); Langfield et al. (2020)*
	Amount purchased	Amount that is purchased. This can be used as a proxy for amount consumed (particularly in field studies with no direct measurement of behaviour).	Calculate the amount spent (e.g., £), and transform into volume (ml) purchased.	*Pechey et al. (2016); Clarke et al. (2019); Troy et al. (2015)*
	Amount poured	Amount that is poured (e.g., ml). This can be a self-defined serving, a specific volume (e.g., "standard drink"). Can be used as a proxy for consumption (or, combined with number of drinks to calculate b amount consumed)	Measure the volume poured (ml), for example by weighing the drink(s) before and after the pour, or by using measuring cylinders.	*Wansink and van Ittersum (2003); Knibb et al. (2018); Langfield et al. (2018)*
	Number of drinks	Number of drinks consumed. This can be calculated for a given consumption occasion (e.g., how many times people pour themselves another glass) or across consumption occasions (e.g., number of drinks per week). Can be used as a proxy for consumption (or, combined with amount poured or served to calculate amount consumed).	Count the number of drinks served, poured, purchased, or consumed. For example, observe and count the total number of beverages (e.g., pints of beer) sold over an evening.	*No studies identified*
Micro	Total drinking time	Time taken to consume a drink (e.g., min). Also referred to as *speed of consumption, drinking speed, drinking rate, total time drinking etc.*	Measure the time it takes to consume a given drink (e.g., with a stopwatch, or from coding video recordings).	*Attwood et al. (2012); Zupan, Pechey et al. (2017); Troy et al. (2017); Brunstrom et al. (2000); Langfield et al. (2018)*

Sip size	Size of sip (ml). Also known as sip volume, bolus volume.	To measure exact sip sizes, hidden weighing scales can be used, or participants can be asked to spit into a cup. To determine average sip size, divide total volume consumed by number of sips, which can be counted from video recordings of drinking sessions.	*Langfield et al. (2020); Lawless et al. (2003); Bennett et al. (2009); Langfield et al. (2018)*
No. of sips	Number of sips taken to consume a drink. Also known as *sip frequency*.	Can count number of sips from video recordings of drinking sessions.	*Attwood et al. (2012); Zupan, Pechey et al. (2017); Troy et al. (2017)*
Sip rate	Rate of sipping (e.g., ml/s).	Mean sip size is divided by total time spent drinking, to give sip rate.	*Tomaszewski et al. (1980)*
Sip duration	Time taken to drink a sip. Related concepts are *orosensory exposure time* and *total bout duration* (although these are often operationalised as a *total* – i.e., across all sips – while sip durations often refer to an average based on individual sips).	Can measure sip durations using video recordings of drinking sessions, and coding when each sip is initiated, and when it ends.	*Attwood et al. (2012); Zupan, Pechey et al. (2017); Troy et al. (2017); Brunstrom et al. (2000); Langfield et al. (2018)*
Interval duration	Length of time between sips. Also known as *inter-sip interval / idle time / inter-bout interval*	Can measure interval durations using video recordings of drinking sessions, and coding when each sip ends, and when the next is initiated.	*Attwood et al. (2012); Troy et al. (2017); Brunstrom et al. (2000); Langfield et al. (2018)*
Drinking trajectory	Dynamic pattern of drinking rate across the drinking period. Also known as *dynamic drinking rate, drinking rate across the drinking period.*	Extract height information from video recordings and map height of liquid:glass to volume, based on a model of volume by height ratios. Alternatively use a hidden weighing scale (for example, in a drinks coaster), to plot the weight of the glass periodically on a graph. Helpful to plot drinking trajectories within a standardised period, if comparing between individuals. Some example drinking trajectories	*Cliceri et al. (2018); Langfield et al. (2020)*

			include: *'S' shaped (cubic); accelerated (exponential); decelerated (logarithmic); linear.*	
	No. of swallows	Number of swallows taken during the consumption of a drink. Note - may differ from number of sips – *e.g.,* a large sip may be swallowed in two gulps.	Microphone attached to throat can be used, to identify timing of swallow (and thus the number of swallows in a given time period).	*Bennett et al. (2009)*

Note. Macro-drinking behaviour: measures of drinking outcomes involving consumption, or proxies for consumption. Micro-drinking behaviour: a form of short-term influence on drinking. Also known as: drinking topography, oral processing behaviours, microstructure of drinking behaviour.

Discussion

Summary of review findings

The first aim of this paper was to review evidence on the impact of glassware design on consumption of alcoholic and non-alcoholic drinks (Aim I). The review reveals a paucity of evidence on the effects of glassware design on drinking behaviour and in particular on volume consumed. Together, the evidence indicates potential effects of glassware design - including size and shape (and relatively less evidence on fullness) - on drinking behaviours using outcome measures that may be correlates or proxies of consumption, such as amount poured and amount purchased. For example, there are some consistent effects of glassware design (size and shape) on amount poured, across a range of drink types, sizes, portions, and shapes. Taken together, the research suggests that more is poured into larger than smaller glasses, short-wide than tall-narrow glasses, and straight-sided than outward-sloped glasses, though these effects may vary depending on how much is being poured (e.g., Caljouw & van Wijck, 2014), whether pouring is 'supersizing' or 'downsizing' (Chandon & Ordabayeva, 2009), viewing angle (e.g., Chen et al., 2017), and whether the pour is self-defined (e.g., Knibb et al., 2018) or a specific volume (e.g., Wansink & van Ittersum, 2003).

One particular area for future research concerns the extent to which macro-drinking behaviours, such as amount poured, may act as proxies for consumption. Studies might involve measurements of amounts poured, as well as number of drinks, to explore possible compensatory effects. For example, if less is poured into and consumed from smaller glasses, at what size might the use of smaller glasses increase consumption through compensatory behaviour? This is also important as it will aid the design of glassware which strikes the right balance, addressing the issue of when a glass becomes 'too small', such that compensatory behaviours are elicited.

The review also highlights the growing evidence on the impacts of glassware design on micro-drinking behaviours (Aim II). This includes research on sip size, with some preliminary evidence suggesting larger sips taken from larger (and wider-rimmed) cups. Studying the micro-structure of drinking – using the typology presented here as a starting point – has the potential to develop understanding of these effects and in particular whether and how much they link to volume consumed.

On the basis of the evidence reported in this review, the methods used to measure different micro-drinking behaviours may merit refinement. For example, studies involving sipping behaviours often use crude measures, including *mean* sip size (*e.g.,* Langfield et al., 2018), or *total* number of sips (*e.g.,* Zupan, Pechey et al., 2017; Attwood et al., 2012). A more promising method may be using a more dynamic approach to studying drinking behaviour – including measuring 'drinking trajectories' or sip sizes over time. These approaches provide a more precise estimate of the dynamics of consumption

(*i.e.,* the drinking trajectory), illustrating how drinking behaviour might change over the course of a drinking episode. While eating behaviour has been characterised by a quadratic curve (e.g., Kissileff et al., 1982), the two studies reported here use quadratic (Cliceri et al., 2018) and cubic (Langfield et al., 2020) curves to characterise drinking over time. The shape of these curves may also differ depending on conditions (such as glass shape; see Langfield et al., 2020). Thus, measuring both micro- and macro-drinking behaviours using both static and dynamic measures will provide a more complete picture of drinking which - in turn - may achieve a greater understanding of the effects of glassware design on consumption, though the significance of these drinking trajectories for overall consumption remains unstudied.

Elucidating mechanism: affordance and perceptual effects

In addition to increasing the quality and quantity of evidence on how glassware design affects drinking behaviours, studies are needed to advance understanding of the mechanisms by which glassware design might affect consumption. The third aim of this paper was to highlight two potential mechanisms: perceptions (including hedonic ratings such as subjective ratings of liking and flavour, as well as volume judgments) and affordance (Aim III). The logic model we presented in Figure 1 summarises these proposed mechanisms of action. When evaluating these mechanisms, it is important to identify *i.* how glassware design influences perceptions of a drink and *ii.* how these perceptions influence drinking behaviour, as well as *iii.* how glassware design affords certain behaviours such as liquid flow and embouchures and *iv.* how these in turn influence drinking behaviour. The evidence presented in this review begins to address these questions. There is, for example, much evidence for *i.* but less for *ii.* There is little evidence for *iii.* and *iv.* but what evidence there is appears promising.

Importantly, these are neither the only mechanisms by which drinks containers affect consumption, nor are any mechanisms likely to operate alone. For example, a glass might influence liquid volume judgments, which in turn influences volume poured. This, at one level, could influence how much is consumed. Additionally, the same glass might cue large initial sips due to the physical affordances of the glass and its rim diameter and slope when tipped, as well as the embouchure it elicits. These large initial gulps might then speed up drinking and lead to an increase in amount consumed. Future studies could attempt to isolate each mechanism, to determine whether the effect on drinking behaviour remains. For example, opaque glasses with different shapes, sizes, and fullness could be used, to limit visual perception of drink volumes and possibly midpoint bias, which has been found to vary by glass shape (*e.g.,* Attwood et al., 2012; Langfield et al., 2018). To "limit" the role of affordance via lip embouchures, which may vary depending on glass shape (*e.g.,* Langfield et al., 2020), future studies might provide straws (which likely elicit the same lip embouchure regardless of the glass being sipped

from). Should the effect of glassware design on measures of consumption remain, this might cast some doubt as to the importance of embouchure as a potential mechanism.

Continuing to situate these mechanisms of affordance and perception within studies on glassware design and drinking behaviours is helpful, to advance our understanding of the effects. However, as suggested by Hollands et al. (2016), in the context of behaviour change research, exploring mechanism may only be "fundamentally a means to an end" (p. 390). Ultimately, elucidating the underlying mechanisms driving the effects of glassware design on consumption is helpful primarily to inform the design of better interventions, which in this case, may aim to reduce consumption of health-harming drinks.

Typology of drinking behaviours

The final aim of this paper was to develop a preliminary typology of drinking behaviours. It is clear when reviewing the existing evidence, that there has been a lack of consistency and clarity in reporting on drinking behaviours. For example, small-scale drinking behaviours – which reflect the micro-structure of a drinking episode – have been variously described as "micro-drinking behaviours" (*e.g.,* Zupan, Pechey, Couturier, Hollands & Marteau., 2017; Langfield, Pechey, Pilling & Marteau, 2018), "drinking topography" (Foy & Simon, 1978; Attwood, Scott-Samuel, Stothart & Munafo, 2012; Troy et al., 2017), "kinetics of consumption" (*e.g.,* Giboreau, 2018) or, borrowing from the eating behaviour literature, "oral processing behaviours" (*e.g.,* Ferriday et al., 2016; Krop et al., 2018), "intrameal eating and drinking patterns" (Bellisle & Le Magnen, 1981; Warner & Balagura, 1975), and meal "micro-structure" (*e.g.,* Almiron-Roig et al., 2015; Doulah et al., 2017). The typology presented here contrasts "micro-drinking behaviours" with "larger-scale" drinking behaviours (consumption and proxies for it), which we term "macro-drinking behaviours". See Table I for typology.

Using this typology as a framework and starting point for understanding the micro-structure of a drinking episode may harness important insights for developing interventions aimed at reducing consumption. Indeed, as mentioned previously, this level of detail might illuminate *how* an intervention works to reduce intake. For example, certain glass designs may cue less consumption *via* smaller sips, or *via* slower-paced consumption characterised by long intervals in between sips. This level of detail in describing a drinking episode may also give clues to important effects on drinking behaviours that may not be captured by a 'macro' measure of drinking in a given study.

Limitations

When manipulating glassware design (shape, size or fullness), it is rare that the manipulation isolates a particular design feature, without other features confounding with these features. For example, when varying glass shape, in attempting to keep glass capacity constant, glass height (Attwood et al., 2012), and rim diameter (Langfield et al., 2018; Langfield et al., 2020), can vary. Similarly, when attempting to keep glass height constant, capacity may vary (which can lead to differences in fullness, given the same portion served; as in Langfield et al., 2018). It is similarly difficult to determine the causes of some of the effects, where both portion size and glass size are varied (*e.g.,* Lawless et al., 2003; Kersbergen et al., 2018). Thus, a limitation of this body of research is that it can be difficult to determine the exact feature of a drinks container that influences consumption.

Further, many of the studies reported in this review were conducted in laboratory settings which, though advantageous for elucidating mechanism, may be limited in reflecting intervention effects in real world settings. Relatively few studies took place in real-life settings such as pubs and restaurants (but see Pechey et al., 2016; 2017; Troy et al., 2015; Clarke et al., 2019). It should be noted that measuring food or drink consumption directly is difficult in field studies, with selection and purchasing data used as a proxy for the amount consumed. Nonetheless, these field studies are crucial to estimate effect sizes – at a population level – of any intervention involving drinks containers such as glassware. Such settings include many contextual effects that may influence behaviour which cannot be reproduced in laboratory settings (Giboreau, 2018). Laboratory studies of drinking behaviour often involve solitary drinking (*e.g.,* Attwood et al., 2012; Langfield et al., 2018; Langfield et al., 2020; Troy et al, 2017), potentially failing to reflect social nature of much drinking, especially common for consumption of alcohol. Semi-naturalistic laboratories set up to appear like restaurants and bars provide greater ecological validity than traditional laboratory settings (*e.g.,* Cliceri et al., 2018, Kersbergen et al., 2018) although still less than that of a field setting. Future studies should also examine consumption of multiple drinks, to investigate how drinking behaviours change over longer periods, which may, again, be more reflective of real-life drinking (especially for alcohol). As discussed previously, smaller glasses might lead to less drink poured for a single glass. However, it is possible that compensatory strategies lead people to consume more overall – for example, by consuming a higher number of drinks over a longer drinking period. Here, measuring number of drinks consumed, as well as amount poured, could be informative.

This review summarises evidence on studies using alcoholic and non-alcoholic drinks. One limitation is that in most cases it isn't possible to compare the effects of glassware design on consumption of different drink types due to the lack of evidence. However, there are potential differences between these drink types, including the effects of alcohol on decision making, and motivations behind consumption, with quantity of alcohol consumed likely more salient than quantity of soft drinks consumed, in certain contexts. Given these possible differences, further research here would be particularly beneficial.

167

Implementation of interventions involving glassware design

There are several routes to implementing an intervention involving glassware design to reduce consumption of health-harming drinks. These include voluntary action, regulation, and legislation. Given possible barriers to change, including public acceptability of interventions and potential cost, researchers should continue to strive for evidence of the effectiveness and likely parameters for any given intervention involving glassware design. Such parameters include drink-type (*e.g.,* alcoholic *vs* non-alcoholic), drinking context (*e.g.,* bar, restaurant, or home, with drinks pre-served or self-served), and drinking pattern when multiple drinks are consumed. Effect size estimates, generated from multiple studies, are also required to make predictions about the possible impact of an intervention at a population level. Together, these factors would help to form a robust evidence base which is required for any regulation-based policies, especially given that these policies are likely to be resisted by producers and retailers of the drinks targeted by the policy (Freudenberg, 2014; Pomeranz & Brownell, 2014). Perhaps one of the key challenges to implementation is to "change minds" about changing behaviour, with a focus on changing *environments* (in this case, glassware), not *individuals* (Marteau, 2018).

Conclusion

There is a paucity of evidence on the impact of the design of glassware on drinking behaviours, although several studies suggest it might affect how much is consumed, with some evidence for several candidate mechanisms. The provisional typology presented here and analysis of the limited existing evidence provides a starting point for subsequent research in order to generate a coherent body of evidence that can advance understanding of the impact of glassware design on macro-drinking behaviours - consumption and its proxies - as well as micro-drinking behaviours that contribute to this including sip size. To identify glassware design features worth targeting for intervention, research needs to continue a focus on the effects of glassware design on amount consumed and on micro-drinking behaviours, which may be important in understanding the mechanisms driving any overall consumption effects. The robustness of this research will be enhanced by more valid and granular measures of macro- and micro-drinking behaviours, in both laboratory and field settings. In addition, to optimise these effects, the underlying mechanisms warrant further exploration. This review highlighted perceptions and affordances as two possibilities, though neither exclusive nor exhaustive. The evidence summary presented here – including the logic model and typology – provides an initial basis for building an evidence base on a promising set of interventions to reduce consumption of alcoholic and non-alcoholic drinks that harm health.

Acknowledgements

References

Almiron-Roig, E., Tsiountsioura, M., Lewis, H. B., Wu, J., Solis-Trapala, I., & Jebb, S. A. (2015). Large portion sizes increase bite size and eating rate in overweight women. *Physiology & behavior*, *139*, 297-302.

Andrade, A. M., Greene, G. W., & Melanson, K. J. (2008). Eating slowly led to decreases in energy intake within meals in healthy women. *Journal of the American Dietetic Association, 108*(7), 1186-1191.

Attwood, A. S., Scott-Samuel, N. E., Stothart, G., & Munafò, M. R. (2012). Glass shape influences consumption rate for alcoholic beverages. *PloS one*, *7*(8), e43007.

Bellisle, F., & Le Magnen, J. (1981). The structure of meals in humans: eating and drinking patterns in lean and obese subjects. *Physiology & Behavior*, *27*(4), 649-658.

Bennett, J. W., Van Lieshout, P. H., Pelletier, C. A., & Steele, C. M. (2009). Sip-sizing behaviors in natural drinking conditions compared to instructed experimental conditions. *Dysphagia*, *24*(2), 152-158.

Blackman, D. E. (1985). Contemporary Behaviourism: A Brief Overview. In C. F. Lowe, M. Richelle, D. E. Blackman, C. M. Bradshaw (Eds.), *Behaviour Analysis and Contemporary Psychology* (pp. 259-281). London: Lawrence Erlbaum Associates Ltd.

Bolhuis, D. P., Lakemond, C. M., de Wijk, R. A., Luning, P. A., & de Graaf, C. (2013). Consumption with large sip sizes increases food intake and leads to underestimation of the amount consumed. *PloS one*, *8*(1), e53288.

British wine glasses have got bigger over the years. (2017, December 23). *The Economist*. Retrieved from https://www.economist.com/science-and-technology/2017/12/23/british-wine-glasses-have-got-bigger-over-the-years.

Brocklebank, L (2019): Straight-sided glasses for alcohol reduction. *ISRCTN*. https://doi.org/10.1186/ISRCTN10456720

Brunstrom, J. M., Tribbeck, P. M., & MacRae, A. W. (2000). The role of mouth state in the termination of drinking behavior in humans. *Physiology & behavior*, *68*(4), 579-583.

Caljouw, S. R., & van Wijck, R. (2014). Is the glass half full or half empty? How to reverse the effect of glass elongation on the volume poured. *PloS one*, *9*(10), e109374.

Chandon, P., & Ordabayeva, N. (2009). Supersize in one dimension, downsize in three dimensions: Effects of spatial dimensionality on size perceptions and preferences. *Journal of Marketing Research*, *46*(6), 739-753.

Chandon, P., & Ordabayeva, N. (2017). The accuracy of less: Natural bounds explain why quantity decreases are estimated more accurately than quantity increases. *Journal of Experimental Psychology: General*, *146*(2), 250.

Chazelas, E., Srour, B., Desmetz, E., Kesse-Guyot, E., Julia, C., Deschamps, V., ... & Deschasaux, M. (2019). Sugary drink consumption and risk of cancer: results from NutriNet-Santé prospective cohort. *bmj*, *366*, l2408.

Chen, Y. L., & Lee, Y. C. (2019). Effects of lighting, liquid color, and drink container type on volume perception. *i-Perception*, *10*(5), 2041669519880916.

Chen, Y. L., Lee, Y. C., Lee, T. Y., & Chen, M. Z. (2017). Effect of Viewing Angle on Volume Perceptions for Paired Tumblers. *i-Perception*, *8*(4), 2041669517719296.

Clarke, N., Pechey, R., Pilling, M., Hollands, G. J., Mantzari, E., & Marteau, T. M. (2019). Wine glass size and wine sales: four replication studies in one restaurant and two bars. *BMC research notes*, *12*(1), 426.

Cliceri, D., Petit, E., Garrel, C., Monteleone, E., & Giboreau, A. (2018). Effect of glass shape on subjective and behavioral consumer responses in a real-life context of drinking consumption. *Food Quality and Preference*, *64*, 187-191.

de Graaf, C. (2011). Why liquid energy results in overconsumption. *Proceedings of the Nutrition Society*, *70*(2), 162-170.

De Visser, R. O., & Birch, J. D. (2012). My cup runneth over: Young people's lack of knowledge of low-risk drinking guidelines. *Drug and alcohol review*, *31*(2), 206-212.

Department of Health. (2016). Childhood Obesity: A Plan for Action. Available from: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/546588/Childhood_obesity_2016__2__acc.pdf

Department of Health. (2016). UK Chief Medical Officers' Alcohol Guidelines Review. Summary of the Proposed New Guidelines. Available from: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/489795/summary.pdf

Doulah, A., Farooq, M., Yang, X., Parton, J., McCrory, M. A., Higgins, J. A., & Sazonov, E. (2017). Meal microstructure characterization from sensor-based food intake detection. *Frontiers in nutrition*, *4*, 31.

Ferriday, D., Bosworth, M. L., Godinot, N., Martin, N., Forde, C. G., Van Den Heuvel, E., ... & Brunstrom, J. M. (2016). Variation in the oral processing of everyday meals is associated with fullness and meal size; a potential nudge to reduce energy intake?. *Nutrients*, *8*(5), 315.

Foy, D. W., & Simon, S. J. (1978). Alcoholic drinking topography as a function of solitary versus social context. *Addictive Behaviors*, *3*(1), 39-41.

Freudenberg, N. (2014). *Lethal but legal: corporations, consumption, and protecting public health*. Oxford University Press.

Giboreau (2018). Situational Factors and the Design of In Situ Evaluations. In G. Ares, P. Varela (Eds.), *Methods in Consumer Research, Volume 2: Alternative Approaches and Special Applications* (pp. 109-116). Woodhead Publishing.

Gibson, J.J. (1979). *The Ecological Approach to Visual Perception*. Boston: Houghton Mifflin.

Stanaway, J. D., Afshin, A., Gakidou, E., Lim, S. S., Abate, D., Abate, K. H., ... & Abdela, J. (2018). Global, regional, and national comparative risk assessment of 84 behavioural, environmental and occupational, and metabolic risks or clusters of risks for 195 countries and territories, 1990–2017: a systematic analysis for the Global Burden of Disease Study 2017. *The Lancet*, *392*(10159), 1923-1994.

Hagger, M. S. (2016). Non-conscious processes and dual-process theories in health psychology. *Health psychology review*, *10*(4), 375.

Hill, K. M., Foxcroft, D. R., & Pilling, M. (2018). "Everything is telling you to drink": understanding the functional significance of alcogenic environments for young adult drinkers. *Addiction Research & Theory*, *26*(6), 457-464.

Hill, K. M., Pilling, M., & Foxcroft, D. R. (2018). Alcohol-related affordances and group subjectivities: A Q-Methodology study. *Drugs: Education, Prevention and Policy*, *25*(5), 376-385.

Hollands, G. J., Bignardi, G., Johnston, M., Kelly, M. P., Ogilvie, D., Petticrew, M., ... & Marteau, T. M. (2017). The TIPPME intervention typology for changing environments to change behaviour. *Nature Human Behaviour*, *1*(8), 0140.

Hollands, G. J., Marteau, T. M., & Fletcher, P. C. (2016). Non-conscious processes in changing health-related behaviour: a conceptual analysis and framework. *Health Psychology Review*, *10*(4), 381-394.

Hollands, G. J., Shemilt, I., Marteau, T. M., Jebb, S. A., Kelly, M. P., Nakamura, R., ... & Ogilvie, D. (2013). Altering micro-environments to change population health behaviour: towards an evidence base for choice architecture interventions. *BMC public health*, *13*(1), 1218.

Hollands, G. J., Shemilt, I., Marteau, T. M., Jebb, S. A., Lewis, H. B., Wei, Y., ... & Ogilvie, D. (2015). Portion, package or tableware size for changing selection and consumption of food, alcohol and tobacco. *The Cochrane database of systematic reviews*, (9).

Iborra-Bernad, C., Wathelet, O., & Giboreau, A. (2012) Measuring bread use in a French restaurant. A naturalistic approach: Grid analysis for the French culture. In A. Spink, F. Grieco, O. Krips, L. Loijens, L. Noldus, P. Zimmerman (Eds.) *Measuring behaviour 2012, 8th International Conference on Methods and Techniques in Behavioural Research,* pp. 434-438. Available from: http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.388.1603&rep=rep1&type=pdf#page=434.

James, W. (1899). *Talks to Teachers on Psychology: And to Students on Some of Life's Ideals* (New York, NY: Henry Holt), 65.

Kersbergen, I., Oldham, M., Jones, A., Field, M., Angus, C., & Robinson, E. (2018). Reducing the standard serving size of alcoholic beverages prompts reductions in alcohol consumption. *Addiction*.

Kissileff, H. R., Klingsberg, G., & Van Itallie, T. B. (1980). Universal eating monitor for continuous recording of solid or liquid consumption in man. *American Journal of Physiology-Regulatory, Integrative and Comparative Physiology*, *238*(1), R14-R22.

Kissileff, H. R., Thornton, J., & Becker, E. (1982). A quadratic equation adequately describes the cumulative food intake curve in man. *Appetite*, *3*(3), 255-272.

Knibb, G., Jones, A., & Christiansen, P. (2018). Pour Guess: The Effect of Glass Shape and an Ice Substitute on Alcohol Pouring and Estimation. *Alcoholism: Clinical and Experimental Research*, *42*(7), 1228-1236.

Krider, R. E., Raghubir, P., & Krishna, A. (2001). Pizzas: π or square? Psychophysical biases in area comparisons. *Marketing Science*, *20*(4), 405-425.

Krop, E. M., Hetherington, M. M., Nekitsing, C., Miquel, S., Postelnicu, L., & Sarkar, A. (2018). Influence of oral processing on appetite and food intake–A systematic review and meta-analysis. *Appetite*, *125*, 253-269.

Langfield, T., Pechey, R., Gilchrist, P. T., Pilling, M. A., & Marteau, T. M. (2020) Straight-sided glasses: a promising intervention to reduce how much we drink? *Scientific Reports, 10*, 13362.

Langfield, T., Pechey, R., Pilling, M., & Marteau, T. M. (2018). Impact of glass shape on time taken to drink a soft drink: A laboratory-based experiment. *PloS one*, *13*(8), e0202793.

Lawless, H. T., Bender, S., Oman, C., & Pelletier, C. (2003). Gender, age, vessel size, cup vs. straw sipping, and sequence effects on sip volume. *Dysphagia*, *18*(3), 196-202.

Malik, V. S., Popkin, B. M., Bray, G. A., Després, J. P., & Hu, F. B. (2010). Sugar-sweetened beverages, obesity, type 2 diabetes mellitus, and cardiovascular disease risk. *Circulation*, *121*(11), 1356-1364.

Marchiori, D. R., Adriaanse, M. A., & De Ridder, D. T. (2017). Unresolved questions in nudging research: Putting the psychology back in nudging. *Social and Personality Psychology Compass*, *11*(1), e12297.

Marteau, T. M. (2018). Changing minds about changing behaviour. *The Lancet*, *391*(10116), 116-117.

Marteau, T. M., Hollands, G. J., & Fletcher, P. C. (2012). Changing human behavior to prevent disease: the importance of targeting automatic processes. *science*, *337*(6101), 1492-1495.

Maynard, O. M., Langfield, T., Attwood, A. S., Allen, E., Drew, I., Votier, A., & Munafò, M. R. (2017). No impact of calorie or unit information on ad libitum alcohol consumption. *Alcohol and Alcoholism*, *53*(1), 12-19.

McGrenere, J., & Ho, W. (2000). Affordances: Clarifying and evolving a concept. In *Graphics interface*, 179-186.

Mirabito, A., Oliphant, M., Van Doorn, G., Watson, S., & Spence, C. (2017). Glass shape influences the flavour of beer. *Food Quality and Preference*, *62*, 257-261.

Murray, K. A., Larson, C. R., & Logemann, J. A. (1998). Electromyographic response of the labial muscles during normal liquid swallows using a spoon, a straw, and a cup. *Dysphagia, 13*(3), 160-166.

Norman, D. (1988). *The psychology of everyday things*. New York: Basic Books.

Norman, D. (2013). *The design of everyday things*. MIT Press.

Pechey, R., Attwood, A. S., Couturier, D. L., Munafò, M. R., Scott-Samuel, N. E., Woods, A., & Marteau, T. M. (2015). Does glass size and shape influence judgements of the volume of wine?. *PloS one*, *10*(12), e0144536.

Pechey, R., Couturier, D. L., Hollands, G. J., Mantzari, E., Munafò, M. R., & Marteau, T. M. (2016). Does wine glass size influence sales for on-site consumption? A multiple treatment reversal design. *BMC public health*, *16*(1), 390.

Pechey, R., Couturier, D. L., Hollands, G. J., Mantzari, E., Zupan, Z., & Marteau, T. M. (2017). Wine glass size and wine sales: a replication study in two bars. *BMC research notes*, *10*(1), 287.

175

Piaget, J. (1967) *Six Psychological Studies.* New York: Random House.

Pilling, M., Clarke, N., Pechey, R., Hollands, G. J., & Marteau, T. M. (2020). The effect of wine glass size on volume of wine sold: A mega-analysis of studies in bars and restaurants. *Addiction*.

Pomeranz, J. L., & Brownell, K. D. (2014). Can government regulate portion sizes?. *The New England journal of medicine*, *371*(21), 1956.

Pudel, V. (1971). Food-Dispenser eine Methode zur Untersuchung des ‚spontanen ‘Appetitverhaltens. *Zeitschrift für Ernährungswissenschaft*, *10*(4), 382-393.

Raghubir, P., & Krishna, A. (1999). Vital dimensions in volume perception: Can the eye fool the stomach?. *Journal of Marketing research*, 313-326.

Raudenbush, B., Meyer, B., Eppich, W., Corley, N., & Petterson, S. (2002). Ratings of pleasantness and intensity for beverages served in containers congruent and incongruent with expectancy. *Perceptual and motor skills*, *94*(2), 671-674.

Robinson, E., Almiron-Roig, E., Rutters, F., de Graaf, C., Forde, C. G., Tudur Smith, C., ... & Jebb, S. A. (2014). A systematic review and meta-analysis examining the effect of eating rate on energy intake and hunger. *The American journal of clinical nutrition*, *100*(1), 123-151.

Room, R., Babor, T., & Rehm, J. (2005). Alcohol and public health. *The Lancet*, *365*(9458), 519-530.

Rosenbluth, J., Nathan, P. E., & Lawson, D. M. (1978). Environmental influences on drinking by college students in a college pub: Behavioral observation in the natural environment. *Addictive Behaviors*, *3*(2), 117-121.

Sheeran, P., Klein, W. M., & Rothman, A. J. (2017). Health behavior change: Moving from observation to intervention. *Annual review of psychology*, *68*, 573-600.

Scientific Advisory Committee on Nutrition. (2015). *Draft Carbohydrates and Health Report*. Available from https://www.gov.uk/government/publications/sacn-carbohydrates-and-health-report.

Singh, G. M., Micha, R., Khatibzadeh, S., Lim, S., Ezzati, M., & Mozaffarian, D. (2015). Estimated global, regional, and national disease burdens related to sugar-sweetened beverage consumption in 2010. *Circulation*, *132*(8): 639–66. Available from: https://doi.org/10.1161/CIRCULATIONAHA.114.010636.

Skinner, B. F. (1974). *About behaviorism*. New York: Knopf.

Spence, C. (2011). Crystal clear or gobbletigook. *World of Fine Wine*, *33*, 96-101.

Spence, C., & Van Doorn, G. (2017). Does the shape of the drinking receptacle influence taste/flavour perception? A review. *Beverages*, *3*(3), 33.

Spence, C., & Wan, X. (2015). Beverage perception and consumption: The influence of the container on the perception of the contents. *Food quality and preference*, *39*, 131-140.

Stead, M., Angus, K., Macdonald, L., & Bauld, L. (2014). Looking into the glass: Glassware as an alcohol marketing tool, and the implications for policy. *Alcohol and alcoholism*, *49*(3), 317-320.

Te Morenga, L., Mallard, S., & Mann, J. (2013). Dietary sugars and body weight: systematic review and meta-analyses of randomised controlled trials and cohort studies. *Bmj*, *346*, e7492.

Thaler, R. & Sunstein, C.R. (2008). *Nudge: Improving decisions about health, wealth, and happiness*. New Haven: Yale University Press.

Tomaszewski, R. J., Strickler, D. P., & Maxwell, W. A. (1980). Influence of social setting and social drinking stimuli on drinking behavior. *Addictive behaviors*, *5*(3), 235-240.

Troy, D. M., Attwood, A. S., Maynard, O. M., Scott-Samuel, N. E., Hickman, M., Marteau, T. M., & Munafò, M. R. (2017). Effect of glass markings on drinking rate in social alcohol drinkers. *European journal of public health*, *27*(2), 352-356.

Troy, D. M., Attwood, A. S., Maynard, O. M., Scott-Samuel, N. E., Hickman, M., Woods, A., & Munafò, M. R. (2018). Effect of glass shape on the pouring accuracy of liquid volume. *PloS one*, *13*(10), e0204562.

Troy, D. M., Maynard, O. M., Hickman, M., Attwood, A. S., & Munafò, M. R. (2015). The effect of glass shape on alcohol consumption in a naturalistic setting: a feasibility study. *Pilot and feasibility studies*, *1*(1), 27.

U.S. Department of Health and Human Services and U.S. Department of Agriculture. 2015–2020. (2015). Dietary Guidelines for Americans. 8th Edition. December 2015. Available from: http://health.gov/dietaryguidelines/2015/guidelines/

Walker, D., Smarandescu, L., & Wansink, B. (2014). Half full or empty: Cues that lead wine drinkers to unintentionally overpour. *Substance Use & Misuse*, *49*(3), 295-302.

Wan, X., Zhou, X., Woods, A. T., & Spence, C. (2015). Influence of the glassware on the perception of alcoholic drinks. *Food quality and preference*, *44*, 101-110.

Wansink, B. (1996). Can package size accelerate usage volume?. *Journal of marketing*, *60*(3), 1-14.

Wansink, B., & Van Ittersum, K. (2003). Bottoms up! The influence of elongation on pouring and consumption volume. *Journal of consumer research*, *30*(3), 455-463.

Wansink, B., & Van Ittersum, K. (2005). Shape of glass and amount of alcohol poured: comparative study of effect of practice and concentration. *BMJ*, *331*(7531), 1512-1514.

Warner, K. E., & Balagura, S. (1975). Intrameal eating patterns of obese and nonobese humans. *Journal of comparative and physiological psychology*, *89*(7), 778.

Weijzen, P. L., Smeets, P. A., & de Graaf, C. (2009). Sip size of orangeade: effects on intake and sensory-specific satiation. *British Journal of Nutrition*, *102*(7), 1091-1097.

Westerterp-Plantenga, M. S., Wouters, L., & Ten Hoor, F. (1991). Restrained eating, obesity, and cumulative food intake curves during four-course meals. *Appetite*, *16*(2), 149-158.

White, A. M., Kraus, C. L., Flom, J. D., Kestenbaum, L. A., Mitchell, J. R., Shah, K., & Swartzwelder, H. S. (2005). College students lack knowledge of standard drink volumes: implications for definitions of risky drinking based on survey data. *Alcoholism: Clinical and Experimental Research*, *29*(4), 631-638.

White, A. M., Kraus, C. L., McCracken, L. A., & Swartzwelder, H. S. (2003). Do college students drink more than they think? Use of a free-pour paradigm to determine how college students define standard drinks. *Alcoholism: Clinical and Experimental Research*, *27*(11), 1750-1756.

World Health Organization. (2015). *Guideline: sugars intake for adults and children*. World Health Organization. Available from: https://apps.who.int/iris/bitstream/handle/10665/149782/9789241549028_eng.pdf?sequence=1

World Health Organization. (2018). WHO Global Status Report on Alcohol and Health. Available from: https://apps.who.int/iris/bitstream/handle/10665/274603/9789241565639-eng.pdf

Zandian, M., Ioakimidis, I., Bergh, C., Brodin, U., & Södersten, P. (2009). Decelerated and linear eaters: effect of eating rate on food intake and satiety. *Physiology & behavior*, *96*(2), 270-275.

Zandian, M., Ioakimidis, I., Bergström, J., Brodin, U., Bergh, C., Leon, M., ... & Södersten, P. (2012). Children eat their school lunch too quickly: an exploratory study of the effect on food intake. *BMC Public Health*, *12*(1), 351.

Zandy, S. L., Pang, J. S., Ho, M. H. R., & Matthews, D. B. (2013). Singaporean college students overpour drinks similar to western populations: Influence of peer presence in a simulated alcohol-pouring task. *Alcoholism: clinical and experimental research*, *37*(11), 1963-1970.

Zupan, Z., Evans, A., Couturier, D. L., & Marteau, T. M. (2017). Wine glass size in England from 1700 to 2017: a measure of our time. *BMJ*, *359*, j5623.

Zupan, Z., Pechey, R., Couturier, D. L., Hollands, G. J., & Marteau, T. M. (2017). Micro-drinking behaviours and consumption of wine in different wine glass sizes: a laboratory study. *BMC psychology*, *5*(1), 17.
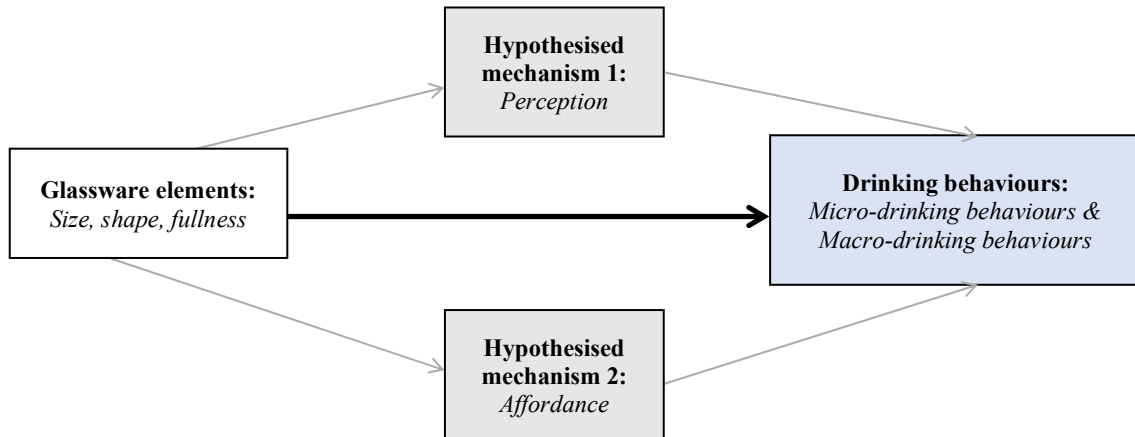
Figures

Figure 1. Logic model to organise evidence on the impacts of drinks containers on micro- and macro-drinking behaviours, with two proposed mechanisms: perception and affordance.

Figure 2. Image to depict the midpoints of 330ml portions in outward-sloped and straight-sided glasses, as in Langfield et al. (2018) and Langfield et al. (2020).
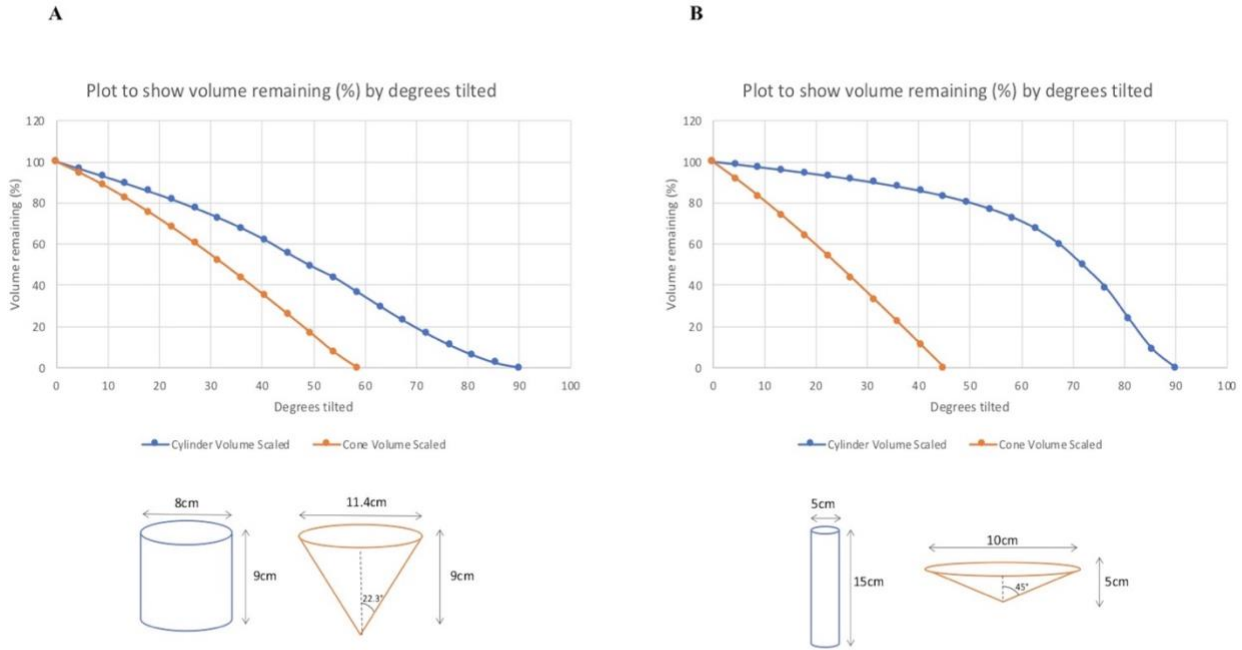
Figure 3. Plots to show affordance by glass shape of volume remaining (%) by angle of tilt. 'A' illustrates the relationship with glass dimensions as used by Langfield et al. 2018; Study 1 (Langfield et al., 2020). 'B' illustrates the relationship with more extreme dimensions.

2.2. Review – Search strategy

An electronic literature search was completed on 2 Sep 2020, to source relevant papers on the impact of glassware design (size, shape, fullness) on macro- and micro- drinking behaviours. Eligibility criteria included: experimental design (i.e., non-observational or literature reviews), measuring human drinking behaviour (i.e., not measured virtually, online, or using self-reported drinking), with researcher assignment to condition (i.e., glassware design features manipulated, not participant self-selected, in between-subjects designs) or presentation order (within-subject designs).

Databases searched: **MEDLINE** and **PsycInfo**.

All searches combined: 671

Removing duplicates: 607

Papers meeting eligibility criteria: 23

Snowball searching and personal communication: 4

Total papers included in review: 27

MEDLINE Database (including In-Process & Other Non-Indexed Citations 1946 to September 2, 2020)

Date searched = 2nd September 2020

Papers returned = <u>311</u>

((glass* or drinkware or cup or container) adj9 (size* or capacit* or portion* or volume* or shape* or fullness))

AND

(drink* or drunk* or consum* or sale* or sold or purchas* or sip* or taste* or pour* or drink frequency or drink number or number of drinks)

PsycInfo Database (from 1835-2020)

Date searched = 2nd September 2020

Papers returned = <u>360</u>

(glass* OR drinkware OR cup OR container)

AND

(size* OR capacit* OR portion* OR volume* OR shape* OR fullness)

AND

(drink* OR drunk* OR consum* OR sale* OR sold OR purchas* OR sip* OR taste* OR pour* OR drink frequency OR drink number OR number of drinks)

Additional papers

Snowball searching revealed an additional three papers (de Visser & Birch, 2012; Bennett et al., 2009; Kersbergen et al., 2018). Personal communication with authors revealed one trial pre-registration (Brocklebank, 2019). All included papers are listed in Table S1 and S2, including study details and findings.

2.3. Review – Table of studies

Table 1. Experimental studies investigating the impact of glassware design (size, shape, fullness) on macro-drinking behaviours

Author (date)	Study setting	Glassware manipulation (size, shape, fullness)	Drinks served (including portion size)	Outcome measure (drinking behaviour)	Study finding
Amount consumed					
Kersbergen et al. (2018)	Study 1 Semi-naturalistic laboratory study; N = 114; between-subjects design Study 2 Field study – bar; N = 166*; between-subjects design Both UK *N.B. after excluding participants aware of alcohol intake measure - n = 164	Glass size* Study 1: 'standard' wine 310ml vs 'smaller' wine 250ml; 'standard' beer 530ml vs 'smaller' beer 370ml Study 2: 'standard' wine 245ml vs 'smaller' wine 195ml; 'standard' beer 568ml vs 'smaller' beer 379ml *N.B. actual manipulation – portion size –confounded with glass size	Alcohol (wine, beer, cider) Study 1: wine served by the glass in 'standard' 165ml or 'reduced' 125ml portions; beer and cider served by the glass in 'standard' 460ml or 'reduced' 345ml portions. Study 2: wine served by the glass in 'standard' 175ml or 'reduced' 125ml portions; beer and cider served by the glass in 'standard' 568ml or 'reduced' 379ml portions.	Amount consumed (in UK alcohol units)* *N.B. though consumption was measured directly in the laboratory study (through weighing the glasses before and after consumption), to measure intake in the bar, drinking was measured through observation by researchers	Study 1 - reducing the serving size of alcohol led to reduction in alcoholic units consumed (p=.02) Study 2 - reducing the serving size of alcohol led to reduction in alcoholic units consumed (p=.001) N.B. Study 1 analysis adjusted for covariates; Study 2 analysis unadjusted
Langfield et al. (2020)	Study 2 Laboratory study; N = 72; between-subjects design; UK	Glass shape: outward-sloped martini coupes (260ml) vs straight-sided wine flutes (210ml)	Non-alcoholic (passionfruit drink), 660ml served, divided into four 165ml portions	Amount consumed (ml) in bogus taste test	72ml less was consumed from straight-sided glasses than outward-sloped glasses (p=.022)
Raghubir & Krishna (1999)	Study 4 Field study – classroom; N = 16; within-subjects design; USA	Glass shape (taller vs shorter; both 296ml)	Non-alcoholic (cola), portion size NR	Amount consumed (ml) when asked to taste the two drinks	11% more was consumed from the taller glass (p<.0001).
Amount purchased					
Pechey et al. (2016)	Field study – 1 establishment with bar and restaurant; multiple-treatment reversal design; UK	Wine glass size 'standard' 300ml vs 'larger' 370ml and 'smaller' 250ml	Alcohol (wine), served by the glass (125ml, 175ml), bottle (750ml) or carafe (500ml, 1000ml)	Daily volume of wine purchased (ml)	Daily volume of wine purchased was 9% higher from larger wine glasses than standard glasses (p=.015) No difference between smaller and standard glasses (p=.63)

Pechey et al. (2017)	Field study – 2 bars; multiple-treatment reversal design; UK	Wine glass size Bar 1: 'standard' 370ml vs 'smaller' 300ml and 'larger' 510ml Bar 2: 'smaller' 300ml vs 'larger' 510ml	Alcohol (wine), served by the glass (125ml, 175ml, 250ml), bottle (750ml)	Daily volume of wine purchased (ml)	Bar 1: Daily volume of wine purchased was 11% higher from larger wine glasses than standard glasses (95%CI 1%, 21%) No difference between smaller and standard glasses (smaller, 95% CI -5%,20%) Bar 2: No difference between larger and smaller glasses (larger 95%CI 12.6%,11.9%)
Clarke et al. (2019)	Study 1 & 2 Field study – restaurant Study 3 Field study – bar Study 4 Field study – bar All multiple-treatment reversal design; UK	Wine glass size Study 1: 'smaller' 290ml vs 'standard' 350ml and 'larger' 450ml Study 2: 'smaller' 290ml vs 'standard' 350ml and 'larger' 450ml Study 3: 'standard' 350ml vs 'smaller' 290ml and 'larger' 450ml Study 3: 'standard' 350ml vs 'smaller' 290ml and 'larger' 450ml	Alcohol (wine), served by the glass (125ml, 175ml, 250ml – the latter, Study 3 and 4 only), bottle (750ml), and carafe (500ml, 1000ml – carafe, Study 1 & 2 only)	Daily volume of wine purchased (ml)	Study 1: Daily volume of wine purchased was 13% higher from standard wine glasses than smaller glasses (95% CI 2%, 24%) Study 2: Daily volume of wine purchased was 6% higher from standard wine glasses than smaller glasses (95% CI − 1%, 15%) Study 3: Daily volume of wine purchased was 21% higher from larger wine glasses than standard wine glasses (95% CI 9%, 35%) Study 4: No evidence of replication of Study 3 found (− 7%, 95% CI − 16%, 3%) No meaningful differences with other glass comparisons
Troy et al. (2015)	Field study – 3 public houses, UK	Beer glass shape	Alcohol (beer, cider), served by	Monetary takings (not including	Monetary takings were 24% lower on weekends when

		Outward-sloped (284ml, 568ml) vs straight-sided (290ml, 585ml)	the glass (568ml, 284ml)	food), over each weekend period* *N.B. primary outcome was feasibility; overall monetary takings included other purchases	straight-sided glasses were used, though confidence intervals crossed zero (95% CI: -77%, 29%)
Brocklebank (2019)	Field study pre-registration – 24 public houses; multi-period crossover trial with randomisation; UK	Beer glass shape Straight-sided (568ml, 284ml) vs usual curved* glassware (568ml, 284ml) *width of the curved glassware not consistent from bottom to top	Alcohol (beer, ale, cider), served by the glass (568ml, 284ml)	Volume of lager, ale and cider purchased (ml)	N/A – study underway
Amount poured					
Wansink & van Ittersum (2003)* *N.B. Several papers from Brian Wansink have been retracted or are under suspicion.	Study 1 Field study –fitness camp cafeteria; N = 97 children at a fitness camp; between-subjects design Study 2 Field study – cafeteria; N = 89 adults; between-subjects design Both USA	Study 1 & 2 Glass shape: short-wide tumbler (659ml) vs tall-narrow highball (659ml)	Study 1 & 2 Non-alcoholic (juice)	Study 1 & 2 - Volume poured (ml), in a freely poured self-serving	Study 1 – 74% more juice was poured into short-wide glasses than tall-narrow ones (p<.05) Study 2 – 19% more juice was poured into short-wide glasses than tall-narrow ones (p<.05)
Knibb et al. (2018)	Study 1 Laboratory study; N = 126; between-subjects; UK	Glass shape: short-wide vs tall-narrow (capacity both 300ml)	Alcohol* in a vodka bottle *N.B. all drinks poured were non-alcoholic	Volume of alcohol poured (ml), when asked to pour their usual serving of spirit	No evidence of difference in poured servings between short-wide and tall-narrow (p=.748)
Walker et al. (2014)	Laboratory study; N = 73; mixed design; USA	Glass shape: Wider red wine glass vs narrower white wine glass Glass size: Smaller vs larger wine glass Capacities NR	Alcohol (red and white wine)	Volume of wine poured (ml), when pouring a typical serving	More poured into wider glass than narrower one (12%, p<.05) No effect of glass size on amount poured (p>.05)
De Visser & Birch (2012)	Laboratory study; N = 125; within-subjects design; UK	Cup size Wine (250ml, 150ml); Beer (570ml, 340ml)	Alcohol* in 750ml red wine bottle, 660ml beer bottle and 375ml vodka bottle *N.B. all drinks poured were non-alcoholic, dyed to appear the correct colour	Amount poured (in UK alcohol units), when pouring "usual self-serving" and a "standard drink" for wine, beer, and vodka	Units poured increased with cup size, for wine and beer, for both "unit" and "usual serving" pours (p NR)
Wansink & van Ittersum (2003)*	Study 3 Field study – bars; N = 45 bartenders;	Glass shape: short-wide tumbler (355ml) vs tall-	Alcohol (gin, vodka, rum and whiskey; from 1500ml bottles)	Volume of alcohol poured (ml), estimating a	Study 3 – 27% more poured into short-wide glasses

	between-subjects design, USA	narrow highball (355ml)		standard 1.5oz (44.4ml) serving	than tall-narrow ones (p<.01)
Wansink & van Ittersum (2005) 	Study 1 Laboratory study; N = 198; between-subjects design Study 2 Field study – bars; N = 86 bartenders; between-subjects design Both USA	Glass shape: short-wide tumbler (355ml) vs tall-narrow highball (355ml)	Alcohol* (gin, vodka, rum and whiskey; from 1500ml bottles) *N.B. all drinks poured were non-alcoholic	Volume of alcohol poured (ml), estimating a standard 1.5oz (44.4ml) serving	Study 1 – 30% more poured into short-wide glasses than tall-narrow ones (p<.001) Study 2 –20.5% more poured into short-wide glasses than tall-narrow ones (p<.0001)
White et al. (2003)	Laboratory study; N = 106; within-subjects design, USA	Cup size: Shot glass (44.4ml) and cups (88.7ml, 177ml) Mixed drink cups (177ml, 296ml, 355ml) Beer cups (473ml, 710ml, 946ml)	Alcohol* in a clear glass 750ml liquor bottle (shot/mixed drinks) and 9464ml cooler with a spigot (beer) *N.B. all drinks poured were non-alcoholic	Volume of alcohol poured (ml), estimating a standard 1.25oz (37.0ml) serving of liquor, and 12oz (355ml) serving of beer	Increasing cup size led to increased volume pours of water for 'shots' in shot glasses (p<.001), 'shots' in mixed drink glasses (p<.001), and 'beer' in beer glasses (p<.001)
White et al. (2005)	Laboratory study; N = 133; within-subjects design, USA	Cup size: Shots (88.7ml, 266.ml, 355ml) Mixed drink (266ml, 355ml, 473ml) Beer (473ml, 591ml, 946ml) Wine (355ml, 473ml, 591ml)	Alcohol* in a clear glass 750ml liquor bottle (shot/mixed drinks) and 9464ml cooler with a spigot (beer), and a clear glass 750ml wine bottle (wine) *N.B. all drinks poured were non-alcoholic, dyed to appear the correct colour	Volume of alcohol poured (ml), estimating a standard 1.25oz (37.0ml) / 1.5oz (44.4ml) serving of liquor, 12oz (355ml) serving of beer, 4oz (118ml) / 5oz (148ml) serving of wine	Increasing cup size led to increased volume pours for 'beer' in beer cups, 'wine' in wine cups, and 'shots' in mixed drink glasses (linear trends, ps<.05). There was a non-linear trend for shots poured in shot cups (p<.001).
Zandy et al. (2013)	Laboratory study; N = 105; within-subjects design, Singapore	Cup size Shots (44.4ml, 88.7ml, 207ml) Beer (473ml, 651ml, 946ml)	Alcohol* in 1000ml pitchers (beer) and a glass 1000ml liquor bottle (shot) *N.B. all drinks poured were non-alcoholic, dyed to appear the correct colour	Volume of alcohol poured (ml), estimating a standard 30ml serving of liquor, and 220ml serving of beer	Increasing cup size led to increased volume pours for 'beer' p<.0001, and 'shots' p<.0001.
Chen & Lee (2019)	Laboratory study; N = 60; mixed design; Taiwan	Glass elongation (short-wide vs tall-narrow wine glasses and tumblers)	Alcohol (red wine) and non-alcohol (water)	Volume poured (ml) when estimating set portions (100ml or 200ml, depending on glass)	Pouring into tumblers, 27% more was poured into large vs small ones (p<.001).

		Glass size (large vs small wine glasses and tumblers) NB this study also manipulated lighting level and liquid colour			Pouring into wine glasses, 7% more was poured into large vs small glasses (*p*<.05). Pouring into tumblers, 17% more was poured into tall-slender vs short-wide glasses (*p*<.001). Pouring into wine glasses, 10% more was poured into the tall-slender vs short-wide glasses (*p*<.001).
Langfield et al. (2018)	Laboratory study; N = 162; between-subjects design; UK	Glass shape: outward-sloped (400ml) vs straight-sided (400ml) vs inward-sloped (440ml) tumblers	Non-alcoholic (carbonated apple drink), 330ml serving, and 660ml in jug	Volume poured (ml) when estimating 165ml portions (i.e., midpoint of full 330ml portion)	Less poured into outward-sloped glass than straight-sided ones (*p*<.001). No evidence of difference between inward-sloped and straight-sided (*p*=.82)
Langfield et al. (2020)	Study 1 Laboratory study; N = 200*; between-subjects design; UK *N.B. final sample 198 participants	Glass shape: outward-sloped vs straight-sided tumblers (capacity both 400ml)	Non-alcoholic (carbonated apple drink), 330ml serving, and 660ml in jug	Study 1 Volume poured (ml) when estimating 165ml portions (i.e., midpoint of full 330ml portion)	Less poured into outward-sloped glass than straight-sided ones (*p*<.001)
" "	Study 2 Laboratory study; N = 72; between-subjects design; UK	Glass shape: outward-sloped martini coupes (260ml) vs straight-sided wine flutes (210ml)	Non-alcoholic (passionfruit drink), 165ml serving, and 500ml in jug	Study 2 Volume poured (ml) when estimating 82.5ml portions (i.e., midpoint of full 165ml portion)	No evidence of difference in poured estimates between outward-sloped and straight-sided (*p*=.531)
Troy et al. (2018)	Study 2 Laboratory study; N = 96; within-subjects design; UK	Glass shape: straight-sided vs outward-sloped vs tulip vs inverted (capacity all 568ml)	Non-alcoholic (water in a jug)	Volume poured (ml) when estimating 284ml portions (i.e., midpoint of the full 568ml portion)	Less poured into outward-sloped and tulip glasses than straight-sided ones (*ps*<.001). No evidence of a difference between inverted and straight-sided (*p*=.95).
Caljouw & van Wijck (2014)	Study 1 Laboratory study; N = 42; within-subjects; The Netherlands	Glass shape: short-wide vs tall-narrow (capacity both 300ml) NB this study also manipulated pouring instructions	Non-alcoholic (lemonade), 1.5 litre jug	Volume poured (ml), when pouring a "drink" and a "shot"	Interaction between glass shape and instruction (*p*<.001): when pouring shots, volume poured is greater in short-

					wide than tall-narrow glass, but when pouring drinks, the opposite is true
Chen et al. (2017)	Laboratory study; N = 50; mixed design; Taiwan	Glass shape (square vs round, both 230ml) Glass elongation (short-wide tumbler vs tall-narrow highball, both 230ml) Glass size (large vs small tumbler of same shape, 250ml vs 370ml) NB this study also manipulated viewing angle (0°, 30°, 60°, 90°)	Non-alcoholic (water coloured to appear as juice, 500ml in jug)	Volume poured (ml) when estimating 150ml (glass elongation; shape) and 200ml (glass size)	No differences found for square vs round, at any viewing angle. Glass elongation When pouring at 0° & 30°, less was poured into tall-slender glasses than short-wide ones ($ps<.01$), but when pouring at 60° & 90°, the opposite was true ($ps<.001$). Glass size When pouring at 0° & 30°, less was poured into large glasses than small ones ($ps<.006$), but when pouring at 60° & 90°, the opposite was true ($ps<.007$).
Chandon & Ordabayeva (2009)	Study 3 Laboratory study; N = 47; between-subjects design*; France *NB Randomisation to condition NR	Glass shape (outward-sloped ("3D") vs straight-sided ("1D"); capacities identical – vodka glasses both 100ml, cocktail glasses both 250ml, and infant drinks 20ml*). * Data was pooled and rescaled across product variations NB This study also manipulated pouring instructions (i.e., downsize vs supersize)	Alcoholic (vodka, cocktail) and non-alcoholic (infant medicine), in opaque jugs	Volume poured (expressed as a multiple of initial dose), when asked to pour 'three times' the served dose (supersizing), or 'a third' of the served dose (downsizing)	When asked to pour three times the initial serving, more was poured into outward-sloped glasses than straight-sided ones ($p<.005$). When asked to pour a third of the initial serving, less was left in outward-sloped glasses than straight-sided ones ($p<.003$).

Note. Exact p values given unless where not reported.

189

Table 2. Experimental studies investigating the impact of glassware design (size, shape, fullness) on micro-drinking behaviours

Author (date)	Study setting	Glassware manipulation (size, shape, fullness)	Drinks served (including portion size)	Outcome measure (drinking behaviour)	Study finding
Total drinking time					
Attwood et al. (2012)	Laboratory study; N = 160*; between-subjects design; UK *N.B. useable data available for 159 participants	Glass shape (beer glasses: 340ml outward-sloped vs 340ml straight-sided) Glass fullness (half - 170ml vs full - 340ml portions)	Alcohol (beer) and non-alcoholic (lemonade), 340ml and 170ml servings	Total drinking time (min), measured from coded video recordings of participants drinking at their own pace	Stratified analyses on full (340ml) portions – slower drinking from straight-sided glasses for beer ($p=$.007) but not lemonade ($p=$.78) Incorporating all data, main effect of portion: slower drinking of full portions than half-full portions ($p<$.001)
Langfield et al. (2018)	Laboratory study; N = 162; between-subjects design; UK	Glass shape: outward-sloped (400ml) vs straight-sided (400ml) vs inward-sloped (440ml) tumblers	Non-alcoholic (carbonated apple drink), 330ml serving	Total drinking time (min), measured from coded video recordings of participants drinking at their own pace	Slower drinking from straight-sided glasses than outward-sloped glasses (percentage difference = 21.4%), $p=$.048
Langfield et al. (2020)	Study 1 Laboratory study; N = 200*; between-subjects design; UK *N.B. useable drinking time data available for 198 participants	Glass shape: outward-sloped vs straight-sided tumblers (capacity both 400ml)	Non-alcoholic (carbonated apple drink), 330ml serving	Total drinking time (min), measured from coded video recordings of participants drinking at their own pace	No evidence of a difference in total drinking time ($p=$.979)
Cliceri et al. (2018)	Field study – "Living Lab" restaurant; N = 123*; between-subjects design; France *N.B. useable data available for 90 participants	Glass shape: short-wide tumbler (200ml) vs tall-narrow highball (220ml)	Alcohol (orange based cocktail), 150ml serving	Total drinking time (sec), measured from coded video recordings of participants drinking at their own pace	Slower drinking from tall-narrow glasses than short-wide glasses, (mean difference = 48 sec), though no statistical evidence that this difference was meaningful ($p=$.168).
Zupan, Pechey, et al. (2017)	Laboratory study; N = 166; between-subjects design; UK	Wine glass size 'smaller' 250ml vs 'larger' 370ml	Alcohol (red wine), 175ml serving	Total drinking time (sec), measured from coded video recordings of participants drinking at their own pace	Larger wine glasses led to slower drinking times than smaller wine glasses ($p=$.024).
Sip size					

Lawless et al. (2003)	Study 1 Laboratory study; N = 100*; within-subjects design; USA *N.B. split into two groups – Group 2 (n = 50) contained taller women and shorter men to minimize body size variable predicting sip size	Cup size* (150ml vs 300ml vs 600ml capacity) *N.B. to keep fullness constant, cup size was confounded with portion size	Non-alcoholic (water, filled to 0.6cm from the top of each of the three cups)	Sip size (ml), measured by asking participants to take a sip and spit into a cup	Larger cups led to increased sip sizes in Group 1 ($p<.05$) and Group 2 ($p<.01$)
Bennett et al. (2009)	Laboratory study; N = 32; within-subjects design; Canada	Cup size (exact capacities NR, though largest was 227ml) *N.B. actual manipulation – presence/absence of explicit instructions to sip, i.e., natural vs instructed sipping – confounded with cup size and portion size	Non-alcoholic (water, served in portions of 200ml ("uninstructed"), 50ml and 20ml ("instructed"))	Sip sizes (ml) measured by experimenter when drinks placed on hidden weighing scales between sips	Sips were smaller during "instructed" task, i.e., when sipping from smaller cups, as compared to the "uninstructed" task, i.e., when sipping from larger cups $p<.0001$
Langfield et al. (2020)	Study 3 Laboratory study; N = 40; within-subjects design; Australia	Glass shape: outward-sloped martini coupes (260ml) vs straight-sided wine flutes (210ml)	Non-alcoholic (passionfruit drink), 660ml served, divided into four 165ml portions	Sip sizes (ml) measured by experimenter when drinks placed on hidden weighing scales between sips, during adapted bogus taste test	Sip sizes were smaller from straight-sided glasses than outward-sloped ones, $p<.0001$
Number of sips					
Cliceri et al. (2018)	Semi-naturalistic laboratory study – "Living Lab" restaurant; N = 123*; between-subjects design; France *N.B. useable data available for 90 participants	Glass shape: short-wide tumbler (200ml) vs tall-narrow highball (220ml)	Alcohol (orange based cocktail), 150ml serving	Number of sips, measured from coded video recordings of participants drinking at their own pace	Slightly higher number of sips from tall-slender glass than short-wide glass, though no statistical evidence ($p=.259$)
Attwood et al. (2012)	Laboratory study; N = 160*; between-subjects design; UK *N.B. useable data available for 159 participants	Glass shape (beer glasses: 340ml outward-sloped vs 340ml straight-sided) Glass fullness (half - 170ml vs full - 340ml portions)	Alcohol (beer) and non-alcoholic (lemonade)	Number of sips, measured from coded video recordings of participants drinking at their own pace	Incorporating all data, main effect of glass shape, with more sips taken from straight-sided glasses ($p=.016$), and a main effect of glass fullness, with more sips taken from full portions ($p<.001$)
Langfield et al. (2018)	Laboratory study; N = 162; between-subjects design; UK	Glass shape: outward-sloped (400ml) vs straight-sided (400ml) vs inward-	Non-alcoholic (carbonated apple drink), 330ml serving	Number of sips (transformed into mean sip size, by expressing as a proportion of total amount consumed	Mean sip sizes were larger from inward and outward-sloped glasses than straight-sided

		sloped (440ml) tumblers		– 330ml), measured from coded video recordings of participants drinking at their own pace	glasses, though no statistically meaningful difference observed (*p*=.057, *p*=.13, respectively)
Langfield et al. (2020)	Study 1 Laboratory study; N = 200*; between-subjects design; UK *N.B. useable number of sips data available for 198 participants	Glass shape: outward-sloped vs straight-sided tumblers (capacity both 400ml)	Non-alcoholic (carbonated apple drink), 330ml serving	Study 1 Number of sips (transformed into mean sip size, by expressing as a proportion of total amount consumed – 330ml), measured from coded video recordings of participants drinking at their own pace	Mean sip sizes were larger from outward-sloped glasses than straight-sided glasses, though no statistically meaningful difference observed (*p*=.123)
" "	Study 2 Laboratory study; N = 72*; between-subjects design; UK **N.B. useable sip data available for 71 participants	Glass shape: outward-sloped martini coupes (260ml) vs straight-sided wine flutes (210ml)	Non-alcoholic (passionfruit drink), 660ml served, divided into four 165ml portions	Study 2 Number of sips, measured from coded video recordings of participants tasting and rating four drinks in a bogus taste test Also transformed to mean sip size, as a proportion of total amount consumed – the primary outcome measure)	Number of sips did not differ (*p*=.58), though when expressed as a proportion of total amount consumed, mean sip size did differ, with smaller sips from straight-sided glasses (*p*=.017)
Zupan, Pechey, et al. (2017)	Laboratory study; N = 166; between-subjects design; UK	Wine glass size 'smaller' 250ml vs 'larger' 370ml	Alcohol (red wine), 175ml serving	Number of sips, measured from coded video recordings of participants drinking at their own pace	Number of sips did not differ between smaller vs larger glasses (*p*=.26)
Sip duration					
Attwood et al. (2012)	Laboratory study; N = 160*; between-subjects design; UK *N.B. useable data available for 159 participants	Glass shape (beer glasses: 340ml outward-sloped vs 340ml straight-sided) Glass fullness (half - 170ml vs full - 340ml portions)	Alcohol (beer) and non-alcoholic (lemonade)	Total sip duration (sec), measured from coded video recordings of participants drinking at their own pace	Incorporating all data, main effect of glass fullness, with longer total sip duration from full portions (*p*<.001)
Zupan, Pechey, et al. (2017)	Laboratory study; N = 166; between-subjects design; UK	Wine glass size 'smaller' 250ml vs 'larger' 370ml	Alcohol (red wine), 175ml serving	Mean sip duration (sec), measured from coded video recordings of participants	Mean sip durations were shorter from the larger glass (*p*=.045)

					drinking at their own pace	
Langfield et al. (2018)	Laboratory study; N = 162; between-subjects design; UK	Glass shape: outward-sloped (400ml) vs straight-sided (400ml) vs inward-sloped (440ml) tumblers	Non-alcoholic (carbonated apple drink), 330ml serving	Mean sip duration (sec), measured from coded video recordings of participants drinking at their own pace	Mean sip durations did not differ between straight-sided vs outward-sloped glasses (*p*=.40)
Langfield et al. (2020)	Study 1 Laboratory study; N = 200*; between-subjects design; UK *N.B. useable data available for 198 participants	Glass shape: outward-sloped vs straight-sided tumblers (capacity both 400ml)	Non-alcoholic (carbonated apple drink), 330ml serving	Mean sip duration (sec), measured from coded video recordings of participants drinking at their own pace	Mean sip durations did not differ between straight-sided vs outward-sloped glasses (*p*=.19)
Interval duration					
Attwood et al. (2012)	Laboratory study; N = 160*; between-subjects design; UK *N.B. useable data available for 159 participants	Glass shape (beer glasses: 340ml outward-sloped vs 340ml straight-sided) Glass fullness (half - 170ml vs full - 340ml portions)	Alcohol (beer) and non-alcoholic (lemonade)	Total interval duration (sec), measured from coded video recordings of participants drinking at their own pace	Incorporating all data, main effect of glass shape, with longer total interval duration from straight-sided glasses (*p*=.031), and a main effect of glass fullness, with longer total interval duration from full portions (*p*=.001) Stratified analyses on full (340ml) portions – longer total interval duration from straight-sided glasses for beer (*p*=.008), but not for lemonade (*p*=.83).
Langfield et al. (2018)	Laboratory study; N = 162; between-subjects design; UK	Glass shape: outward-sloped (400ml) vs straight-sided (400ml) vs inward-sloped (440ml) tumblers	Non-alcoholic (carbonated apple drink), 330ml serving	Mean interval duration (sec), measured from coded video recordings of participants drinking at their own pace	Mean interval durations did not differ between straight-sided vs outward-sloped glasses (*p*=.68)
Langfield et al. (2020)	Study 1 Laboratory study; N = 200*; between-subjects design; UK *N.B. useable data available for 198 participants	Glass shape: outward-sloped vs straight-sided tumblers (capacity both 400ml)	Non-alcoholic (carbonated apple drink), 330ml serving	Mean interval duration (sec), measured from coded video recordings of participants drinking at their own pace	Mean interval durations did not differ between straight-sided vs outward-sloped glasses (*p*=.31)
Drinking trajectory					

Cliceri et al. (2018)	Semi-naturalistic laboratory study – "Living Lab" restaurant; N = 123*; between-subjects design; France *N.B. useable data available for 90 participants	Glass shape: short-wide tumbler (200ml) vs tall-narrow highball (220ml)	Alcohol (orange based cocktail), 150ml serving	Drinking trajectory (i.e., i."intake pattern" – proportion accelerated or decelerated, and ii. amount consumed at 50% time)	Proportion of decelerated drinkers (relative to accelerated drinkers) larger in short-wide condition (p=.035). More consumed from short-wide glasses than tall-narrow glasses at 50% time (p=.004).
Langfield et al. (2020)	Study 1 Laboratory study; N = 200*; between-subjects design; UK *N.B. useable trajectory data available for n = 16 or n = 94 participants, depending on exclusion criteria	Glass shape: outward-sloped vs straight-sided tumblers (capacity both 400ml)	Non-alcoholic (carbonated apple drink), 330ml serving	Drinking trajectory (i.e., plot cumulative intake (%) over time (%) and determine: i. amount consumed at 50% time (>50% indicative of decelerated pattern) ii. area under individual's drinking curve (higher values indicative of more decelerated pattern)	From cubic models predicting cumulative intake over time, at 50% time, more was consumed from outward-sloped glasses (59-66%) than straight-sided glasses (50-56%), indicative of decelerated pattern Areas under drinking curves were larger from outward-sloped glasses, indicative of more decelerated pattern (ps<.023)

Note. Exact p values given unless where not reported.

2.4. Review – Angle of tilt vs. amount poured graphs

Determining volume poured when glasses are tilted

Outward-sloped glasses – "cone"

Initially consider a simple symmetric verticle cone with the vertex at the bottom and filled with liquid, with height h and radius r. The volume of this cone is given by $V_{cone} = \frac{1}{3}\pi r^2 h$. At the cone is tilted, liquid is lost and the remaining liquid also forms a cone with h given by the perpendicular distance from the vertex to the the remaining level of the fluid. The volume of this oblique cone, no matter the angle of tilt, is given by the same formula. The perpendicular height h can be expressed as a function of the length of the longest side (l) of the cone and the angle (radians) of tilt (δ) and the internal angle of the cone (φ) from verticle as $h = l.\cos(\varphi + \delta)$. This formula is used to estimate the volume of liquid remaining as the cone is tilted.

Straight-sided glasses – "cylinder"

Initially consider a simple symmetric verticle cylinder with the vertex at the bottom and filled with liquid, with height h and radius r. The volume of this cone is given by $V_{cylinder} = \pi r^2 h$. As the cone is tilted by an angle ($\theta = \frac{\pi}{2} - \delta$), as seen in Figure 2.4.1 below, the remaining liquid initially forms i) a smaller cylinder of height h-x and ii) a half-cylinder of height x. The distance x is given by $\frac{2r}{\tan\theta}$. When x=h (second image) then half the volume has been poured, which occurs when $\tan(\theta) = 2r/h$. Let z be height along the bottom after half the liquid has been poured, given by $z = h.\tan(\theta)$. The new volume remaining is half the volume of a segment across the cylinder with of height z, and is given by

$V_{cylinder} = \frac{1}{2}h(r^2\cos^{-1}\left(\frac{r-z}{r}\right) - (r-z)\sqrt{(2rz - z^2)})$ for the remainder of the pour.
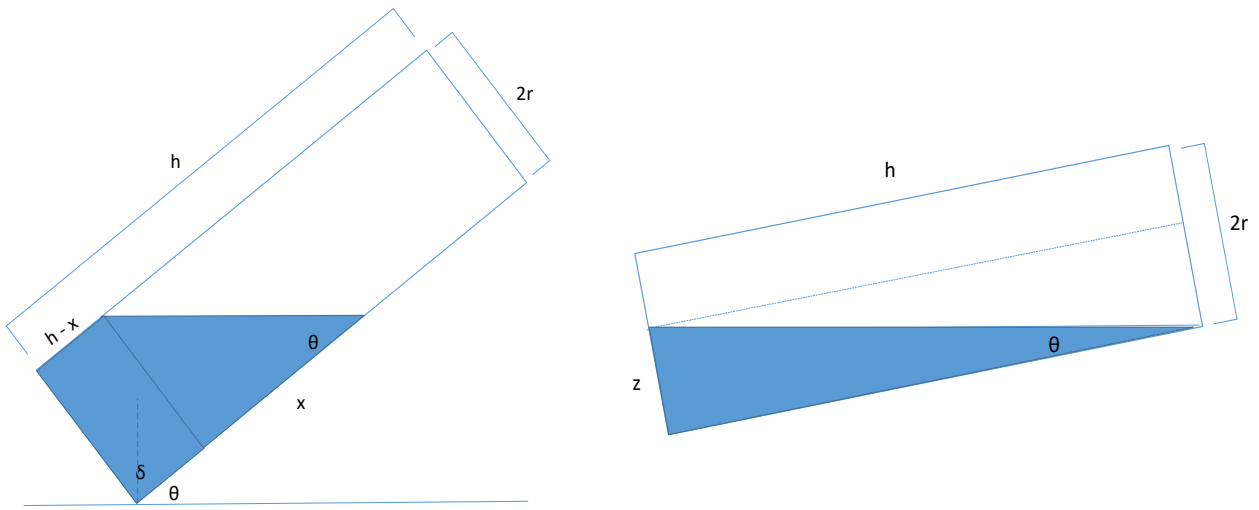
Figure 2.4.1. Images to show volumes poured from cylinders, at varying degrees of tilt (δ)

Appendix for Chapter 3

3.1. Study 1 pre-registered study protocol

Langfield, T., Pechey, R., Pilling, M., & Marteau, T. M. (2017). Study protocol: Impact of glass shape on drinking rate: an experimental study testing mechanisms.

Available at: https://osf.io/fwmg9/

Study protocol: Impact of glass shape on drinking rate: an experimental study testing mechanisms

Abstract

Background

Reducing consumption of sugary and alcoholic drinks would lessen the substantial economic, social, and health burden that arises from their overconsumption. There is increasing evidence that the design of glassware can influence drinking behaviour. While studies indicate an effect of glass shape and size on amount purchased, speed of consumption, and micro-drinking behaviours (e.g., sip size, number of sips), it is not clear what the mechanisms driving these effects are. One possibility addressed in a previous study relates to biases in the perception of volume. An additional or alternative mechanism could be the affordance of micro-drinking behaviours from drinks in different shapes and sizes. Ease of extracting liquid likely varies with the glass design and its fullness, and this mechanism may account for the patterns of micro-drinking behaviours and drinking rate seen when individuals drink from different containers. This hypothesis awaits testing.

Method

162 participants will be randomised to receive 330ml of carbonated apple juice in a glass that is either a) convex, b) straight-sided, or c) concave. The primary outcome measure will be the total time taken to consume the drink. Secondary outcome measures include micro drinking behaviours (sip size, number of sips, sip duration, interval duration, drinking 'tempo'), drink enjoyment, and bias in estimating the mid-point of their drink.

Discussion

The current study will contribute evidence regarding the impact of glass shape on drinking rate for soft drinks, using a set of three differently-shaped glasses. In addition, the results of this study will inform the possible mechanisms that may drive the effects, knowledge of which should inform future studies.

Background

Overconsumption of sugary drinks and alcohol is a major public health concern, contributing to rising levels of obesity and ill health. Interventions that inform consumers of the health risks associated with their behaviours may lack the reach required to change health at a population level, and there are concerns about widening health inequalities through measures that require engagement on the part of the individual (Marteau, Hollands & Fletcher, 2012; McGill et al., 2015). There is thus increasing policy interest in 'choice architecture' interventions (Department of Health, 2010), which, through moulding the environment in which choices are made, 'nudge' consumers to make healthier decisions (Thaler & Sunstein, 2008). These interventions are thought to work through automatic processes, without relying much on conscious engagement or individual agency (Marteau et al., 2012; Hollands, Marteau & Fletcher, 2016).

Glassware represents a modifiable environmental cue, and is thus a candidate for interventions that aim to change drinking behaviour at a population level. There is growing evidence that the design of glass and tableware can influence the amount consumed, for food and non-alcoholic drinks (Hollands et al., 2015), as well as for wine (Pechey et al., 2016). One mechanism that may drive differences in intake is through the speed at which a drink is consumed. Attwood et al. (2012) found that individuals consumed full portions of beer 60% more slowly from straight, compared with curved, beer glasses, although no differences were found for smaller portions, or for a soft drink. These authors attributed the effect to biased midpoint estimation, which, they hypothesised, was greater for curved glasses, due to the nonlinear relationship between height and volume. Supporting this, they found that participants underestimated the mid-point of the glass to a greater extent for curved glasses, as compared with straight glasses. However, there was only a trend towards an association between the degree of this perceptual bias and rate of consumption, suggesting that other mechanisms may have contributed to the differences in drinking rate. Indeed, a subsequent study from the same group investigated whether clear midpoint labelling could slow consumption rate from curved glasses (Troy et al., 2016). Findings suggested slower drinking from labelled glasses, relative to unmarked glasses, but the confidence intervals were wide and also consistent with faster drinking.

An additional or alternative mechanism that may contribute to the effects of glass shape on drinking rate could be the cueing or affordance of sip size from glasses of different shapes and sizes. In the traditional Gibsonian sense, an object affords action possibilities, which are relative to the individual's capability to act on them, and exist outside of an individual's perceptual awareness (Gibson, 1977; 1979; but see Norman, 1988 for importance of understanding *perceived* affordances). Generally speaking, then, drinking glasses can be said to *afford* drinking. However, at a finer level of specification, different drinking glasses can be said to afford different drinking behaviours. Indeed, Ellis and Tucker (2000) introduced the idea of 'micro-affordances', and demonstrated affordance for a specific motor configuration that was appropriate to the object in question (power vs. precision grip), rather than affordance generally (grasping). Thus it is possible that different glasses may afford different motor configurations required to interact with them, the results of which may be reflected in differences in micro-drinking behaviours (e.g., sip size, number of sips, time between sips etc.)

In line with this, research suggests a possible association between glassware and micro-drinking behaviours. Two studies report people taking larger sips from larger cups (Lawless et al., 2003; Bennett et al., 2009) although confounding of cup size with other variables in these studies mean it is not clear whether differences are due to effects of the container size (as interpreted by Lawless et al., 2003), portion size (known to impact *ad libitum* consumption; for a review see Zlatevs.ka et al., 2014), or whether drinking was 'instructed' or 'natural' (as interpreted by Bennett et al., 2009). A further two studies report a greater number of sips and slower drinking from larger vs. smaller wine glasses (Zupan et al., submitted) and straight vs. fluted beer glasses (Attwood et al., 2012). Taken together, evidence indicates an association

between smaller sips and slower overall drinking rate, but it is not yet clear which particular aspects of glass shape or size afford differences in sipping behaviours.

One possibility is that glasses afford differences in sipping based on the ease of extracting liquid from the container. Glasses with a fluted design (as used in Attwood et al., 2012; Troy et al., 2016) may lead to larger sips, relative to straight sided glasses, due to the extent to which the glass must be raised in order to extract the liquid from within. For straight sided glasses, by comparison, the angle of tilt required to extract liquid is greater. There may be an additional effect of relative fullness of container. For glasses that are relatively empty, a larger angle of tilt is generally required to drain the drink, but for full glasses, relatively less effort is required. This may explain why differences in drinking rate were only found between glass shapes when the glasses contained a full portion (Attwood et al., 2012). This could also inform as to why a constant portion of wine was consumed more slowly in larger, compared with smaller, wine glasses (Zupan et al., submitted), despite contrary predictions based on a field study on wine purchasing (Pechey et al., 2016). If ease of extraction is one mechanism that drives the effect of glass design on drinking rate, then a larger wine glass (which is relatively less full) may be predicted to lead to slower consumption, relative to a smaller wine glass (which is relatively more full), due to differences in the ease of extracting wine from the glass. This hypothesis thus depends on aspects of the glass design as well as its fullness, and may account for some of the inconsistencies in previous studies.

To investigate the hypothesis that the effect of glass shape on drinking rate is driven by ease of extraction, we will investigate whether glass shape predicts drinking rate of a soft drink, by using convex, straight-sided, and concave glasses. Based on the ease of extraction hypothesis, we would predict that convex glasses lead to slower drinking rate, relative to straight-sided glasses and concave glasses, and that concave glasses lead to faster drinking than straight sided glasses.

We will also examine whether glass shape predicts possible mediators of drinking rate (sip size, number of sips, sip duration, interval duration, and drink enjoyment). We will explore whether drinking 'tempo' differs between glass shapes, as ease of extraction may vary across the drinking period, as the fullness of the glass changes (see Table 1 for a description and definition of each of the micro-drinking behaviours examined in this study).

To explore sip size across the drinking period, we aim to use a prototype 'coaster', which measures the weight of the glass before, and after, each sip. In line with Attwood et al. (2012), we will also examine perceptual mechanisms that may account for any effect shown, by testing whether bias in midpoint estimation predicts drinking rate.

Table 1. Table demonstrating outcome measures, their definitions, and methods of measurement.

Primary outcome

Outcome measure	Definition	Measurement
Drinking rate	Total time taken to consume a drink	Time between initiation of first sip, and draining of last sip (assessed using video camera recordings)

Secondary outcomes

Outcome measure	Definition	Measurement
Sip size	Amount of liquid (ml) taken into the mouth each time the individual sips from the drink	Prototype coaster with hidden weighing scale determines weight of the glass before and after a sip is taken
Number of sips	Number of sips taken to consume the drink	Video recordings will be coded when a sip is initiated, and when it ends. From this, number of sips can be calculated.
Sip duration	Length of time taken for each sip (between the period that the glass touches the lips, and leaves the lips again)	Video recordings will be coded when a sip is initiated, and when it ends. From this, average sip duration can be calculated by summing all sip durations and dividing by number of sips.
Interval duration	Length of time taken between each sip (between the period that the glass leaves the lips, and touches the lips again)	Video recordings will be coded when a sip is initiated, and when it ends. From this, average interval duration can be calculated by summing all interval durations and dividing by number of intervals.
Drink enjoyment	Subjective measure of much the drink was enjoyed	Ratings of how 'tasty' and 'pleasant' the drink was will be averaged for each participant, with higher scores reflecting greater enjoyment
Drinking 'tempo'	Pattern of drinking rate across the drinking period, to distinguish linear, accelerated, and decelerated drinkers	A graphical display of volume remaining and its changes across time

Study Objective(s):

The main study objective is to examine the impact of glass shape on speed of drinking and a range of other micro-drinking behaviours.

The specific research questions are:
Does glass shape affect:
  (a) rate of consumption?
  (b) other micro-drinking behaviours (sip size, number of sips, sip duration, interval duration, drinking 'tempo')?
  (c) enjoyment of drinking?
  (d) mid-point estimates?

Study Design

This human laboratory study will measure drinking rate of a fixed portion (330ml) of a carbonated soft drink during a single study session.

In a between-subjects design, participants will be randomised to receive their drink in one of three glasses of similar height, weight and capacity but varying in shape: 1) convex, 2) straight-sided, or 3) concave.

Primary outcome measure
  • Total time taken to consume the drink

Secondary outcome measures
  • Micro-drinking behaviours (sip size, number of sips, sip duration, interval duration, drinking 'tempo').
  • Subjective measure of drink enjoyment
  • Degree of bias in estimating the halfway point of their drink (expressed as a difference from 0, in poured estimations of 165ml).

Study Site

Department of Psychology, Downing Site, Downing Street, Cambridge, CB2 3EB.

Participants and recruitment

A convenience sample of 162 (50% female) participants will be recruited from the students and staff at the University of Cambridge, as well as the general population. Potential participants will be informed about the study through mailing lists, flyers, and word of mouth, and those who express an interest will be sent more information in advance of attending a session. Participants will be reimbursed £7 for their time and expenses, in line with similar single session studies (e.g., Troy et al., 2016). Eligibility will be assessed at the start of the study session, and requires that individuals:

  - Are over 18 years old;
  - Are in good physical health;
  - Have English as a first language or an equivalent level of fluency;
  - Are prepared to consume a drink that contains sugar;
  - Have no known allergies to any ingredients in Appletiser ®.

The first ten participants will be tested as a pilot sample, but provided that procedures and methods generally work (including allowing appropriate time for participants to consume the beverage), this set of participants will be incorporated into the full sample ($N = 162$).

Sample size determination

We calculated that in order to detect a medium effect of $f = .25$, with 80% power, and at an alpha level of .05, a sample of 159 would be needed. In order to allow for equal numbers of males and females, a total sample size of $N = 162$ will be used in this study, with $n = 54$ in each group.

Withdrawal of Participants

Participants will be able to withdraw from the study at any time, without having to give a reason, and will be informed of this at the start of the study session. If a participant experiences an adverse event that leads them to withdraw, they will be fully reimbursed, while for all other withdrawals the participant will receive a reimbursement that reflects the time they have spent in the laboratory (e.g., 50% reimbursement if they have completed half of the study).

Randomisation

Participants will be randomised into one of three conditions, using a random number generator (with the constraint that each condition contain 54 participants, and even numbers of males and females).

Measures and Materials

Drinking task

Participants will be provided with a standard serving (330ml) of Appletiser ® (47 calories per 100ml), to consume at their own pace, while watching a nature documentary. Cans will be chilled in the fridge, and will be opened immediately prior to serving, in front of the participant. Participants will receive their drink in one of three glasses. Given that people have been found to perceive the contents differently depending on the weight (see Spence & Wan, 2015), and height (e.g., Yang & Raghubir, 2005) of the container, glasses were chosen that were roughly matched in height (90-95mm), weight (130-170g) and capacity (390-440ml), as shown in Figure 1.

Figure 1. Images of the glasses that will be used in the study. From left to right: convex, straight-sided, concave.

The outcome variables of interest concern micro drinking behaviours. Total time taken to consume the beverage (drinking rate), sip size, number of sips, sip durations and interval durations will be measured, while participants consume the beverage at their own pace.

These measures will be assessed using a video camera which will record participants while they consume their drink. To code the recordings, the lead researcher will use a computer program to indicate the initiation and end point of each sip, thus providing the data necessary to calculate: total time taken to consume the drink, number of sips, total sip duration, and total interval duration. A second independent coder will assess 20% of the videos, to determine extraction reliability (as in Troy et al., 2016).

In addition, a hidden weighing scale will be used to record the weight of the glass before and after each sip is taken (see Bennett et al., 2009 for similar procedure). This prototype coaster would will allow for an exploration of the change in drinking rate over the drinking period (drinking 'tempo'). Readings from the coaster will indicate the weight of the glass before and after each sip, thus giving a measure of sip size (from which average sip size can be calculated, and drinking 'tempo' can be explored). However, if this method proves to be unfeasible, mean sip size can be derived using the coding of sips from the video recordings (calculated as volume consumed/number of sips), as in previous studies (e.g., Zupan et al., submitted).

'Cognitive performance'

To disguise the true aims of the study, participants will be told that we are investigating the effect of glucose on cognitive performance. Thus, after they have consumed the beverage, they will complete a 4-min word-search task, as in Attwood et al. (2012) and Troy et al. (2016), using the computer. The results of this task will not be analysed.

'Taste perception'

After completing the word-search, participants will be asked to rate the drink they consumed previously, in terms of its sensory characteristics. This will follow the questions typically used in bogus taste test procedures (e.g., Field & Eastwood, 2005), although here the task will be presented *after* the drinking episode, and without the typically accompanying measure of *ad libitum* consumption. Participants will be asked to rate, from 1 (Not at all) to 10 (Extremely), how: 'fruity', 'smooth', 'sweet', 'refreshing', 'bitter', 'strong tasting', 'gassy', 'pleasant', 'light' and 'tasty', the drink was. Participants will be told that this is to investigate the effect of glucose on taste perception, although the only dimensions to be analysed include

how 'tasty' and 'pleasant' they found the drink. The ratings for these two items will be averaged, to provide the measure of drink enjoyment.

Perceptual bias task

Framed as another aspect of the impact of glucose on cognitive and perceptual performance, participants will finally complete a pouring task, assessing their ability to estimate the halfway point of the drink they previously consumed. Here, the measure will allow us to examine whether bias in midpoint estimation predicts drinking rate, as this is the mechanism that is hypothesised in previous studies (Attwood et al., 2012; Troy et al., 2016).

For this task, participants will again receive a 330ml portion of Appletiser®, in the same glass they drank from previously. They will be asked to pour out the liquid from this glass into a jug, until they think there is half the portion left in the glass. Following this first pouring task, participants will be asked to pour from the jug, into the glass, where they think half of the 330ml portion would be. Pours will be attempted three times, for each task (in the order: A, B, A, B, A, B), and the experimenter will weigh drinks after each poured estimate. For reference, they will be presented with a full 330ml glass of Appletiser ® (as in Figure 2), placed to their left.
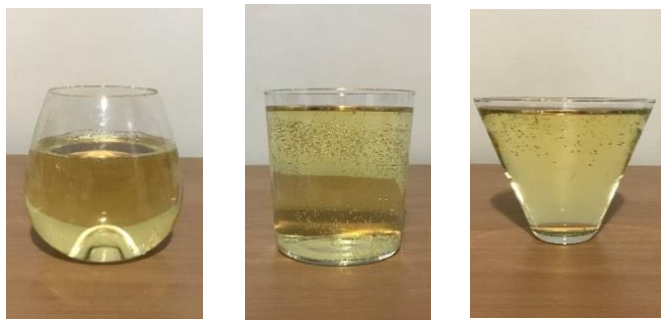
Figure 2. Images show references glasses which will be presented during the Perceptual Bias task. Images, from left to right, show the convex, straight-sided, and concave glasses, with 330ml soft drink inside.

To provide a measure of their estimated halfway point, an average will be taken from the three pours (for each of the two tasks). Perceptual bias will be coded as mean difference in ml between actual (165ml) and poured volume, with 0ml reflecting zero bias, for each of the two pouring tasks. An average perceptual estimate will then be taken from the two tasks, for each participant.

Covariates

Baseline characteristics, including age, gender, and thirst, will be recorded at the start of the study, to be adjusted for in the main analysis.

Participants will be asked to indicate on a scale from 1 (Not at all) to 10 (Extremely), how thirsty they feel.

Other variables to be adjusted for in the analysis include maximum daily temperature in Cambridge on the day of testing (see Pechey et al., 2016), and time of day, coded as minutes after midday (see Jones et al., 2016).

Funnelled debrief questions

At the end of the study, participants will be asked to indicate what they think the primary purpose of the study was. They will be given various options, to select one from the following:

1. To investigate differences in the effect of glucose on perception and cognitive performance between females and males
2. To investigate the effect of different levels of glucose on perception and cognitive performance
3. To investigate the impact of different levels of glucose on taste perception
4. To compare my taste ratings with those of participants who had different drinks
5. To investigate the impact of glass design on drinking rate
6. To investigate the impact of portion size on taste perception
7. To investigate the impact of glass design on taste perception
8. Other
9. Do not know

Participant awareness will be coded dichotomously (1 = aware, 0 = unaware), depending on whether they correctly identify '5' as the primary purpose of the study.

This will allow us to conduct sensitivity analyses, to check whether excluding individuals who correctly identified the study aims impacts the main findings.

Procedures

Participants will be recruited to the study via mailing lists, flyers and word of mouth, and told that the study is investigating the impact of glucose on cognitive performance. This is to disguise the true nature of the study, knowledge of which could influence natural drinking behaviour. Eligible participants will be invited to attend a single study session, scheduled between 10 am and 8 pm.

On arrival, participants will be given the opportunity to read the Information Sheet, and to ask questions. They will also complete eligibility screening, via a self-reported checklist as part of the Consent Form. If they are eligible, and happy to take part, participants will be asked to complete demographic questions including age, gender, and level of education. They will also be asked to rate their thirst. All questions will be administered using the Qualtrics platform on the computer.

While the participants complete these questions, the experimenter will leave to prepare the drink, by placing the can and glass on a tray. The glass the participant will receive depends on randomisation, which is constrained by participant gender. Once gender is known, the experimenter will select the appropriate condition on the Randomisation Sheet. The experimenter will then return to the testing room, and, after wiping the top of the can with a napkin, pour the full 330ml can of chilled Appletiser ® into the glass. This will be done immediately before serving to ensure consistent carbonation and temperature. The experimenter will place the drink on the coaster and inform the participant that they should try to ensure they use it. Before leaving, the experimenter will turn the camera on.

Participants will be asked to consume the beverage in their own time, whilst watching a video (as in Attwood et al., 2012). They will not be informed that they should finish within any timeframe, although after 20 minutes, the experimenter will return to the room to ensure everything is OK. Participants will be asked to open the door when they have finished the drink. Video recordings will be taken during this time, to indicate when and for how long sips are taken. In addition, the coaster will provide an indication of the volume remaining in the glass, and the size of each sip (based on the weight before/after a sip is taken).

Once the participant has finished their drink, or after 30 minutes is up (whichever comes first), the experimenter will return to the room, and remove the glass. Participants will be asked to complete the pen-and-paper word-search task, which requires them to find as many words as possible within 4 minutes. After this, the experimenter will return, and indicate that they should complete the taste perception task, where they rate the perceptual characteristics of the drink, along various descriptors, on the computer.

After this, the experimenter will return with for the perceptual bias task. The experimenter will place a mat labelled 'Reference Glass' to the participant's left. Then the reference glass (the same glass as they received earlier, and containing a full 330ml serving), will be placed on top. The experimenter will then place an identical glass directly in front of the participant. Participants will be asked to pour half of it away, into a jug with 500ml of Appletiser® already inside, which is placed to the participant's right. After the experimenter has weighed the glass to determine the volume of the pour, participants will be asked to pour from the jug, into the empty glass (half the 330ml portion on the screen). They will repeat these pouring exercises 3 times for each task. The reference glass will remain untouched to the left of the participant, throughout the exercise.

Finally, participants will be asked to complete the funnelled debrief using the computer, where they will be asked to indicate what they thought the purpose of the study was. This will allow us to examine the effectiveness of the cover story in blinding participants to the behavioural measures and the true nature of the study.

Once the participant has completed the study, a basic debrief will be provided, and they will be informed that more information will be available after testing is complete. They will be asked not to discuss the nature of the study with potential participants. Finally, they will be provided with reimbursement (£7) for their time and expenses.

Statistical Plan

The primary analysis will be a multiple linear regression to determine whether glass shape (convex, straight-sided, concave) predicts drinking rate. Using hierarchical regression, two dummy variables ('convex', 'concave') will be entered, with 'straight-sided' as a reference variable. Analyses will also be run to adjust for baseline differences; age, thirst, time of day, and maximum daily temperature will be entered as covariates, along with gender (as a dummy variable). Next, bias in midpoint estimation will be entered to examine whether it predicts drinking rate.

Secondary analyses will include linear regressions to investigate whether glass shape (convex, straight-sided, concave) predicts micro-drinking behaviours (sip size, number of sips, sip duration, interval duration), or drink enjoyment. Exploratory analyses will compare 'drinking tempo', or the change in drinking rate across the drinking period, between conditions.

Sensitivity analyses will exclude participants who correctly guessed the purpose of the study, to determine whether this impacts the main findings.

References

Attwood, A. S., Scott-Samuel, N. E., Stothart, G., & Munafò, M. R. (2012). Glass shape influences consumption rate for alcoholic beverages. *PloS one*, *7*(8), e43007.

Bennett, J. W., Van Lieshout, P. H., Pelletier, C. A., & Steele, C. M. (2009). Sip-sizing behaviors in natural drinking conditions compared to instructed experimental conditions. *Dysphagia*, *24*(2), 152-158.

Department of Health. (2010). *Healthy lives, healthy people: our strategy for public health in England* (Vol. 7985). The Stationery Office. Available at: https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/216096/dh_127424.pdf (08 February 2017, date last accessed).

Ellis, R., & Tucker, M. (2000). Micro-affordance: The potentiation of components of action by seen objects. *British journal of psychology*, *91*(4), 451-471.

Field, M., & Eastwood, B. (2005). Experimental manipulation of attentional bias increases the motivation to drink alcohol. *Psychopharmacology*, *183*(3), 350-357.

Gibson, J. J. (1977). Perceiving, acting, and knowing: Toward an ecological psychology. *The Theory of Affordances*, 67-82.

Gibson, J. J. (1979). *The ecological approach to visual perception.* Boston, MA: Houghton-Mifflin.

Hollands, G. J., Shemilt, I., Marteau, T. M., Jebb, S. A., Lewis, H. B., Wei, Y., Higgins, J., & Ogilvie, D. (2015). Portion, package or tableware size for changing selection and consumption of food, alcohol and tobacco. *The Cochrane Library*.

Hollands, G. J., Marteau, T. M., & Fletcher, P. C. (2016). Non-conscious processes in changing health-related behaviour: a conceptual analysis and framework. *Health psychology review*, *10*(4), 381-394.

Lawless, H. T., Bender, S., Oman, C., & Pelletier, C. (2003). Gender, age, vessel size, cup vs.. straw sipping, and sequence effects on sip volume. *Dysphagia*, *18*(3), 196-202.

Marteau, T. M., Hollands, G. J., & Fletcher, P. C. (2012). Changing human behavior to prevent disease: the importance of targeting automatic processes. *Science*, *337*(6101), 1492-1495.

McGill, R., Anwar, E., Orton, L., Bromley, H., Lloyd-Williams, F., O'Flaherty, M., Taylor-Robinson, D., Guzman-Castillo, M., Gillespie, D., Moreira, P., & Allen, K. (2015). Are interventions to promote healthy eating equally effective for all? Systematic review of socioeconomic inequalities in impact. *BMC public health*, *15*(1), 457.

Norman, D. A. (1988). *The psychology of everyday things*. New York: Basic Books.

Pechey, R., Couturier, D. L., Hollands, G. J., Mantzari, E., Munafò, M. R., & Marteau, T. M. (2016). Does wine glass size influence sales for on-site consumption? A multiple treatment reversal design. *BMC public health*, *16*(1), 390.

Spence, C., & Wan, X. (2015). Beverage perception and consumption: the influence of the container on the perception of the contents. *Food Quality and Preference*, *39*, 131-140.

Thaler, R. H., & Sunstein, C. (2008) *Nudge: improving decisions about health, wealth, and happiness*. New Haven: Yale University Press.

Troy, D. M., Attwood, A. S., Maynard, O. M., Scott-Samuel, N. E., Hickman, M., Marteau, T. M., & Munafò, M. R. (2016). Effect of glass markings on drinking rate in social alcohol drinkers. *The European Journal of Public Health*, ckw142.

Yang, S., & Raghubir, P. (2005). Can bottles speak volumes? The effect of package shape on how much to buy. *Journal of Retailing*, *81*(4), 269-281.

Zlatevs.ka, N., Dubelaar, C., & Holden, S. S. (2014). Sizing up the effect of portion size on consumption: a meta-analytic review. *Journal of Marketing*, *78*(3), 140-154.

Zupan, Z., Pechey, R., Couturier, D.L,. Hollands, G.J., & Marteau, T.M. Micro-drinking behaviours and consumption of wine in different wine glass sizes: A laboratory study (Submitted)

3.2. Study 1 published article

Langfield, T., Pechey, R., Pilling, M., & Marteau, T. M. (2018). Impact of glass shape on time taken to drink a soft drink: A laboratory-based experiment. *PLOS ONE*, *13*(8).

Available at: https://journals.plos.org/plosone/article?id=10.1371/journal.pone.0202793

209

3.3. Study 1 recruitment

3.3.1 Flyer used for recruitment

UNIVERSITY OF CAMBRIDGE
Public Health and Primary Care
The Primary Care Unit

Earn £7 for 30-45 min!

The impact of glucose on cognitive performance

Are you…
- over 18 years old?
- in good physical health?
- fluent in English?
- prepared to consume a drink that contains sugar?
- Not allergic to the ingredients in Appletiser ®?

WHERE?!
Sir William Hardy Building, Downing Site, Downing Street, CB2 3EB.

HOW DO I SIGN UP?!
Contact Tess on ▮▮▮▮▮▮▮▮▮▮▮▮ for more information or to choose a time slot!

WHAT DO I HAVE TO DO?
The study involves drinking a glass of Appletiser®, and completing some questionnaires and short tasks.

3.3.2 Email used for mailing lists

Psychology experiment – earn £7 for a 30-45min task!

I am currently running a study looking to investigate the impact of glucose on cognitive performance.

We are looking for participants who:
- are aged 18 or over;
- are in good physical health;
- have English as a first language/equivalent level of fluency;
- are prepared to consume a drink that contains sugar;
- have no known allergies to the ingredients in Appletiser ®.

The study involves consuming a 330ml glass of Appletiser ®, and completing some questionnaires and other short tasks. It should last about 45 minutes, and you would be reimbursed with **£7** for your time and expenses.

The study takes place in the Sir William Hardy Building, Downing Site, Cambridge, CB2 3EB.

If you would like to sign up, please contact Tess on ▮▮▮▮▮▮▮▮▮▮▮▮▮

3.4. Study 1 participant information and consent

UNIVERSITY OF CAMBRIDGE
Public Health and Primary Care
The Primary Care Unit

Participant Information Sheet:

Glucose and Cognitive Performance study

You are being invited to take part in a research study. Before you decide to take part it is important for you to understand why the research is being done and what it will involve. Please take time to read the following information carefully and discuss it with others if you wish. A member of the team can be contacted if there is anything that is not clear or if you would like more information. Take time to decide whether or not you wish to take part.

Purpose of the study

This study will investigate the short-term effects of glucose on cognitive performance. You will be asked to attend a single session of approximately 45 minutes, in which you would consume a glass of Appletiser ®, and then complete a word-search task, as well as some perceptual measures.

Why have I been chosen?

You have been invited to take part as you expressed an interest in this study.

Do I have to take part?

It is up to you whether you decide to take part. If you do decide to take part, you will be asked to sign a consent form prior to commencing the study. If you change your mind, withdrawal will involve no penalty or loss, now or in the future.

What will happen to me if I take part?

You will be asked to come to the Department of Psychology for a single 45-minute session. If you are eligible to take part, you will be given the opportunity to ask questions, and asked to sign a consent form. After an initial questionnaire, you would be asked to drink a glass of Appletiser® at your own pace, whilst watching a nature documentary. You would be videotaped during this time to ensure implementation fidelity. You would then be given 4 minutes to find as many words as possible in a word-search task. After this you would complete a short questionnaire, followed by an exercise on perceptions that involves pouring liquids. After finishing the study, you would then be reimbursed £7.

Are there possible disadvantages and/or risks in taking part?

There are no risks associated with taking part.

What are the possible benefits of taking part?

There are no direct benefits of taking part in this research study and your participation is entirely voluntary.

Will my taking part in this project be kept confidential?

All data and personal information will remain confidential, and would only be available to members of the research team. Any personal details would be kept on a secure computer, and access to this information would only be available to the immediate research team.

What will happen to the results of the research project?

Once the study is complete, the data will be analysed and written up for publication in journals. Results may also be presented at conferences. Your personal responses during the study would not be identifiable in any way, as data will be aggregated. If you would like a copy of the final paper, you may request that this be sent to you once it is published.

Video recordings will be identified only by a code, and will only be available to those on the research team. They will not be used for any purposes other than the research project. These tapes will be destroyed after 10 years.

At the end of the study your data would become "open data". This means that it would be stored on an online database, so that anyone who is interested in the research is able to examine the data, and conduct their own analyses. However, as stated, all data will be anonymised before being made publicly available, so there would be no way to identify you personally.

Can I withdraw my data?

Yes. If you decide that you do not want your data to be used you can withdraw your data at any time after the study, for any reason, up until the data is shared as "open data". After this, all links between your personal information and the research data would be destroyed. Thus we would not be able to withdraw your data because we would not be able to identify which data came from you.

Who is organising and funding the research?

This study is being organised by the Behaviour and Health Research Unit at the University of Cambridge, and funded by a PhD grant from the Medical Research Council.

Ethical review of the study

The project has received ethical approval from the Psychology Research Ethics Committee of the University of Cambridge (reference: PRE.2017.018)

Contact for further information

For any questions or concerns about the study, please contact Tess Langfield at ▇▇▇▇▇▇▇▇▇▇ or Professor Theresa Marteau at ▇▇▇▇▇▇▇▇▇▇▇▇▇▇▇▇▇ or on ▇▇▇▇▇▇▇. Alternatively, please write to us at: Institute of Public Health, Robinson Way, Cambridge, CB2 0SR, UK.

UNIVERSITY OF CAMBRIDGE

Public Health and Primary Care
The Primary Care Unit

Tess Langfield

████████████████

CONSENT FORM

Glucose and cognitive performance study

Please confirm that you agree to the following statements, by writing your initials in each box.

PLEASE CONFIRM THAT YOU:

Have read and understand the Information Sheet;

Have had satisfactory answers to any questions asked about the study;

Understand that all personal information will remain confidential and all efforts will be made to ensure you cannot be identified (except as might be required by law);

Agree that data gathered in this study may be stored anonymously and securely, and may be used for future research;

Understand that this study will be recorded, and that video recordings will not be made available beyond the research team (recordings will be kept securely for 10 years before being destroyed);

Understand that participation is voluntary and that you are free to withdraw at any time without having to give a reason;

Are at least 18 years of age;

Are in good physical health;

Have English as a first language or an equivalent level of fluency;

Are prepared to drink a drink that contains sugar, and have no known allergies to the ingredients in Appletiser ®;

Agree to take part in this study.

I HEARBY FULLY AND FREELY CONSENT TO MY PARTICIPATION IN THIS STUDY

Date					Signature of the participant:
	Day	Month	Year		
					Print name:
					Signature of the investigator:

213

3.5. Study 1 online questionnaire

UNIVERSITY OF CAMBRIDGE

PARTICIPANT INFORMATION

Before we begin the study, please answer the following questions about yourself.

Gender

O Male
O Female
O Other
O Prefer not to say

Age

[   ]

What is the highest level of education you have achieved?

O GCSE/O Level
O AS/A Level
O Undergraduate degree
O Postgraduate degree (e.g. Masters, PhD)
O None

Now, thinking about how you feel right now, how thirsty are you?

Please give your answers from 1 to 10, where 1 represents 'Not at all' and 10 represents 'Extremely'.

1	2	3	4	5	6	7	8	9	10
O	O	O	O	O	O	O	O	O	O

Please click 'Next' and wait for the experimenter to return.

Next

WORDSEARCH TASK

You have **4 minutes** to find as many words as you can from this letter grid. The experimenter will return when your time is up.

Type your answers in the text box below, separated by a comma (e.g. cat, there, going etc.)

There are over **30** possible words to find. They may be written forwards, or backwards.

```
A R A L O P O E G X B H E P L C
N H S R J G U C T A O R R O E A
M O Y O R K E A L U O E F Q U E
R H I A R M C L S B U G N E F R
O W C S O E R E R U E A Y F H A
F V D T S O A A N A R C O T I C
E C I E O I H S K F U D Z O C R
D O O M N E M E O P T S R O Q E
N D E N T S A D R N U I M O C T
D P L S S R E H A O F M B O P T
D R I N K P S J X N E P L A D E
T W H Y E I I R Q R D L W Q K L
L S G S M D A R C Z L E J N T E
R Z I E E W I I E M F E I L E B
S P L O E R A H E S R U N W E L
E B Q W M L F B H S U B M A F Y
```

Please enter words you find here:

The experimenter will return after 4 minutes. Please use the time to find as many words as you can.

215

TASTE PERCEPTION

Thinking back to the drink you consumed previously: please judge it along the following criteria. Give your answers from 1 to 10, where 1 represents **'Not at all'** and 10 represents **'Extremely'**.

	1 = 'Not at all'								10 = 'Extremely'	
	1	2	3	4	5	6	7	8	9	10
Fruity	O	O	O	O	O	O	O	O	O	O
Smooth	O	O	O	O	O	O	O	O	O	O
Sweet	O	O	O	O	O	O	O	O	O	O
Refreshing	O	O	O	O	O	O	O	O	O	O
Bitter	O	O	O	O	O	O	O	O	O	O
Strong tasting	O	O	O	O	O	O	O	O	O	O
Gassy	O	O	O	O	O	O	O	O	O	O
Pleasant	O	O	O	O	O	O	O	O	O	O
Light	O	O	O	O	O	O	O	O	O	O
Tasty	O	O	O	O	O	O	O	O	O	O

Please open up the door when you have completed the ratings.

Next

216

VOLUME PERCEPTION TASK

Please wait for the experimenter to return before proceeding.

Next

Please indicate what you think the *main* purpose of the study was, choosing one from the following options.

○ To investigate differences in the effect of glucose on perception and cogntive performance between females and males

○ To investigate the effect of glucose on perception and cognitive performance

○ To investigate the impact of different levels of glucose on taste perception

○ To compare my taste ratings with those of participants who had different drinks

○ To investigate the impact of glass design on drinking rate

○ To investigate the impact of glass design on perception of volume

○ To investigate the impact of glass design on taste perception

○ Other

○ Do not know

If you selected 'Other', please specify what you think the main purpose of the study was:

Next

217

3.6. Study 1 debrief

3.6.1 Initial debrief

UNIVERSITY OF CAMBRIDGE
Public Health and Primary Care
The Primary Care Unit

Short-term effects of glucose on cognitive performance

Thank you very much for taking part in this study, exploring the short-term impacts of glucose on cognitive performance. We can give you more information about the study aims via email, once all participants have completed the study. If you have any questions or concerns about this, please do not hesitate to contact one of the research team using the details below.

CONTACT DETAILS:

If you have any questions or concerns about the study, please contact:

Prof. Theresa Marteau	*or*	Tess Langfield
Email:		
Tel:		
Address:	Institute of Public Health, Robinson Way, Cambridge, CB2 0SR, UK	

3.6.2 Final debrief

UNIVERSITY OF CAMBRIDGE
Public Health and Primary Care
The Primary Care Unit
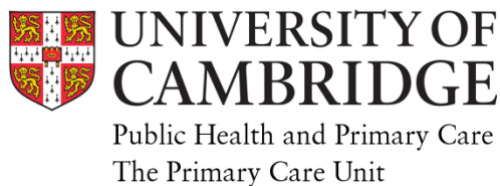
Impact of glass shape on drinking rate: an experimental study testing mechanisms

Thank you very much for taking part in this study. Your participation has been valuable in helping us to understand more about drinking behaviour. You were originally told that the purpose of the study was to investigate the effect of glucose on cognitive performance. Now that the study is complete, we would like to inform you of the true purpose of the research.

Those taking part received 330ml of Appletiser ® served in glass that was (a) convex, (b) straight-sided, or (c) concave.

To examine drinking behaviour in detail:
- We took video recordings of the study sessions. These recordings will only be available to the study researchers, and are for research purposes only. Recordings will be destroyed after 10 years.
- We may have used hidden weighing scales to monitor your rate of consumption of the drink.

The purpose of the study was to determine whether aspects of our drinking environment (in this case, the glass used) affect drinking speed, and other drinking behaviours such as sip size. These findings have possible implications as to the optimal design of glassware, in efforts to reduce consumption of sugary and alcoholic drinks. We withheld the true aims of the study from you because we did not want you to be conscious of your drinking behaviour during the task. For example, knowing that we were interested in your drinking behaviour may have caused you to speed up or slow down your drinking.

All data will be stored anonymously and securely. However, if you are unhappy about your information being used in relation to the study aim described above, please let us know, and we can withdraw it from the study immediately. You have the right to withdraw from the study, at any time, without having to give a reason, up until the data is shared as "open data" (when we will no longer be able to identify which data is yours).

To stay up to date with our research group and its publications, please visit our website: http://bhru.iph.cam.ac.uk/.

CONTACT DETAILS:

If you have any questions or concerns about the study, please contact:

Prof. Theresa Marteau   *or*   Tess Langfield
Email: ████████████████   ████████████████
Tel: ████████████
Address: Institute of Public Health, Robinson Way, Cambridge, CB2 0SR, UK

Appendix for Chapter 4

4.1. Study 2 pre-registered study protocol

Langfield, T., Pechey, R., Pilling, M., & Marteau, T. M. (2018). Study protocol: Impact of glass shape on drinking time: a laboratory-based replication study exploring mechanism

Available at: https://osf.io/yhvtk/

Study protocol: Impact of glass shape on drinking time: a laboratory-based replication study exploring mechanism

Background

There is some evidence that the design of glassware can influence drinking behaviour (Attwood et al., 2012; Pechey et al., 2016; 2017; Hollands et al., 2015). In a previous experiment we found an effect of glass shape on total drinking time, with wider rimmed, outward-sloped tumblers leading to faster consumption of a soft drink, compared to straight-sided tumblers. While the mechanisms underlying this effect are largely unknown, micro-drinking behaviours, sip size and biases in midpoint estimates have been suggested as potential candidates. The aims of the current study are to (1) to replicate previous findings with regard to the effect of glass shape on time taken to consume a soft drink, and (2) further explore the role of (a) micro-drinking behaviours including sip size and (b) biases in midpoint estimates as potential mechanisms underlying any differences in consumption time by glass shape.

Research questions

1. Does glass shape (outward-sloped vs straight-sided) affect total drinking time?

2. Do glasses of different shapes lead to differences in:
   (c) micro-drinking behaviours of sip size (ml), sip durations (sec), interval durations (sec), and 'drinking tempo' patterns (decelerated, accelerated, linear)?
   (d) bias in mid-point estimates?

3. Do micro-drinking behaviours and bias in midpoint estimates predict speed of drinking?

Study Design

This human laboratory study will measure drinking rate of a fixed portion (330ml) of a carbonated soft drink during a single study session.

In a between-subjects design, participants will be randomised to receive their drink in one of two glasses of similar height, weight and capacity but varying in wall slope: straight-sided or outward-sloped.

Primary outcome measure
- Total time taken to consume the drink (min)

Secondary outcome measures

- Micro-drinking behaviours of mean sip size, mean sip duration, mean interval duration, 'drinking tempo' (decelerated, accelerated, linear). These outcome measures will be analysed both overall, and within different subsets of the data (e.g., first half of drinking period, second half of drinking period).
- Degree of bias in estimating the halfway point of their drink, expressed as a difference from zero, in poured estimations of 165ml.

Measures

Primary outcome measure

Total drinking time - Total drinking time (min) will be measured using video recordings of the drinking sessions. These video recordings will be coded using a program which extracts the time at each sip initiation and sip end (indicated by key press). Total drinking time is calculated by taking the difference in time between: the initiation of the first sip (when the glass touches the lips for the first time), and the endpoint of the last sip (when the glass leaves the lips for the final time).

Secondary outcome measures

(a) Micro-drinking behaviours

Micro-drinking behaviours will also be measured using video recordings of the drinking sessions, coded manually using a program (with key presses signalling the initiation and endpoint of sips).

Mean sip size - Mean sip size (ml), or the average volume consumed per sip, will be measured by dividing 330ml (total volume consumed in the task) by the number of sips (extracted from the video coded data).

Mean sip duration - Mean sip duration (sec), or the average time spent sipping, will be calculated by taking the average of all sip durations (the difference between the initiation and end point of a given sip), again derived from the video coded data.

Mean interval duration - Mean interval duration (sec), or the average time spent in between sips, will be calculated by taking the average of all inter-sip intervals (the difference between the endpoint of a given sip and initiation of the next sip), again derived from the video coded data.

Drinking tempo - 'Drinking tempo', or the dynamic pattern of drinking rate across the drinking period, will be measured by obtaining periodic estimates of volume remaining in the glass. This will give us a measure of cumulative intake across time. These volume estimates will be recorded (ideally) after each sip, or (more likely) after each time the glass is clearly visible to the camera, located on the table (i.e., not in motion). These individual data points about the estimated volume remaining will then allow us to plot an individual's 'drinking curve', to determine their drinking tempo pattern (linear, decelerated, accelerated; see Figure 1). The volume estimates will be based on an algorithm that compares the image from the video recording with images of the drink at different volumes.
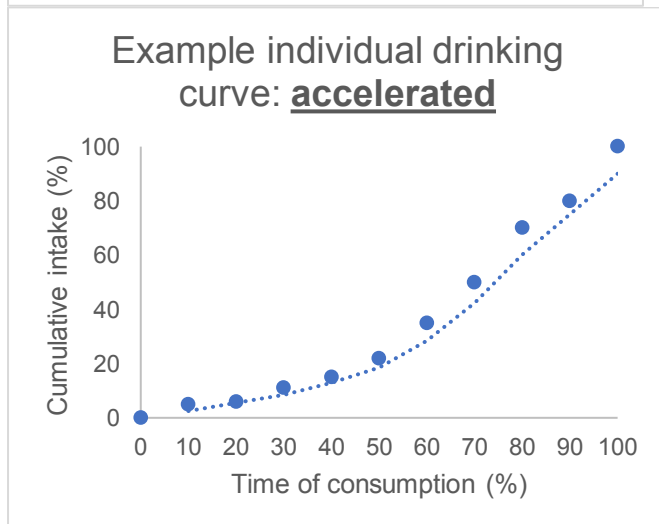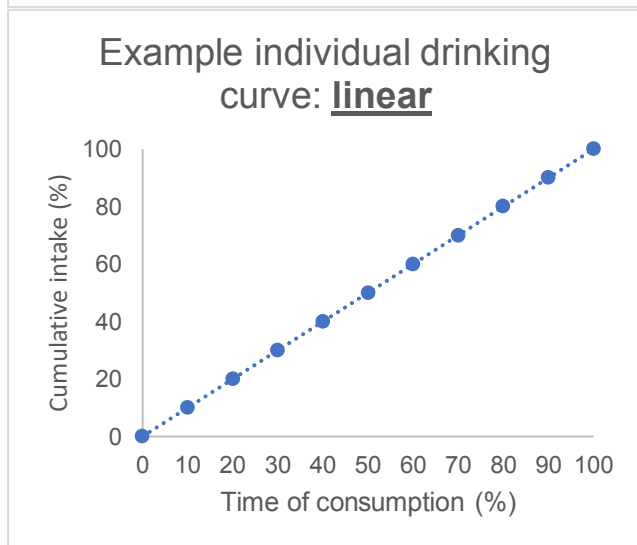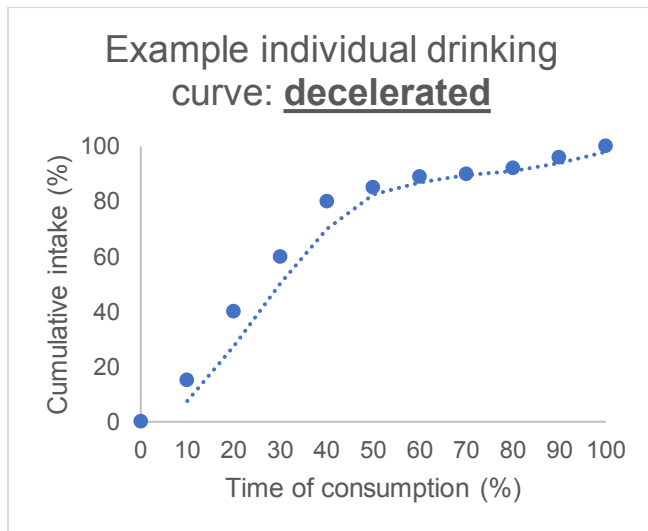
Figure 1. Graphs to show hypothetical examples of 'drinking tempo', the change of drinking rate across the drinking period (linear, decelerated, accelerated).

(b) Bias in midpoint estimation

Six poured estimates of the midpoint of the drink (165ml) will be averaged to provide a single estimate for each participant. This will then be subtracted from 165 (the true midpoint), to determine bias. Negative values reflect underestimation of the true midpoint (pouring too little liquid into the glass), while positive values indicate overestimation of the true midpoint (pouring too much liquid into the glass).

Materials

Glassware

The glasses in the study are roughly matched in height, weight, and capacity, but differ in wall slope (see Figure 2).
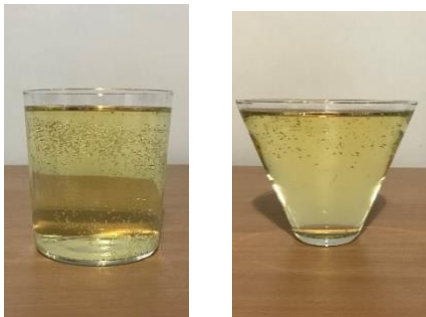
Figure 2. Images of the glasses to be used, with 330ml Appletiser inside.

Participants and recruitment

A convenience sample of 200 (50% female) participants will be recruited from the students and staff at the University of Cambridge, as well as the general population. Potential participants will be informed about the study through mailing lists, flyers, and word of mouth. Participants will be reimbursed £7 for their time and expenses. Eligibility will be assessed at the start of the study session, and requires that individuals:

-   Have <u>not</u> taken part in my previous experiment;
-   Are over 18 years old;
-   Are in good physical health;
-   Have English as a first language or an equivalent level of fluency;
-   Are prepared to consume a drink that contains sugar;
-   Have no known allergies to any ingredients in Appletiser ®.

Sample size determination

A previous study gave a mean (SD) drinking time (mins) on the log scale as 0.802 (0.277) & 0.691 (0.314) for the straight-sided and outward-sloped glass groups respectively. A power calculation for log drinking time, using a one-tailed test with unequal variances, with 80% power, at an alpha level of 5%, indicated that we would need a sample of $N = 182$ (91 per group) to detect the effect size of 0.372 observed in the previous study. To ensure equal proportions of males and females in each group, and to allow for possible attrition due to video equipment malfunction or obscured video footage, a total sample size of $N = 200$ (100 per group) will be used.

Randomisation

Participants will be randomised into one of the two conditions, using a random number generator (with each condition containing 100 participants, and equal numbers of males/females).

Procedure

Eligible participants attend a single study session, lasting around 30-40 minutes, scheduled between 8 am and 8 pm. On arrival, participants complete eligibility screening, via a self-reported checklist as part of the Consent Form. To begin the study, they will be asked demographic questions, including age, gender, height, weight, and thirst (1-10).

For the drinking task, a 330ml can of chilled Appletiser ® will be poured into the glass they have been randomised to drink from. This will be done immediately before serving to ensure consistent carbonation and temperature. Participants will be asked to consume the beverage in their own time, whilst watching a documentary. They will be videotaped during this time.

Once the participant has finished their drink, the experimenter will return and remove the glass. Participants then complete the word-search task (as a cover story for the experiment), which requires them to find as many words as possible in a letter grid, within 4 minutes. After this, they rate the taste/flavour of the drink along 10 descriptors (again, as a filler task).

They will then complete the volume estimation task. First, the experimenter will place a 330ml glass of Appletiser directly in front of the participant (the same glass as they were randomised to drink from). Participants then pour half of it into a jug with 660ml of Appletiser® already inside, placed behind the glass. After the experimenter has noted down the estimated pour (ml), the participant pours another midpoint estimate, from the jug into their empty glass. There will be six estimates in total (three of each type). Participants will be invited to use a 'Reference Glass' throughout the task, which contains the full 330ml portion.

Finally, participants will be asked what they thought the purpose of the study was. This will allow us to examine the effectiveness of the cover story in blinding participants to the behavioural measures and the true nature of the study.

Once the participant has completed the study, a basic debrief will be provided, and they will be informed that more information will be available after testing is complete. They will be asked not to discuss the nature of the study with potential participants. Finally, they will be reimbursed (£7).

Analysis plan

The primary analysis will be a multiple regression to determine whether glass shape (straight-sided, outward-slope) predicts total drinking time (min). Analyses will also be run to adjust for potential baseline differences; age, thirst, BMI, and gender (as a dummy variable).

Secondary analyses will include regressions to investigate whether glass shape (straight-sided, outward-sloped) predicts micro-drinking behaviours (mean sip size, mean sip duration, mean interval duration, drinking tempo), or bias in midpoint estimation. We will also analyse whether micro-drinking behaviours and bias in midpoint estimates predict drinking rate, and whether micro-drinking behaviours change over time.

Sensitivity analyses will exclude participants who correctly guessed the purpose of the study, to determine whether this impacts the main findings.

References

Attwood, A. S., Scott-Samuel, N. E., Stothart, G., & Munafò, M. R. (2012). Glass shape influences consumption rate for alcoholic beverages. *PloS one*, *7*(8), e43007.

Cliceri, D., Petit, E., Garrel, C., Monteleone, E., & Giboreau, A. (2017) Effect of glass shape on subjective and behavioral consumer responses in a real-life context of drinking consumption. *Food Quality and Preference, 64* (July, 2017), 187-191. doi:10.1016/j.foodqual.2017.09.008

Hollands, G. J., Shemilt, I., Marteau, T. M., Jebb, S. A., Lewis, H. B., Wei, Y., Higgins, J., & Ogilvie, D. (2015). Portion, package or tableware size for changing selection and consumption of food, alcohol and tobacco. *The Cochrane Library* (9). doi:10.1002/14651858.CD011045.pub2.

Pechey, R., Couturier, D. L., Hollands, G. J., Mantzari, E., Munafò, M. R., & Marteau, T. M. (2016). Does wine glass size influence sales for on-site consumption? A multiple treatment reversal design. *BMC public health*, *16*(1), 390. doi:10.1186/s12889-016-3068-z

Pechey, R., Couturier, D. L., Hollands, G. J., Mantzari, E., Zupan, Z., & Marteau, T. M. (2017). Wine glass size and wine sales: a replication study in two bars. *BMC Research Notes, 10*(287). doi:10.1186/s13104-017-2610-0.

4.2. Study 2, 3 and 4 article

Langfield, T., Pechey, R., Gilchrist, P. T., Pilling, M. A., & Marteau, T. M. (2020). Glass shape influences drinking behaviours in three laboratory experiments. *Scientific Reports, 10*(1), 1-11.

Straight-sided glasses: a promising intervention to reduce how much we drink?

Tess Langfield[1*], Rachel Pechey[1], Philippe T. Gilchrist[2,3], Mark Pilling[1], Theresa M. Marteau[1].

[1] Behaviour and Health Research Unit, Department of Public Health and Primary Care, University of Cambridge, Cambridge, CB2 0SR, United Kingdom

[2] Department of Psychology, Macquarie University, Macquarie Park, NSW 2109, Australia

[3] MRC/BHF Cardiovascular Epidemiology Unit, Department of Public Health and Primary Care, University of Cambridge, Cambridge, CB1 8RN, United Kingdom.

* To whom correspondence may be addressed. Email: ▮▮▮▮▮▮▮▮▮▮

ORCiDs - TL - ORCiD 0000-0003-0552-1019; RP - ORCiD 0000-0002-6558-388X; PTG – 0000-0001-5036-3369; MP - ORCiD 0000-0002-7446-6597; TMM - ORCiD 0000-0003-3025-1129.

Abstract

Reducing consumption of drinks which contain high levels of sugar and/or alcohol may improve population health. There is increasing interest in health behaviour change approaches which work by changing cues in physical environments ("nudges"). Glassware represents a modifiable cue in the drinking environment that may influence how much we drink. Here, we report three laboratory experiments measuring consumption of soft drinks served in different glasses (straight-sided vs outward-sloped), using distinct paradigms to measure drinking. In Study 1 (N=200), though total drinking time was equivalent, participants consumed a soft drink with a more 'decelerated' trajectory from outward-sloped tumblers, characterised by a greater amount consumed in the first half of the drinking episode. In Study 2 (N=72), during a bogus taste test, participants consumed less from straight-sided wine flutes than outward-sloped martini coupes. In Study 3 (N=40), using facial electromyography to explore a potential mechanism for decreased consumption, straight-sided glasses elicited more 'pursed' lip embouchures, which may partly explain reduced consumption from these glasses. Using a combination of methods, including objective measures of volume drunk and physiological measures, these findings suggest that switching to straight-sided glasses may be one intervention contributing to the many needed to reduce consumption of health-harming drinks.

227

Main Text

Introduction

Overconsumption of drinks containing excess sugars and alcohol is a major threat to population health globally (1-4). Developing novel and effective interventions to change drinking behaviour is thus an important goal of research and policy. There is increasing interest in approaches that work by changing cues in physical environments – known also as "nudging" (e.g., 5-8). Broadly speaking, these interventions are thought to engage automatic (rather than reflective) processes, requiring relatively less active engagement or high-level cognitive processing to elicit a change in behaviour than other types of behaviour change techniques (9). One aspect of the drinking environment that has the potential to influence drinking behaviour – possibly outside of awareness – is the glassware in which drinks are served.

There is a growing evidence base for the effect of glass size and shape on drinking behaviours. Wine glass size has increased over the past 300 years – in particular in the last 30 years (10) – with some evidence that the use of larger wine glasses increases wine consumed (11-13). The shape of a glass – in particular, whether it is outward-sloped or straight-sided – may also influence consumption. Two studies have explored the impact of glass shape on the total time spent drinking, finding slower consumption from straight-sided glasses for beer served in beer glasses (14) and for a soft drink served in tumblers (15). It remains to be seen whether straight-sided glasses also reduce the amount consumed, and what the underlying mechanisms might be.

Several mechanisms might contribute to the effects of glassware design on consumption. One concerns biases in visual perception. Specifically, when estimating the volume remaining in a drink, people may use height as a cue to volume (16). For example, the true midpoint of drinks presented in outward-sloped glasses is underestimated, as compared to straight-sided ones (14-15, 17). This midpoint bias reflects an inability to make accurate visual judgments about the volume remaining in the glass, which might in turn influence drinking speed and amount consumed.

Another possible mechanism concerns the physical characteristics of the container such that glasses of certain shapes cue or 'afford' larger or smaller sip sizes and/or other micro-drinking behaviours affecting consumption. For example, there is some evidence that glasses of different shapes lead to different drinking trajectories, with

228

more decelerated drinking found from short, wide glasses than from tall, narrow ones (18). Decelerated drinking is characterised by a greater amount being consumed in the first half of the drinking episode. Characterising these trajectories may help understand the mechanisms that drive the effects of glass shape on consumption.

One way that affordance of glass shape on drinking may operate is via the position of the lips – 'embouchures' – and in particular, the extent to which they are pursed during sipping. The orbicularis oris muscle is responsible for compressing the lips and protruding them forward into a pucker (19). Activity in these muscles has been found to distinguish subtle differences in embouchures of musicians playing brass and wind instruments (20-22). To our knowledge, only one study has investigated the impact of the receptacle from which a drink is consumed on activity in the orbicularis oris muscle (23). These researchers measured lip muscle activity using facial electromyography and found higher levels of muscle activity – indicative of a more pursed embouchure – when sips were taken through a straw, as compared to those taken from a cup or a spoon. However, there is an absence of evidence characterising the embouchures associated with drinking from differently-shaped glasses and the relationship between embouchure and sip size.

The present research

The present set of studies aimed to estimate the effects of glass shape – straight-sided vs outward-sloped – on several drinking behaviours, measured in laboratory studies using distinct paradigms to measure drinking, including direct observation and physiological measures.

Study 1 tested the effect of glass shape – straight-sided vs outward-sloped tumblers (see Fig. 1) – on drinking rates. We used video recordings to extract relevant information, including the height of liquid remaining in the glass, which allowed us to model the pace of consumption over time – i.e., 'drinking trajectory'– from the images. The experimental procedures have been used in previous studies also measuring the effect of glass shape on total drinking time (14-15), and drinking trajectory (18). Study 2 extended Study 1 by exploring the effect of glass shape on the volume consumed, using more extreme differences in glass shape – comprising straight-sided wine flutes vs outward-sloped martini coupes (see Fig. 1). This experiment involved a bogus taste test in which participants were asked to drink as much or as little as they liked while rating the flavour of the drinks (e.g., 24,25). The bogus taste test has been validated and correlates with other measures of intake for alcohol (26) and

229

food (27). Study 3 tested a potential mechanism for decreased consumption from straight-sided glasses, namely, the extent the lips are pursed during sipping – lip embouchure. We used facial electromyography (EMG) to detect the muscle activity of the upper and lower lips during sipping of soft drinks from straight-sided wine flutes and outward-sloped martini coupes (see Fig. 2 for placement of facial electrodes). Taken together, this set of studies provides evidence to advance our understanding both of the potential impact of glass shape on soft drink consumption, and 'why' it might be effective (i.e., through exploring mechanisms).

All studies (including planned analyses) were pre-registered on the Open Science Framework, where data and code is also available (https://osf.io/4tx3c/; https://osf.io/j9hqu/; https://osf.io/75b89/). Analyses were conducted in RStudio. For a summary of key outcome measures split by condition, see Table 1. Model diagnostics were checked and were all found to be satisfactory. Removing individuals who guessed the purpose of each study did not impact the findings (see SI Appendix). Video coding reliability was checked by an independent coder for Study 1 and 2 and was found to be satisfactory (see SI Appendix).

Results

Study 1

Overview

In Study 1, we sought to test whether drinking rates differed, depending on the glass being drunk from. We predicted that, in line with a previous study (15), soft drinks would be consumed more slowly from straight-sided glasses than outward-sloped ones. Additionally, we explored whether micro-drinking behaviours, including drinking trajectories – the pattern of consumption over time, mean sip size, mean sip duration, mean interval duration, as well as visual perception of drink midpoints, would differ.

We recruited 200 participants (50% female) – predominantly students and staff at the University of Cambridge, England – to take part in the study between May and July 2018. For more information on sample size determination and eligibility, see SI Appendix. Due to a video-recording malfunction, data from two participants (both female) were excluded from the analysis, leaving a total sample of N=198. Baseline demographic and study-relevant characteristics are given in SI Appendix Table S1.

In a between-subjects design, participants were randomised (stratified by gender) to receive a soft drink in one of two glasses (straight-sided or outward-sloped tumbler). Participants consumed the drink at their own pace while watching a nature documentary (as in previous studies; 14,15), and the primary outcome was total drinking time. Video recordings were taken during the experiment and subsequently coded for all drinking behaviours - total drinking time, drinking trajectory i.e., drinking pattern over time, mean sip size, mean interval duration, and mean sip duration. After finishing the drink, participants completed a midpoint estimation task by physically filling or emptying drinks from the same shape glass they had previously drunk from until the glass was perceived to be

231

half-full (a task used in previous studies; 15, 17). Midpoint bias reflected estimations which deviated from the drink's true halfway point (i.e., underfilling or overfilling the glass).

Results

Total drinking time

Visual inspection of distributions indicated a positive skew for total drinking time. This was transformed using a log10 function to satisfy regression modelling assumptions. Back-transformed geometric means (geomeans) with 95% CIs are thus reported. Adjusting for pre-specified covariates - gender, thirst, and BMI - there was no evidence that total drinking time differed between glass shapes (0.26% faster from the straight glass than the outward glass; 95%CI: -21.4%, 18.1%, *p*=.979, see SI Appendix Table S2 for adjusted and unadjusted regression analyses).

Drinking trajectory

Drinking trajectories – drinking patterns over time – were compared between glass shapes. Drinking trajectory was determined by plotting estimates of volume remaining in the glass – which started at 330ml and ended at 0ml – over elapsed time. Time was standardized to represent the proportion of overall time taken, to account for differences between participants in total drinking times, and volume consumed was transformed to 0-100% cumulative intake.

For the great majority of participants (182/198), the volumes remaining in the glass were not recorded after every sip taken. This was due to not placing the glass on the table in-between sips, and/or holding the glass and occluding the liquid. These factors prevented the accurate measurement of heights of the liquid and glass to determine volume remaining after each sip. To deal with missing data, we excluded participants who had incomplete drinking trajectory data – leaving Subset A: participants for whom volume remaining was recorded after every sip (n=16), and Subset B: participants for whom volume remaining was recorded after at least 50% of sips (n=94). As a result, one limitation of the trajectory data is that the tendency of participants in these subsets to put down

their glass may represent a particular style of drinking behaviour. For participant characteristics and outcome measures split by subset, see SI Appendix Table S3.

For both subsets, a cubic (S-shaped) model had the lowest AIC, as compared to quadratic models (used to represent the drinking trajectory data in a previous paper – see 18), for both outward and straight conditions, and thus was the best fit of the drinking trajectory data. Using Subset A, the cubic model predicted that at 50% time, 66.0% had been consumed from outward glasses (95%CI: 59.6%, 72.7%), while 50.3% had been consumed from straight glasses (95%CI: 47.5%, 52.7%), see Fig. 3A. Using Subset B, this model predicted that at 50% time, 59.2% had been consumed from the outward glasses (95%CI: 56.8%, 61.8%), while 55.5% had been consumed from straight glasses (95%CI: 53.4%, 57.8%), see Fig. 3B. Confidence intervals were calculated by bootstrapping.

The area under the drinking curves (AUC) – a proxy for drinking trajectory – was also calculated. Larger AUCs (i.e., closer to 1) are indicative of a more decelerated pattern (characterized by more consumed in the first half of the drinking period). AUCs were 24.6% larger for the outward-sloped glasses for Subset A (95%CI: 8.9%, 40.3%; $t(8.264)=3.60$, $p=.0067$) and 6.3% larger for the outward-sloped glasses for Subset B (95%CI: 0.91%, 11.7%; $t(85.06)=2.32$, $p=.023$), see SI Appendix Table S4 for average AUCs, by condition, for both subsets.

Sip size, sip duration, interval duration

Adjusting for the effects of gender on log mean sip size ($B_{Male}=0.15$, $p<.0001$), sips were 11.1% larger from the outward-sloped glass than the straight glass, however the data were also consistent with smaller sips (95%CI: -2.8%, 27.0%), $p=.123$). Larger sips were associated with faster total drinking times, $r(198)=-.50$, $p<.0001$). Gender did not significantly predict mean sip duration or mean interval duration, so was not included in these models. Sip durations did not differ between glass shapes (8.1% longer from outward-sloped glasses, 95%CI: -

233

3.8%, 21.6%, *p*=.190). Interval durations did not differ between glass shapes (10.7% longer from outward-sloped glasses, 95%CI: -9.1%, 34.7%), *p*=.312).

Midpoint bias

Midpoints were underestimated from both glasses, consistent with under-filling the glass when estimating the halfway point. Individuals under-estimated the midpoints of outward-sloped glasses to a greater degree (mean difference = 14.1ml, 95%CI: 9.5ml, 18.7ml), *t*(196)=6.1, *p*<.0001). Midpoint bias was not associated with total drinking time, *r*(198)=-.09, *p*=.196).

Summary

There was no evidence that total drinking time differed depending on the glass being drunk from (failing to replicate a previous study, 15), though there was some evidence that drinking trajectories differed, with more decelerated drinking from outward-sloped glasses - characterised by a greater amount consumed in the first half of the drinking episode – and more linear drinking from straight-sided glasses. While this indicates that straight-sided glasses may lead to a different pace of drinking, it remains to be seen whether glass shape influences the amount that is consumed. As in previous research, there was evidence of midpoint bias, with midpoints underestimated more from outward-sloped glasses (e.g., 14-15, 17). However, there was no evidence that this bias in perception of drink midpoints was associated with drinking time.

Study 2

Overview

In Study 2, we sought to extend Study 1 by investigating whether glass shape would influence amount of a soft drink consumed. In particular, we predicted that straight-sided glasses would lead to less overall consumed than

outward-sloped ones. As in Study 1, we also compared micro-drinking behaviours (number of sips) and visual perception of drink volumes (midpoint bias).

We recruited 72 (50% female) participants – predominantly students and staff at the University of Cambridge, England – to take part in this study between February and March 2019. This study used an adaptive design with an internal pilot (see 28-30). For more information on the stopping rules for recruitment, see SI Appendix. Baseline characteristics are shown in SI Appendix Table S5. Due to video-recording malfunction, data for number of sips was only available for 71/72 participants.

In a between-subjects design, participants were randomised to one of two conditions (stratified by gender), receiving four soft drinks to taste and rate (each 165ml), served in either straight-sided wine flutes or outward-sloped martini coupes (see Fig. 1. for images of the glasses). The primary outcome was amount consumed during a 10-minute bogus taste test (a validated measure of intake; see 26). Secondary outcome measures were number of sips (determined from video recordings which were subsequently coded for sips), and midpoint bias (assessed after the taste test, in the same way as in Study 1).

Results

Amount consumed

Visual inspection indicated no evidence of skew in the primary outcome measure: volume consumed (ml). Adjusting for pre-specified covariates (gender, thirst, drink enjoyment and maximum oral capacity), our model indicated that 72.1ml less was consumed from straight-sided glasses than outward-sloped glasses (95%CI: -11.7ml, -132.6ml), p=.022 (see SI Appendix Table S6 for full unadjusted and adjusted linear models).

Number of sips

Total number of sips did not differ between glass shapes (mean difference=-1.6 sips from the outward-sloped glass, 95%CI: -7.2, 4.0), p=.58. Number of sips was positively associated with total amount consumed, with fewer

235

sips associated with less being consumed overall, $r(71)=.48$, $p<.0001$. Mean sip size – though not pre-specified - was also explored, to account for differences in amount consumed. This was calculated by dividing total volume consumed by number of sips. Mean sip sizes were 2.7ml smaller from straight-sided glasses than from outward-sloped glasses (95%CI: 0.48ml, 4.8ml), $p=.017$. Mean sip size was also strongly and positively associated with total amount consumed, with smaller mean sips associated with less consumed overall, $r(71)=.67$, $p<.0001$.

Midpoint bias

Drink midpoints were underestimated for both glasses. Though outward-sloped glasses led to lower midpoint estimates than straight-sided glasses, there was no evidence that the difference in midpoint bias was meaningful (mean difference=-1.4ml, 95%CI: -5.8ml, 3.0ml), $t(68)=-0.63$, $p=.531$). Midpoint bias was not associated with amount consumed, $r(72)=-.03$, $p=.827$.

Summary

Consistent with our predictions, Study 2 demonstrated that, in a bogus taste test paradigm, less was consumed from straight-sided glasses than outward-sloped ones, this time using stemmed glasses rather than tumblers, and using a non-carbonated soft drink. Lower number of sips and smaller average sips size were associated with less consumed overall. Midpoint bias was not associated with amount consumed.

Study 3

Overview

In Study 3, we sought to investigate a potential mechanism for reduced intake from straight-sided glasses – namely, the extent lips are pursed during sipping, or lip embouchures. We predicted that when sipping from straight-sided glasses, lips would be more pursed (characterised by higher levels of muscle activity in the upper and lower lips, measured using surface EMG) than when sipping from outward-sloped ones. We also measured

sip sizes in real time, to explore whether glass shape influenced sip size, and whether embouchure mediated effects of glass shape on sip size.

We recruited 40 females - predominantly students and staff at Macquarie University – to take part in an experiment on campus at Macquarie University, Australia, between June and July 2019. For more information on sample size determination, see SI Appendix. For demographic and study-relevant information see SI Appendix Table S7.

In a within-subjects design, participants were served four soft drinks (165ml each), in two straight-sided glasses (wine flutes) (A), and two outward-sloped glasses (martini coupes) (B), in the sequence ABAB or BABA, with order randomised. Three sips were taken from each drink. Sip volumes were recorded after each sip, using a concealed weighing scale. The study used an adapted bogus taste test with the addition of surface facial electrodes placed on the upper and lower lips, which measured muscle activity, as a proxy for embouchure. The primary outcome measure was lip muscle activity (co-primary endpoints of upper and lower lip muscle activity) which was transformed and expressed as a percentage of each individual's maximal voluntary contraction (%MVC). Maximal voluntary contraction was measured by asking participants to protrude their lips as firmly as possible. The secondary outcome measure was sip size (ml).

Visual inspection of distributions indicated positive skew for embouchure (%MVC upper, %MVC lower) and sip size (ml). All three variables were transformed using a log function, improving the shapes of the distributions. Back-transformed geomeans with 95% CIs are reported in Table 1 for these outcome measures, adjusting only for repeated-measures.

Results

Embouchure

Two linear mixed effects models were used, predicting the co-primary endpoints of i) upper and ii) lower lip muscle activity (log %MVC) from glass shape, adjusting for standard crossover design variables (treatment: glass shape, sequence: ABAB/BABA, and time period: drink number) as well as sip number (1st, 2nd, 3rd) and with

237

participant as a random effect. These models indicated that, when sipping from straight-sided glasses, participants used 8.9% more upper lip muscle activity (95%CI: 3.3% to 14.8%), p=.0017, and 20.03% more lower lip muscle (95%CI: 14.7%, 25.6%) p<.0001, than when sipping from outward-sloped glasses. Findings were significant after adjusting for co-primary endpoints (*i.e.,* significance when alpha <2.5% using Bonferroni adjustment). See SI Appendix Table S8 for full models.

Sip size

Two linear mixed effects models were used, predicting log sip size from upper and lower muscle activity (%MVC), adjusting for the same variables as above, as well as baseline thirst, and maximum oral capacity, and with participant as a random effect. These models indicated that glass shape predicted sip size, with sips that were 17.3% smaller and 16.6% smaller from straight-sided glasses than outward-sloped glasses, when adjusting for upper %MVC (95%CI: 13.3%, 21.3%, p<.0001) and lower %MVC (95%CI: 12.2%, 20.8%, p<.0001), respectively. However, there was no evidence that muscle activity predicted sip size in these models: for every 1% increase in upper lip muscle activity used, there was a 0.19% decrease in sip size (95%CI: -0.56, 0.2), p=.337, and for every 1% increase in lower lip muscle activity used, there was a 0.36% decrease in sip size (95%CI: -0.95, 0.3), p=.251. See Table S9 for full models.

In exploratory analyses, we removed glass shape from these models to determine whether lip muscle activity predicted sip size for upper and lower %MVC respectively, without adjusting for the effects of glass shape on sip size. In this analysis, lower lip muscle activity (%MVC lower) did predict sip size, such that for every 1% increase in lower lip muscle activity used, there was a 1.13% decrease in sip size (95%CI: -1.70, -0.51), p=.0002. There was no evidence that upper lip muscle activity (%MVC upper) predicted sip size; for every 1% increase in upper lip activity used, there was a 0.27% decrease in sip size (95%CI: -0.66, 0.14), p=.191.

Summary

In line with predictions, we found that lips were more pursed when participants sipped from straight-sided glasses, as compared to outward-sloped glasses. Correspondingly, sips were smaller from straight-sided glasses, and there

was some evidence of an association between lip muscle activity and sip size (with smaller sips associated with more pursed lower lips).

Discussion

The studies reported here investigated the effects of varying glass shape – straight-sided *vs* outward-sloped – on the consumption of soft drinks, using diverse techniques to measure drinking behaviours. In Study 1, though the overall time spent drinking was equivalent for those drinking from straight-sided and outward-sloped glasses (failing to replicate 15), when exploring the micro-drinking behaviours in detail, we found that drinking trajectories differed. In particular, drinking from outward-sloped glasses was characterised by a more decelerated pace, a similar finding to previous research (18), which found more decelerated drinking from short-wide glasses than tall-narrow ones. In Study 2, using a bogus taste test paradigm, those tasting and rating drinks served in straight-sided glasses consumed less overall than those drinking from outward-sloped ones. Average sip sizes were also smaller from straight-sided glasses, and there was an association between sip size and total amount consumed. In Study 3, using an adapted bogus taste test paradigm with sips taken in regimented stages to allow for the measurement of lip muscle activity, lips appear to be more pursed when drinking from straight-sided flutes. The same study showed a corresponding effect of glass shape on sip size – with smaller sips taken from straight-sided flutes – and preliminary evidence that embouchure may be associated with sip size – for lower lip embouchure, at least. To our knowledge, this final study is the first to use facial EMG to explore lip embouchures during sipping, a potential mechanism for reduced consumption from straight-sided glasses.

The three studies thus report broadly consistent findings that together suggest that glass shape influences drinking behaviours, including volume consumed. As discussed, one potential mechanism that may underlie some of the differences in drinking behaviour is the extent of lip pursing – or embouchure – during sipping. Affordance of micro-drinking behaviours – such as sip size via embouchures – seems a good candidate mechanism for explaining, at least in part, the reduction of intake from straight-sided glasses. An additional mechanism that we explored involved biases in visual perception of drink volumes. As in previous studies (e.g., 14-15, 17), drink midpoints were underestimated more from outward-sloped than straight-sided tumblers in Study 1, indicative of midpoint bias from outward-sloped glasses. However, there was no evidence of a difference in midpoint bias in

239

Study 2 using flutes and coupes (though the direction of the effect was consistent, and this adaptive design may have lacked power to detect small effects). Importantly, however, there was no evidence that midpoint bias was associated with drinking behaviour, including drinking time (in Study 1) or amount consumed (in Study 2). This suggests that – while sometimes present – biases in visual perceptions of drink volumes may not consistently influence drinking behaviour, and that other factors may better explain the effects of glass shape on drinking time and consumption.

The strength of this research lies in its novelty and scientific rigour: it is the first comprehensive set of studies focused on the impact of glass shape on drinking behaviour, measured using different study paradigms. The key findings are largely consistent across study paradigms testing different primary outcomes, including a novel physiological measure, and across different study designs – *i.e.,* both within- and between-subjects. Regardless of the exact glassware used – *i.e.,* tumblers in Study 1 and stemmed glasses in Study 2 and 3 – or type of drink served – *i.e.,* carbonated in Study 1, non-carbonated in Studies 2 and 3 – the findings suggest that serving drinks in straight-sided glasses is a potentially effective way to reduce consumption of drinks which harm health. The studies also had a number of limitations worth noting. First, it remains unclear which exact features gave rise to the effects – outward-sloped glasses having wider rim apertures than narrower straight-sided ones. The latter two studies used more 'extreme' versions of the Study 1 tumblers, with rim diameters which varied more drastically. Rim diameter may have contributed to the observed effects on drinking behaviours, in addition to, or independently from, the effect of glass wall slope. Second, the study procedures may have failed to reflect real life drinking scenarios, limiting the ecological validity of the findings. Laboratory settings often lack certain characteristics that mark 'real-life' drinking environments – for example, the absence of drinking companions and the artificial nature of the tasks. There is also a need to examine drinking behaviours when people consume multiple drinks, to ascertain whether behaviour change persists after consuming a single drink. Study 2 went some way to address this, using a bogus taste test paradigm which involved tasting multiple drinks. However, while bogus taste tests are sensitive to desire to consume, comprising a valid measure of *ad libitum* consumption (26), they do not offer insight into how drinking might be impacted over a longer drinking session when multiple drinks might be fully consumed (i.e., not tasted).

Future studies might build on this set of findings in a number of ways. First, as discussed, studies are required in real-world drinking environments, which will also enable effect size estimates. This might include studies set in

pubs, bars and restaurants, comparing the volume purchased and consumed according to the glasses drinks are served in, as has been investigated for wine glass size; see 11-13, 31). Relatedly, while developing novel interventions to reduce consumption of health-harming drinks remains important, it is worth investigating whether the converse is true – that is, whether outward-sloped glasses may help to increase consumption of healthy drinks, relative to straight-sided glasses. Thus, future studies could explore the impact of glass shape on water consumption in medical settings where hydration is warranted. Second, research is required to ascertain the parameters of these effects and in particular, whether the effects apply to alcoholic drinks as well as to soft drinks. This is worth exploring given that a previous study found evidence for slower drinking from straight-sided glasses than outward-sloped glasses, but only for beer, and not for a soft drink (14). It is therefore possible that the effects found in the present studies could be stronger for alcohol. Third, though this set of studies has explored two potential mechanisms for the effects of glass shape on consumption – via biases in visual perceptions of glass midpoints and via affordance of embouchures and their potential impact on micro-drinking behaviours – future studies might usefully identify additional mechanisms. Understanding the processes through which glass shape influences consumption will advance our overall understanding of the effects and in turn lead to optimising glassware design for more effective interventions.

This set of studies contributes to a small but growing evidence base of a potentially effective, easily implemented, small-scale physical environment intervention (7-8) for reducing consumption of sugar and alcohol. In combination with other behaviour change strategies, adopting straight-sided glasses may prove to be one intervention contributing to the many needed to reduce consumption of drinks that harm health.

Methods

Written informed consent was obtained for all participants at the start of each study, and approvals were obtained from the University of Cambridge Psychology Research Ethics Committee (Study 1: PRE.2018.015, Study 2: PRE.2018.122, Study 3: PRE.2019.030), and the Macquarie University Research Ethics Committee (Study 3: 5201954159069). All studies were conducted in accordance with the relevant institutional guidelines and regulations. More information (on eligibility and recruitment for each study), is given in SI Appendix. Pre-registered study protocols are available on the OSF (https://osf.io/4tx3c/; https://osf.io/j9hqu/; https://osf.io/75b89/). Written informed consent was obtained from the participant for publication of their image (Fig. 2.) in an online, open access scientific paper.

Study 1

Measures

Drinking behaviours were measured by coding video recordings. The start and end of each sip was coded using a key press, giving total drinking time (the primary outcome measure), mean sip duration, mean interval duration, and total number of sips. To determine mean sip size, we divided the total amount consumed – 330ml – by the total number of sips.

To determine drinking trajectory, we first created models predicting volume from the height of the remaining liquid relative to the height of the glass, for each of the glass shapes. This allowed us to estimate the volume remaining in the glass when it was placed on the table (as long as there was only minimal occlusion to the liquid). We then used these estimates to plot each individual's cumulative intake (%) over time (%). To determine drinking trajectory, we combined the plots and fitted models by condition. Using these models, we calculated amount consumed at 50% time. We also calculated the areas under each individual's drinking curve, as a proxy for trajectory (higher scores are indicative of more decelerated drinking). Due to the need for glasses to be placed on the table with minimal occlusion to the liquid, trajectories were only able to be calculated for subsets of participants – those who regularly placed their glass down (see SI Appendix Table S3).

Midpoint bias was assessed using a task involving six trials of filling or emptying drinks from the allocated glass until the glass was perceived to be half-full. The six poured estimates of the midpoint of the drink were averaged to provide a single estimate for each participant. This was then subtracted from 165ml (the true midpoint), to determine bias. Negative values reflect underestimation of the true midpoint (pouring too little liquid into the glass), while positive values indicate overestimation of the true midpoint (pouring too much liquid into the glass).

Procedure

Participants attended a single session ostensibly exploring 'the impact of glucose on cognitive performance'. On arrival, participants completed eligibility screening, and stated their age, gender, height, weight, and thirst (1-10).

A 330ml can of chilled Appletiser® was served in the appropriate glass (based on randomisation). Participants were asked to consume the drink at their own pace, whilst watching a documentary. Video recordings were taken during this time.

Participants then completed two filler tasks (word search and drink ratings). Finally, they estimated the midpoint of their drink. A full portion was placed in front of participants (in the glass they drank from previously), and they were asked to pour estimates of the halfway point of the drink (i.e., 165ml). There were six estimates in total (three from glass to jug, and three from jug to glass). Participants were invited to use a 'Reference Glass' throughout the task to aid accuracy, which contained the full 330ml portion.

Finally, participants were asked what they thought the purpose of the study was, to examine the effectiveness of the cover story in blinding participants to the true nature of the study.

Study 2

Measures

243

Total amount consumed (ml) – the primary outcome measure - was measured by weighing the four glasses before and after the 10-minute taste test, using high precision scales. The weights of the glasses after consumption were subtracted from the initial weights to determine the total volume consumed.

Micro-drinking behaviours (i.e., number of sips) were measured by coding the video recordings taken during the drinking sessions (with each sip initiation and endpoint coded by a key press, as in Study 1). Midpoint bias was measured in the same way as Study 1 (with the true midpoint of these drinks being 82.5ml).

Maximum oral capacity was measured – to adjust for in the primary analysis – and calculated by asking participants to fill their mouth to full capacity from a cup filled with room temperature water, before spitting into an empty jug (weighed before and after to determine total volume). This task completed twice (with the total volume then divided by two), and was disguised as a 'palate cleanser'. Drink enjoyment was also measured – to adjust for in the primary analysis – from ratings given during the taste test, with scores for 'tasty' and 'pleasant' (rated from 1-10) averaged for all four drinks.

<u>Procedure</u>

Eligible participants attended a single session to take part in a study on 'taste preferences'. On arrival, participants completed eligibility screening, and demographic questions, including age, gender, height, weight, and thirst (1-10). Next, participants completed the 'palate cleanser' – twice filling their mouth with water and spitting into a jug to determine oral capacity.

For the taste test, the experimenter prepared four drinks - a total of 660ml (divided into four 165ml portions) of Teisseire® passion fruit le sirop (1 part syrup, 7 parts water), served in either straight-sided stemmed wine flutes, or outward-sloped stemmed martini coupes, depending on randomisation. The drinks were placed on mats labelled A, B, C, and D. Participants were told to taste and rate the drinks according to 10 descriptors (fruity, smooth, sweet, refreshing, bitter, strong-tasting, gassy, pleasant, light, and tasty) (see 24), for 10 minutes. As well as completing these ratings, participants were be asked to indicate their preferences from 1(favourite) - 4(least

favourite), to reinforce the cover story. They were told to drink as much or as little of the drinks as they would like, to assist their ratings.

After the 10-minute taste test, the experimenter returned and he participant completed the midpoint pouring task (involving six poured estimates of 82.5ml). The procedure was the same as for Study 1. Finally, the participant was asked to guess the purpose of the study, using an open-ended question presented on screen. After the participant had left, the experimenter weighed the glasses to determine volume consumed.

Study 3

Measures

The primary outcome measure in this study was embouchure (%MVC). Embouchure was measured using surface electrodes which detected the amplitude of activity in the upper and lower lips. Higher amplitudes of lip muscle activity are a proxy for a more 'pursed' embouchure. A two-channel Biopac MP160 system was used for continuous electromyographic (EMG) signal acquisition, and data inputs were recorded and processed using *AcqKnowledge* 5.0 software (BIOPAC systems Inc., USA). Raw amplitudes of activity were transformed using a script which generates a rectified and integrated copy of the data over a period of 250ms and then rescales the channel so that this runs from 0-100%, with an individual's maximum voluntary contraction representing 100% (as recommended for facial EMG measurement (32). To determine each individual's maximum voluntary contraction, maximal lip compression trials were run, involving participants protruding their lips as hard as possible three times (as in 23). The signal with the highest amplitude (from the three maximum lip compression attempts) was selected to be used for standardizing by each participant's maximum voluntary contraction.

The secondary outcome measure was sip size (ml). Individual sip sizes (ml) were measured in real time, for each of the three sips taken from each of the four glasses. Sip sizes were noted by the experimenter after each sip, when the glass was placed on concealed weighing scales. The glass was weighed before consumption (i.e., with 165ml drink inside) and subsequently after each sip was taken during the taste test.

245

Maximum oral capacity was also measured – to adjust for in the primary analysis – in the same way as Study 2 (i.e., disguised as a palate cleanser).

<u>Procedure</u>

Participants were invited to attend a single study session investigating 'reactions to drinks served in different containers'. On arrival, participants completed eligibility screening, followed by the 'palate cleanser' task. The participants answered baseline demographic questions, and rated their thirst (1-10).

To prepare the skin for electrode placement, it was wiped with make-up remover, and brushed with an exfoliative pad and a small amount of abrasive gel (NuPrep ®). The four surface electrodes were then filled with electrode gel (SignaGel ®), and affixed to the upper and lower lips on the left side (see Fig. 2.) using adhesive discs. For the lower left quadrant, one electrode was placed 1cm below the cheilion (corner of mouth), and the paired electrode placed 1cm medial and slightly below (corresponding to the edge of the mouth). The upper left quadrant followed the same pattern (see 19, 32 for recommended placement of electrodes for facial EMG). The ground electrode was placed on the temple. Trailing wires were clipped behind the ear. An Impedance checker was used to assess signal conductivity. If impedance was greater than 30 kO the corresponding electrodes would be re-affixed.

Participants were served a total of 660ml (divided into four 165ml portions) of Teisseire® passion fruit le sirop (diluted 1 part syrup, 7 parts water), in two straight-sided stemmed wine flutes, and two outward-sloped stemmed martini coupes, in the order assigned to them.

Participants were instructed to take three sips taken from each drink. Each sip was divided into four stages (adapted from 23). The four stages were indicated on the screen, as follows.

Step 1 – "Relax": "Please relax, keeping your lips at rest"

Step 2 – "Prepare": "Please lift the glass and hold it in front of your mouth"

Step 3 – "Remove": "Now raise the glass to your lips and take a sip"

Step 4 – "Swallow": "Swallow the sip in one swallow"

Participants first practised these stages with a glass of water. They would next begin the taste test, taking three sips from each glass. After taking three sips from the drink, the participant rated the drink on the same 10 descriptors as Study 2. They were also asked to rate, from 1-10, how much they enjoyed the experience of consuming their drink from that glass. All of these questions were filler questions, to add to the cover story and disguise the true aim of the study. Once all four drinks had been tasted and rated, the participant was asked to complete the maximal lip compression tasks. They were asked to "squeeze your lips together as hard as you can, so they protrude as far as possible". They did this 3 times, as prompted by on-screen instructions. After electrodes were removed, participants were asked to describe what they believed to be the purpose of the study.

References

1. GBD 2017 Risk Factors Collaborators, Global, regional, and national comparative risk assessment of 84 behavioural, environmental and occupational, and metabolic risks or clusters of risks for 195 countries and territories, 1990–2017: a systematic analysis for the Global Burden of Disease Study 2017. *Lancet*. **392**, 1923-94 (2018).

2. World Health Organization, "Guideline: sugars intake for adults and children" (2015; https://apps.who.int/iris/bitstream/handle/10665/149782/9789241549028_eng.pdf?sequence=1). [the easiest access to this source is via the URL].

3. World Health Organization, "WHO global status report on alcohol and health" (2018; https://apps.who.int/iris/bitstream/handle/10665/274603/9789241565639-eng.pdf). [the easiest access to this source is via the URL].

4. G. M. Singh, R. Micha, S. Khatibzadeh, S. Lim, M. Ezzati, D. Mozaffaria, Estimated global, regional, and national disease burdens related to sugar-sweetened beverage consumption in 2010. *Circulation*. **132**(8), 639–66 (2015).

5. R. Thaler, C. R. Sunstein, *Nudge: Improving decisions about health, wealth, and happiness* (Yale University Press, New Haven, 2009).

6. T. M. Marteau, G. J. Hollands, P. C. Fletcher, Changing human behavior to prevent disease: the importance of targeting automatic processes. *Science*. **337**(6101), 1492-1495 (2012).

7. G. J. Hollands, I. Shemilt, T. M. Marteau, S. A. Jebb, M. P. Kelly, R. Nakamura, M. Suhrcke, D. Ogilvie, Altering micro-environments to change population health behaviour: towards an evidence base for choice architecture interventions. *BMC public health*. **13**, 1218 (2013).

8. G. J. Hollands, G. Bignardi, M. Johnston, M. P. Kelly, D. Ogilvie, M. Petticrew, A. Prestwich, I. Shemilt, S. Sutton, T. M. Marteau, The TIPPME intervention typology for changing environments to change behaviour. *Nature Human Behaviour*. *1*(8), 0140 (2017).

9. G. J. Hollands, T.M. Marteau, P. C. Fletcher, Non-conscious processes in changing health-related behaviour: a conceptual analysis and framework. *Health Psychology Review*. *10*(4), 381-394 (2016).

10. Z. Zupan, A. Evans, D. L. Couturier, T. M. Marteau, Wine glass size in England from 1700 to 2017: a measure of our time. *BMJ*. *359*, j5623 (2017).

11. R. Pechey, D. L. Couturier, G. J. Hollands, E. Mantzari, M. R. Munafò, T. M. Marteau, Does wine glass size influence sales for on-site consumption? A multiple treatment reversal design. *BMC public health*. *16*, 390 (2016).

12. R. Pechey, D. L. Couturier, G. J. Hollands, E. Mantzari, Z. Zupan, T. M. Marteau, Wine glass size and wine sales: a replication study in two bars. *BMC research notes*. *10*, 287 (2017).

13. M. Pilling, N. Clarke, R. Pechey, G. J. Hollands, T. M. Marteau, The effect of wine glass size on volume of wine sold: A mega-analysis of studies in bars and restaurants. *Addiction*. (2020).

14. A. S. Attwood, N. E. Scott-Samuel, G. Stothart, M. R. Munafò, Glass shape influences consumption rate for alcoholic beverages. *PLOS ONE*. *7*(8), e43007 (2012).

15. T. Langfield, R. Pechey, M. Pilling, T. M. Marteau, Impact of glass shape on time taken to drink a soft drink: A laboratory-based experiment. *PLOS ONE*. *13*(8), e0202793 (2018).

16. P. Raghubir, A. Krishna, Vital dimensions in volume perception: Can the eye fool the stomach?. *Journal of Marketing research*. *36*(3), 313-326 (1999).

17. D. M. Troy, A. S. Attwood, O. M. Maynard, N. E. Scott-Samuel, M. Hickman, A. Woods, M. R. Munafò, Effect of glass shape on the pouring accuracy of liquid volume. *PLOS ONE*. *13*(10), e0204562 (2018).

18. D. Cliceri, E. Petit, C. Garrel, E. Monteleone, A. Giboreau, Effect of glass shape on subjective and behavioral consumer responses in a real-life context of drinking consumption. *Food Quality and Preference*. **64**, 187-191 (2018).

19. A. J. Fridlund, J. T. Cacioppo, Guidelines for human electromyographic research. *Psychophysiology*. **23**(5), 567-589 (1986).

20. E. R. White, J. V. Basmajian, Electromyography of lip muscles and their role in trumpet playing. *Journal of Applied Physiology*. **35**(6), 892-897 (1973).

21. J. V. Basmajian, E. R. White, Neuromuscular control of trumpeters' lips. *Nature*. **241**(5384), 70 (1973).

22. A. Gotouda, T. Yamaguchi, K. Okada, T. Matsuki, S. Gotouda, N. Inoue, Influence of playing wind instruments on activity of masticatory muscles. *Journal of oral rehabilitation*. **34**(9), 645-651 (2007).

23. K. A. Murray, C. R. Larson, J. A. Logemann, Electromyographic response of the labial muscles during normal liquid swallows using a spoon, a straw, and a cup. *Dysphagia*. **13**(3), 160-166 (1998).

24. O. M. Maynard, T. Langfield, A. S. Attwood, E. Allen, I. Drew, A. Votier, M. R. Munafò, No impact of calorie or unit information on ad libitum alcohol consumption. *Alcohol and Alcoholism*. **53**(1), 12-19 (2017).

25. M. Vasiljevic, D. L. Couturier, D. Frings, A. C. Moss, I. P. Albery, T. M. Marteau, Impact of lower strength alcohol labeling on consumption: A randomized controlled trial. *Health Psychology*. **37**(7), 658–667 (2018).

26. A. Jones, E. Button, A. K. Rose, E. Robinson, P. Christiansen, L. Di Lemma, M. Field, The ad-libitum alcohol 'taste test': secondary analyses of potential confounds and construct validity. *Psychopharmacology*. **233**(5), 917-924 (2016).

27. E. Robinson, A. Haynes, C. A. Hardman, E. Kemps, S. Higgs, A. Jones, The bogus taste test: Validity as a measure of laboratory food intake. *Appetite*. **116**, 223-231 (2017).

28. J. Wittes, E. Brittain, The role of internal pilot studies in increasing the efficiency of clinical trials. *Statistics in Medicine*. **9**(1-2), 65-72 (1990).

29. J. A. Kairalla, C. S. Coffey, M. A. Thomann, K. E. Muller, Adaptive trial designs: a review of barriers and opportunities. *Trials*. **13**(1), 145 (2012).

30. G. A. Lancaster, S. Dodd, P. R. Williamson, Design and analysis of pilot studies: recommendations for good practice. *Journal of evaluation in clinical practice*. **10**(2), 307-312 (2004).

31. N. Clarke, R. Pechey, M. Pilling G. J. Hollands, E. Mantzari, T. M. Marteau, Wine glass size and wine sales: four replication studies in one restaurant and two bars. *BMC Research Notes*. **12**(1), 426 (2019).

32. A. van Boxtel, "Facial EMG as a tool for inferring affective states" in *Proceedings of Measuring Behaviour 2010* (Eindhoven, Measuring Behaviour 2010), 104–108.

33. E. W. Carr, P. Winkielman, C. Oveis, Transforming the mirror: Power fundamentally changes facial responding to emotional expressions. *Journal of Experimental Psychology: General*. **143**(3), 997 (2014).

34. J. T. Larsen, C. J. Norris, J. T. Cacioppo, Effects of positive and negative affect on electromyographic activity over zygomaticus major and corrugator supercilii. *Psychophysiology*. **40**(5), 776-785 (2003).

35. Y. Wu, E. van Dijk, L. Clark, Near-wins and near-losses in gambling: a behavioral and facial EMG study. *Psychophysiology*. **52**(3), 359-366 (2015).

251

Acknowledgments

Author contributions

TL, RP, PG, MP, and TM designed research; TL performed research; TL and MP analysed data; TL, RP, PG, MP, and TM wrote the paper.

Additional information

The authors declare no conflict of interest. All data is available on the OSF as follows: Study 1- https://osf.io/yhvtk/; Study 2- https://osf.io/t9bvw/; Study 3 - https://osf.io/r2mp5/.

Figures and Tables

Fig. 1. From left to right: glasses used in Study 1 - straight-sided and outward-sloped tumblers containing 330ml carbonated apple drink, and Studies 2 and 3 – straight-sided wine flutes and outward-sloped martini coupes containing 165ml non-carbonated passion fruit drink.
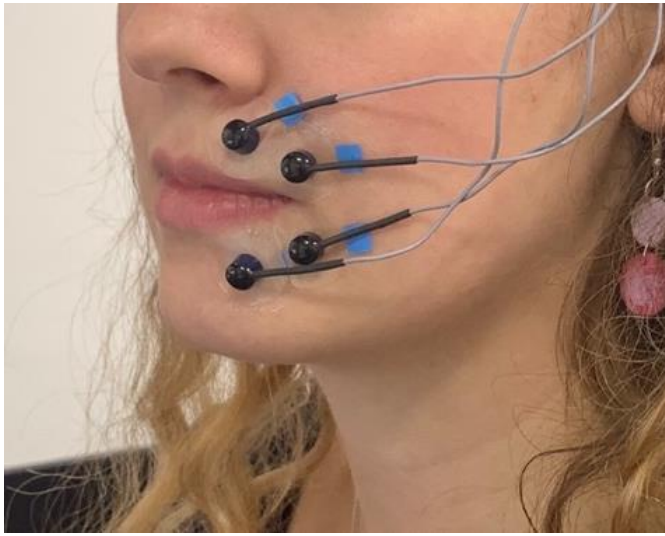
Fig. 2. Placement of surface electrodes on the upper and lower lip, with the ground electrode on the temple, as used in Study 3.
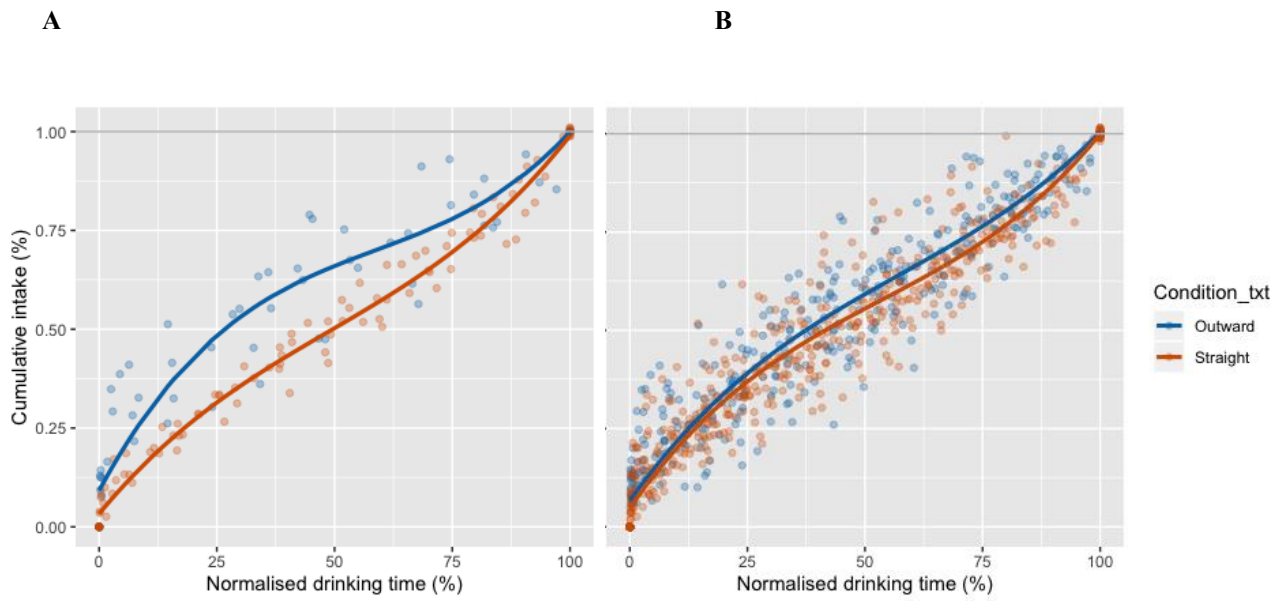
Fig. 3. Cumulative intake over time, Study 1. Lines indicate cubic curve fits.

A – participants with all sips recorded as volumes (n = 16), and **B** – participants with at least 50% of sips recorded as volumes (n = 94).

Table 1. Summary of key outcomes for Studies 1, 2 and 3.

	Glass Shape	
	Straight-sided	**Outward-sloped**
Study 1		
Total drinking time (sec)[a]	299.96 (260.93, 344.83)	300.88 (259.87, 348.37)
Drinking trajectory (AUC)[bc]	0.506 (0.03)	0.630 (0.09)
Mean sip size (ml)[a]	22.61 (20.44, 25.01)	25.21 (22.76, 27.92)
Midpoint bias (ml) [b]	-3.72 (15.53)	-17.81 (17.06)
Study 2		
Amount consumed (ml)[b]	242.79 (113.60)	298.49 (156.69)
Midpoint bias (ml) [b]	-4.60 (8.33)	-6.00 (10.35)
Number of sips[b]	28.97 (12.53)	27.39 (11.15)
Mean sip size (ml)[b]	8.75 (3.47)	11.40 (5.45)
Study 3		
Lip pursing (%) – upper[d]	14.06 (13.33, 14.83)	12.91 (10.69, 15.59)
Lip pursing (%) – lower[d]	14.03 (13.40, 14.68)	11.68 (9.60, 14.20)
Sip size (ml)[d]	10.07 (9.60, 10.56)	12.16 (10.65, 13.89)

Notes.

a. values are back transformed from log10 (Geometric mean and 95% CI), from unadjusted models.

b. values are unadjusted M (SD)

c. AUC refers to the area under the curve, calculated from individual plots of amount consumed (%) over time (%). Larger AUCs indicate more decelerated drinking. Values of AUC taken from participants for whom all sips were recorded as volumes (n = 16).

d. values are back transformed from log (Geometric mean and 95% CI), from models adjusting only for repeated-measures.

Supplementary Information for

Straight-sided glasses: a promising intervention to reduce how much we drink?

Tess Langfield*, Rachel Pechey, Philippe T. Gilchrist, Mark Pilling, Theresa M. Marteau.

* To whom correspondence may be addressed. Email:

This file includes:

Supplementary Text
Tables S1 to S9

Supplementary Text

Participants and sample size determination

Study 1

Participants were recruited from the students and staff at the University of Cambridge (UK), using mailing lists, flyers, and word of mouth. Eligibility was assessed at the start of the study session, and required that individuals: had not taken part in our previous study (15); were over 18 years old; were in good physical health; had English as a first language or an equivalent level of fluency; were prepared to consume a drink that contains sugar; had no known allergies to any ingredients in Appletiser®.

A power calculation with an alpha level of 0.05, power of 80%, and an effect size of 0.372 (observed in the previous study, when comparing total drinking time between straight-sided vs. outward-sloped glasses; 15) indicated that we would need a sample of $N = 182$ (91 per group). To allow for possible attrition due to video equipment malfunction, a sample size of $N = 200$ (100 per group) was used. The study sample size was pre-specified in our pre-registered study protocol (https://osf.io/4tx3c/).

Study 2

Participants were recruited from students and staff at the University of Cambridge (UK), using the same recruitment methods as Study 1. Eligibility criteria was the same as Study 1, though this study required participants to have no known allergies to any of the following ingredients: Fruit Juices from Concentrate 38% (20% Passion Fruit, 18% Lemon), Glucose-Fructose Syrup, Flavourings, Colours: Lutein, Paprika Extract, Stabiliser: E445.

The study sample size (N = 72, 50% female) was primarily driven by pragmatic considerations i.e., time and cost, is in line with convention (28) for an 'internal pilot', forming part of an adaptive design (see 29-30), and was pre-specified in the pre-registered study protocol (https://osf.io/j9hqu/). Given that previous studies had largely focused on the effects of glass shape on speed rather than consumption, we did not know what the effect size on consumption could be. As such, this internal pilot provided the necessary parameters (effect size and p value) for a sample size calculation. This adaptive design used the following stopping rules for recruitment at the interim analysis stage after outcome data had been collected on 72 participants.

1. If the effect of glass shape is significant at $p < 0.3\%$ for the primary interim analysis, or if no additional recruitment was required to achieve $p < 4.7\%$ for the primary final analysis (after sample size re-estimation), further recruitment would not be required. This is the *efficacy (utility) stopping criterion* (O'Brien-Fleming boundary).

2. If the sample size required to demonstrate $p < 4.7\%$ at the primary final analysis is unfeasible (with feasibility based on time and cost, being set at n >150 additional participants required) the trial will be stopped. This is the *futility stopping criterion*.

Together, these criteria represented early stopping rules. We stopped the trial after the internal pilot (N = 72) based on the utility stopping criterion, as our internal pilot analysis was already sufficient to detect an effect for the primary final analysis, at $p < 4.7\%$.

Study 3

Participants were recruited from the students and staff at Macquarie University (Australia), using the same recruitment methods as Studies 1 and 2. Eligibility criteria required that individuals: were female (given problems associated with detecting lip muscle activity in males with extensive facial hair); were over 18 years old; had not eaten, drunk (including water), or smoked anything for 30 minutes prior to the test session; had had no surgical procedures performed on the lips (e.g., cleft lip surgery or cosmetic reconstruction); did not have highly sensitive skin; were prepared to remove facial make up; were prepared to consume drinks that contain sugar; and had no known allergies to any of the following ingredients: Fruit Juices from Concentrate 38% (20% Passion Fruit, 18% Lemon), Glucose-Fructose Syrup, Flavourings, Colours: Lutein, Paprika Extract, Stabiliser: E445.

The sample size (N = 40) was based on pragmatic constraints – i.e., time and cost, was pre-specified in our pre-registered study protocol (https://osf.io/75b89/), and is in line with previous studies (33-35).

Sensitivity analyses

Study 1
Individuals (n = 9) who correctly guessed the purpose of the study and/or the aims of the drinking task (to measure drinking speed) were excluded from the analysis. Removing these data had no impact on results from the primary or secondary analyses.

Study 2

259

Removing individuals (n = 5) who correctly guessed the purpose of the taste test (i.e., to measure volume consumed) had no impact on the primary or secondary analyses.

Study 3
Removing individuals (n = 3) who correctly guessed the true aims of the study did not impact the primary or secondary analyses.

Reliability analyses

Reliability analyses were conducted for Study 1 and 2, given the involvement of coding videos of participant behaviour.

Study 1
Video coding was assessed for reliability, for all video data (total drinking time, mean sip size, mean sip duration, mean interval duration, and volume over time data). For volume over time data (drinking trajectories and AUC), an independent coder measured glass:drink height ratios from the videos of 10 participants (40 observations). The 40 height ratios produced by the coder were then compared with the equivalent height ratios extracted for the primary data.

Video coding was consistent across video coders, with high inter-rater reliability, assessed using single measures intra-class correlation. Strong positive associations were observed for total drinking time (20) > 0.99, $p < .0001$, mean sip size (20) = 1.00, $p < .0001$, mean sip duration (20) = .97, $p < .0001$, mean interval duration (20) > 0.99, $p < .0001$, and height ratios (40) > 0.99, $p < .0001$.

Study 2
Inter-rater video coding reliability was assessed for 10 videos. The recorded number of sips coded from each of the 10 participants was identical.

Table S1.

Study 1 - Baseline characteristics of participants by condition.

	Straight-sided (n = 100)	Outward-sloped (n = 98)	Overall (N = 198)
Gender (%)			
Female	50.0	49.0	49.5
Male	50.0	51.0	50.5
Highest Educational Qualification (%)			
GCSE/O Level	1.0	2.0	1.5
AS/A Level	37.0	32.7	34.8
Undergraduate degree	35.0	47.9	41.4
Postgraduate degree	27.0	17.3	22.2
Age (years)	22 (20,26)	22 (21, 24.75)	22 (20,26)
Thirst (1-10)	6.09 (1.64)	6.16 (1.54)	6.13 (1.59)
BMI (kg/m^2)	22.76 (3.14)	22.75 (3.49)	22.75 (3.31)

Notes. Thirst was rated from 1 ("Not at all") to 10 ("Extremely"). Age is median (IQR); BMI and thirst are mean (SD). Four individuals in the outwardin the outward-sloped condition opted to omit information on BMI.

261

Table S2.

Study 1 - Unadjusted (univariate) and adjusted (multivariate) regression, predicting log10(total drinking time).

	Unadjusted regression analyses					Adjusted regression analyses			
Independent variable	B	Exp(B)	95% CI Exp(B)	p-value	R^2	B	Exp(B)	95% CI Exp(B)	p-value
(Intercept)	-	-	-	-	-	2.762	577.70	271.96 to 1,227.12	< .0001
Glass shape					.00				
Straight-sided	-0.001	0.997	0.815 to 1.219	.976		-0.001	0.997	0.819 to 1.214	0.979
Gender					.075				
Male	-0.174	0.669	0.552 to 0.812	.0001		-0.174	0.669	0.548 to 0.817	.0001
Thirst (1-10)	-0.0013	0.997	0.936 to 1.062	.923	.00	-0.0076	0.983	0.922 to 1.047	.587
BMI (kg/m²)	-0.010	0.977	0.947 to 1.007	.130	.0067	-0.0066	0.985	0.955 to 1.015	.325

Notes. Reference for Glass shape is Outward-sloped. Reference for Gender is Female. Thirst was rated from 1 ("Not at all") to 10 ("Extremely"). Adjusted analyses: $F(4,189) = 4.547$, $p = .0016$, $R^2 = .0685$. Exp = Power of 10.

Table S3.

Study 1 - Baseline characteristics of participants and drinking behaviours, for full sample, and Subset A (100% of sips recorded as volumes) and Subset B (>50% of sips recorded as volumes), used for drinking trajectory analyses.

	Full dataset (N = 198)	Subset A (n = 16)	Subset B (n = 94)
Condition (%)			
Straight	50.5	50	54.2
Outward	49.5	50	45.7
Gender (%)			
Female	49.5	37.5	43.6
Male	50.5	62.5	56.4
Highest Educational Qualification (%)			
GCSE/O Level	1.5	0.0	1.1
AS/A Level	34.8	37.5	33.0
Undergraduate	41.4	50.0	43.6
Postgraduate	22.2	12.5	22.3
Age (years)	22 (20, 26)	22 (20.75, 26.25)	22.50 (21, 26.75)
Thirst (1-10)	6.13 (1.59)	6.06 (1.39)	6.14 (1.60)
BMI (kg/m²)	22.75 (3.31)	21.89 (2.27)	22.83 (3.23)
Total drinking time (min)[a]	300.61 (271.64, 331.89)	351.56 (235.50, 523.60)	380.19 (331.89, 435.51)
Mean sip size (ml)[a]	23.88 (22.23, 25.64)	38.19 (30.69, 47.42)	27.93 (25.53, 30.55)
Mean sip duration (sec)[a]	1.90 (1.79, 2.02)	2.33 (1.77, 3.07)	1.99 (1.83, 2.17)
Mean interval duration (sec)[a]	19.28 (17.46, 21.28)	37.33 (24.72, 56.36)	29.72 (26.24, 33.65)

Notes. Thirst was rated from 1 ("Not at all") to 10 ("Extremely"). Age is median (IQR); BMI and thirst are mean (SD).

a. values are back transformed from log10 (Geometric mean and 95% CI).

263

Table S4.

Study 1 - Impact of glass shape on drinking trajectory and other outcome measures, for Subset A (100% of sips recorded as volumes) and Subset B (>50% of sips recorded as volumes)

		Subset A (n = 16)		Subset B (n = 94)	
	Glass shape	**Straight**	**Outward**	**Straight**	**Outward**
Drinking trajectory	AUC	0.51 (0.03)	0.63 (0.09)	0.55 (0.07)	0.58 (0.07)
	Percentage consumed at 50% time	50.3 (47.5, 52.7)	66.0 (59.6, 72.7)	55.0 (53.4, 57.8)	59.2 (56.8, 61.8)

Notes. AUC refers to the mean areas under the drinking curves (calculated for each participant separately), given as M (SD). Larger AUCs (closer to 1) indicate more decelerated drinking. AUCs of 0.5 indicate linear drinking. AUCs closer to 0 indicate more accelerated drinking. Volume consumed at 50% time is calculated from cubic models of all participants' drinking trajectory data. Values given predict consumption at 50% time, with confidence intervals calculated by bootstrapping.

Table S5.

Study 2 - Baseline characteristics of participants by condition, and overall

	Straight-sided (n = 36)	Outward-sloped (n = 36)	Overall (N = 72)
Gender (N)			
Female	18	18	36
Male	18	18	36
Highest Educational Qualification (%)			
GCSE/O Level	2	1	3
AS/A Level	13	20	33
Undergraduate	9	11	20
Postgraduate	12	4	16
Age (years)	23.50 (19.75, 27)	20 (19, 22)	21.50 (19, 25.25)
Thirst (1-10)	5.94 (1.26)	5.42 (1.54)	5.68 (1.42)
BMI (kg/m²)	23.19 (3.06)	21.58 (2.86)	22.38 (3.05)
Max oral capacity	68.99 (20.09)	65.93 (19.28)	67.44 (19.60)

Notes. Thirst was rated from 1 ("Not at all") to 10 ("Extremely"). Age is median (IQR); BMI and thirst are mean (SD). One participant omitted to complete the max oral capacity measure, in the straight-sided condition.

265

Table S6.

Study 2 - Unadjusted (univariate) and adjusted (multivariate) regression, predicting amount consumed (ml).

Independent variable	Unadjusted regression analyses				Adjusted regression analyses		
	B	95% CI (*B*)	*p*-value	R^2	*B*	95% CI (*B*)	*p*-value
(Intercept)	-	-	-	-	-49.45	-279.51 to 180.61	.675
Glass shape				.027			
Straight-sided	-55.70	-120.03 to 8.64	.089		-72.13	-132.56 to -11.69	.022
Gender				.042			
Male	64.92	1.09 to 128.76	.046		52.94	-19.15 to 125.02	.155
Thirst (1-10)	27.46	5.15 to 49.77	.017	.066	32.97	11.71 to 54.23	.003
Drink enjoyment (1-10)	18.82	-5.97 to 43.60	.135	.018	15.75	-7.07 to 38.57	.181
Max oral capacity (ml)	1.18	-0.51 to 2.87	.168	.013	0.513	-1.33 to 2.36	.588

Notes. Reference for Glass shape is Outward-sloped. Reference for Gender is Female. Thirst was rated from 1 ("Not at all") to 10 ("Extremely"). Drink enjoyment was an average of "pleasant" and "tasty" ratings, which were rated from 1 ("Not at all") to 10 ("Extremely"). Adjusted analyses: $F(5,65) = 3.928$, $p = .0036$, $R^2 = .173$.

Table S7.

Study 3 - Baseline demographics and characteristics of participants (N = 40)

Gender (%)

Female	100

Nationality (%)

Australian	62.5
Chinese	10.0
Bangladeshi	5.0
British	5.0
Other	17.5

Highest Educational Qualification (%)

School Certificate (GCSE equivalent)	2.5
Higher School Certificate (AS/A Level equivalent)	60.0
Bachelors or Associate Degree	22.5
Postgraduate Degree	15.0

Age (years)	20 (19, 24.3)
Thirst (1-10)	5.48 (2.10)
BMI (kg/m^2)	23.06 (4.68)
Max Oral Capacity (ml)	52.46 (15.30)

Notes. Thirst was rated from 1 ("Not at all") to 10 ("Extremely"). Age is median (IQR); BMI, thirst, and maximum oral capacity are mean (SD).

Table S8.

Study 3 - Linear mixed effects models predicting log(% MVC) upper, and log(%MVC) lower, from glass shape, adjusting for order effects.

	Upper Lip				*Lower Lip*			
	B	Exp(B)	95% CI Exp(B)	p-value	B	Exp(B)	95% CI Exp(B)	p-value
(Intercept)	2.632	13.91	10.61 to 18.22	< .0001***	2.487	12.02	9.11 to 15.86	< .0001***
Glass shape								
Straight-sided	0.086	1.089	1.033 to 1.148	.00168**	0.183	1.200	1.147 to 1.256	< .0001***
Sequence								
BABA	-0.097	0.908	0.625 to 1.318	.614	0.118	1.125	0.764 to 1.657	.555
Drink number (1-4)	0.0035	1.003	0.980 to 1.027	.773	-0.0269	0.973	0.954 to 0.993	.009**
Sip number								
2nd sip	-0.043	0.958	0.898 to 1.022	.198	-0.0199	0.980	0.928 to 1.036	.482
3rd sip	-0.065	0.937	0.878 to 1.000	.051	-0.0357	0.965	0.913 to 1.020	.207

Notes. % MVC is percentage of muscle activity used, as a proportion of maximum voluntary contraction (MVC). Participant ID was included as a random effect. Reference for Glass shape is Outward-sloped. Reference for Sequence is ABAB. Drink number is 1st, 2nd, 3rd, 4th. Reference for Sip number is 1st sip. Exp(B) = e^B.

Table S9.

Study 3 – Linear mixed effects models predicting log (sip size) from %MVC upper, and %MVC lower, adjusting for order effects, glass shape, thirst, and maximum oral capacity.

	Upper Lip				*Lower Lip*			
	B	Exp(B)	95% CI Exp(B)	p-value	B	Exp(B)	95% CI Exp(B)	p-value
(Intercept)	2.652	14.18	7.60 to 26.43	< .0001***	2.686	14.68	7.80 to 27.61	< .0001***
%MVC	-0.0019	0.998	0.994 to 1.002	.337	-0.0036	0.996	0.991 to 1.003	.251
Glass shape								
Straight-sided	-0.191	0.826	0.787 to 0.867	< .0001***	-0.182	0.834	0.792 to 0.878	< .0001***
Sequence								
BABA	-0.061	0.941	0.720 to 1.230	.669	-0.055	0.947	0.725 to 1.237	.701
Drink number (1-4)	-0.034	0.967	0.946 to 0.988	.0022**	-0.036	0.965	0.944 to 0.986	.0013**
Sip number								
2nd sip	0.017	1.017	0.959 to 1.079	.580	0.017	1.017	0.959 to 1.078	.580
3rd sip	0.024	1.024	0.965 to 1.086	.434	0.024	1.024	0.966 to 1.086	.426
Thirst (1-10)	-0.022	0.979	0.918 to 1.043	.524	-0.025	0.975	0.915 to 1.040	.468
Max oral capacity (ml)	0.002	1.002	0.993 to 1.011	.676	0.002	1.002	0.993 to 1.011	.661

Notes. % MVC is percentage of muscle activity used, as a proportion of maximum voluntary contraction (MVC). Participant ID was included as a random effect. Reference for Glass shape is Outward-sloped. Reference for Sequence is ABAB. Drink number is 1st, 2nd, 3rd, 4th. Reference for Sip number is 1st sip. Thirst was rated from 1 ("Not at all") to 10 ("Extremely"). Exp(B) = e^{B}.

269

4.3. Models predicting volume from height liquid: height glass

Using a digital ruler, heights of liquids and heights of glasses (in pixels) were measured for images of drinks filled from 0 – 330ml (in 10ml increments). Note three height measurements were taken for each image (i.e., for each volume increment - given possible variation in measurement accuracy).
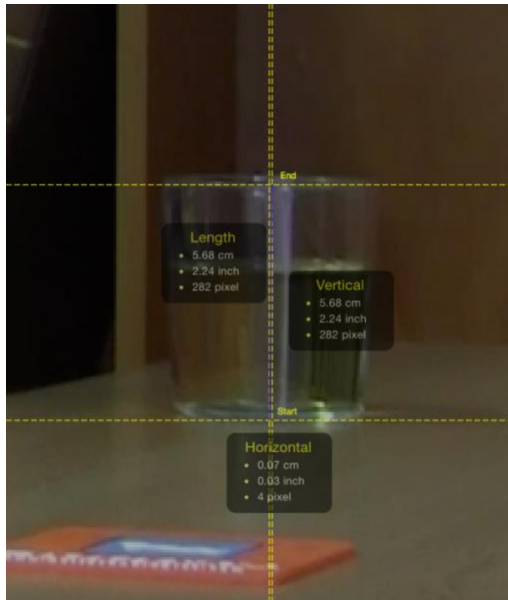
I then plotted **height ratios** (height liquid: height glass - measured using digital ruler) and **volumes** (known, between 0 – 330ml).

From these plots, it was apparent that a linear model predicted volume from height for straight glasses. Transforming height ratios (by squaring them) also produced a linear model predicting volume from height for outward glasses.

Thus the following models fit the data, and were used to predict volume remaining from height ratios alone (i.e., after Study 2 data collection):

Straight-sided liquid volume = -29.88 + 412.889*(Height ratio)
Outward-sloped liquid volume = 0.8301 + 405.3912*(Height ratio^2)

4.4. Study 2 recruitment

4.4.1 Flyer used for recruitment
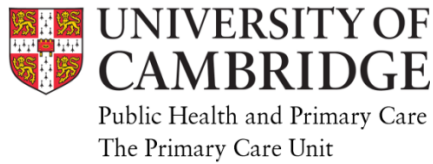
The impact of glucose on cognitive performance

We are looking to recruit participants for a study on the short-term impact of glucose on cognitive performance.

You would be eligible to take part if you:
- have <u>not</u> taken part in my previous experiment;
- are over 18 years old;
- are in good physical health;
- have English as a first language/equivalent level of fluency;
- are prepared to consume a drink that contains sugar;
- have no known allergies to the ingredients in Appletiser ®.

The study involves drinking a 330ml glass of Appletiser®, as well as completing some questionnaires and short tasks. The entire session should last around 45 minutes, and you would be reimbursed **£7** for your time and expenses. Testing takes place in Christ's College, St Andrew's St, Cambridge, CB2 3BU.

Please contact ███████████████ for more information, and to arrange a suitable time to take part.

4.4.2 Email used for mailing lists

Psychology experiment – earn £7 for 30-45min!

The Behaviour and Health Research Unit are currently running a study looking to investigate the impact of glucose on cognitive performance.

We are looking for participants who:
- have **not** taken part in my previous experiment;
- are aged 18 or over;
- are in good physical health;
- have English as a first language/equivalent level of fluency;
- are prepared to consume a drink that contains sugar;
- have no known allergies to the ingredients in Appletiser ®.

The study involves consuming a 330ml glass of Appletiser ®, and completing some questionnaires and other short tasks. It should last between 30-45 minutes, and you would be reimbursed with £7 for your time and expenses.

The study takes place in **<u>Christ's College, Cambridge, CB2 3BU.</u>**

If you would like to sign up, please contact Tess on ███████████████

4.5. Study 2 participant information and consent

UNIVERSITY OF CAMBRIDGE
Public Health and Primary Care
The Primary Care Unit

Participant Information Sheet:
Glucose and Cognitive Performance study

You are being invited to take part in a research study. Before you decide to take part it is important for you to understand why the research is being done and what it will involve. Please take time to read the following information carefully and discuss it with others if you wish. A member of the team can be contacted if there is anything that is not clear or if you would like more information. Take time to decide whether or not you wish to take part.

Purpose of the study

This study will investigate the short-term effects of glucose on cognitive performance. You will be asked to attend a single session of approximately 45 minutes, in which you would consume a glass of Appletiser ®, and then complete a word-search task, as well as some perceptual measures.

Why have I been chosen?

You have been invited to take part as you expressed an interest in this study.

Do I have to take part?

It is up to you whether you decide to take part. If you do decide to take part, you will be asked to sign a consent form prior to commencing the study. If you change your mind, withdrawal will involve no penalty or loss, now or in the future.

What will happen to me if I take part?

You will be asked to come to Christ's College for a single 30-45-minute session. If you are eligible to take part, you will be given the opportunity to ask questions, and asked to sign a consent form. After an initial questionnaire, you would be asked to drink a glass of Appletiser® at your own pace, whilst watching a nature documentary. You would be videotaped during this time to ensure implementation fidelity. You would then be given 4 minutes to find as many words as possible in a word-search task. After this you would complete a short questionnaire, followed by an exercise on perceptions that involves pouring liquids. After finishing the study, you would then be reimbursed £7.

Are there possible disadvantages and/or risks in taking part?

There are no risks associated with taking part.

What are the possible benefits of taking part?

There are no direct benefits of taking part in this research study and your participation is entirely voluntary.

Will my taking part in this project be kept confidential?

All data and personal information will remain confidential, and would only be available to members of the research team. Any personal details would be kept on a secure computer, and access to this information would only be available to the immediate research team.

What will happen to the results of the research project?

Once the study is complete, the data will be analysed and written up for publication in journals. Results may also be presented at conferences. Your personal responses during the study would not be identifiable in any way, as data will be aggregated. If you would like a copy of the final paper, you may request that this be sent to you once it is published.

Video recordings will be identified only by a code, and will only be available to those on the research team. They will not be used for any purposes other than the research project. These tapes will be destroyed after 2 years.

At the end of the study your data would become "open data". This means that it would be stored on an online database, so that anyone who is interested in the research is able to examine the data, and conduct their own analyses. However, as stated, all data will be anonymised before being made publicly available, so there would be no way to identify you personally.

Can I withdraw my data?

Yes. If you decide that you do not want your data to be used you can withdraw your data at any time after the study, for any reason, up until the data is shared as "open data". After this, all links between your personal information and the research data would be destroyed. Thus we would not be able to withdraw your data because we would not be able to identify which data came from you.

Who is organising and funding the research?

This study is being organised by the Behaviour and Health Research Unit at the University of Cambridge, and funded by a PhD grant from the Medical Research Council.

Ethical review of the study

The project has received ethical approval from the Psychology Research Ethics Committee of the University of Cambridge (reference: PRE.2018.015).

Contact for further information

For any questions or concerns about the study, please contact Tess Langfield at ███████████████ or Professor Theresa Marteau at ████████████████████ or on ███████████. Alternatively, please write to us at: Institute of Public Health, Robinson Way, Cambridge, CB2 0SR, UK.

CONSENT FORM
Glucose and cognitive performance study

Please confirm that you agree to the following statements, by writing your <u>initials</u> in each box.

PLEASE CONFIRM THAT YOU:

<u>**INITIALS**</u>

Have read and understand the Information Sheet;

Have had satisfactory answers to any questions asked about the study;

Understand that all personal information will remain confidential and all efforts will be made to ensure you cannot be identified (except as might be required by law);

Agree that data gathered in this study may be stored anonymously and securely, and may be used for future research;

Understand that this study will be recorded, and that video recordings will not be made available beyond the research team (recordings will be kept securely for 2 years before being destroyed);

Understand that participation is voluntary and that you are free to withdraw at any time without having to give a reason;

Have not taken part in my previous experiment;

Are at least 18 years of age;

Are in good physical health;

Have English as a first language or an equivalent level of fluency;

Are prepared to drink a drink that contains sugar, and have no known allergies to the ingredients in Appletiser ®;

Agree to take part in this study.

I HEARBY FULLY AND FREELY CONSENT TO MY PARTICIPATION IN THIS STUDY

Date					Signature of the participant:
	Day	Month	Year		Print name:
					Signature of the investigator:

4.6. Study 2 online questionnaire

UNIVERSITY OF CAMBRIDGE

Participant information

Please answer the following questions about yourself.

Gender

○ Male
○ Female
○ Other
○ Prefer not to say

Age

[   ]

Handedness

○ Right
○ Left
○ Ambidextrous

What is the highest level of education you have completed?

○ GCSE/O Level
○ AS/A Level
○ Undergraduate degree
○ Postgraduate degree (e.g. Masters, PhD)
○ None of the above

Please click 'Next' to continue.

Next

Now, thinking about how you feel right now, how thirsty are you?

Please give your answers from 1 to 10, where 1 represents 'Not at all' and 10 represents 'Extremely'.

1	2	3	4	5	6	7	8	9	10
○	○	○	○	○	○	○	○	○	○

Please click 'Next' to continue.

Next

Please let the experimenter know that you have completed the first few questions.

Please **WAIT** before clicking 'Next'.

Next

WORDSEARCH TASK

You will have **4 minutes** to find as many words as you can from a letter grid. The experimenter will return when your time is up.

Type your answers in the text box below the grid, separated by a comma (e.g. cat, there, going etc.)

There are over **30** possible words to find. They may be written forwards, or backwards, horizontally, vertically, and diagonally.
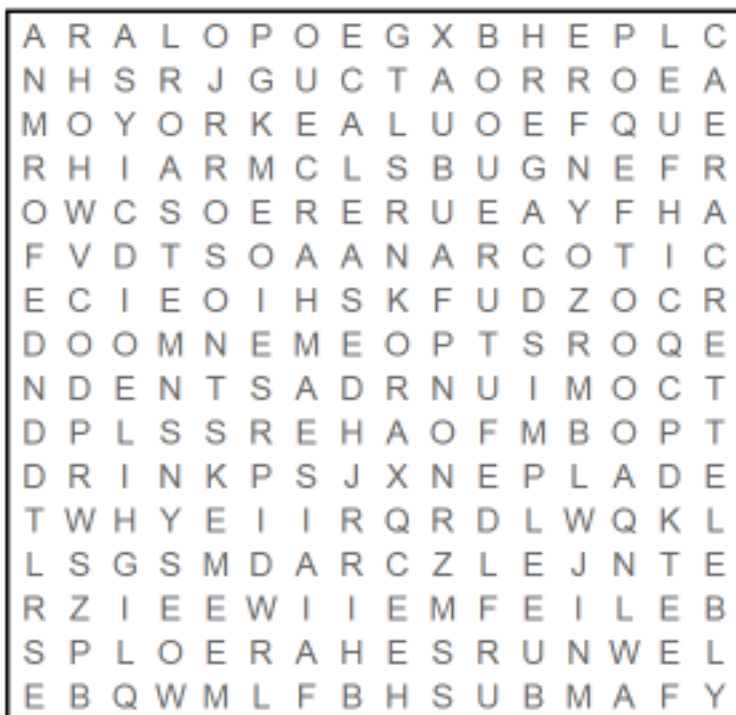
```
A R A L O P O E G X B H E P L C
N H S R J G U C T A O R R O E A
M O Y O R K E A L U O E F Q U E
R H I A R M C L S B U G N E F R
O W C S O E R E R U E A Y F H A
F V D T S O A A N A R C O T I C
E C I E O I H S K F U D Z O C R
D O O M N E M E O P T S R O Q E
N D E N T S A D R N U I M O C T
D P L S S R E H A O F M B O P T
D R I N K P S J X N E P L A D E
T W H Y E I I R Q R D L W Q K L
L S G S M D A R C Z L E J N T E
R Z I E E W I I E M F E I L E B
S P L O E R A H E S R U N W E L
E B Q W M L F B H S U B M A F Y
```

Please enter words you find here:

The experimenter will return after 4 minutes. Please use the time to find as many words as you can.

TASTE PERCEPTION

Thinking back to the drink you consumed previously: please judge it along the following criteria.

Give your answers from 1 to 10, where 1 represents **'Not at all'** and 10 represents **'Extremely'**.

	1 = 'Not at all'								10 = 'Extremely'	
	1	2	3	4	5	6	7	8	9	10
Fruity	○	○	○	○	○	○	○	○	○	○
Smooth	○	○	○	○	○	○	○	○	○	○
Sweet	○	○	○	○	○	○	○	○	○	○
Refreshing	○	○	○	○	○	○	○	○	○	○
Bitter	○	○	○	○	○	○	○	○	○	○
Strong tasting	○	○	○	○	○	○	○	○	○	○
Gassy	○	○	○	○	○	○	○	○	○	○
Pleasant	○	○	○	○	○	○	○	○	○	○
Light	○	○	○	○	○	○	○	○	○	○
Tasty	○	○	○	○	○	○	○	○	○	○

Please click 'Next', and let the experimenter know you have completed the ratings.

Next

VOLUME PERCEPTION TASK

Please wait for instructions from the experimenter for this task.

Next

Final demographic information

Height and Weight

Please enter your height and weight here.

- Height can be given in cm, m, feet, inches, etc.
- Weight can be given in kg, pounds, stone, etc.

If you don't know, please give a reasonable guess!

Height

Weight

Please click 'Next'.

Next

Please indicate what you think the *main* purpose of the study was, in your own words?

279

4.7. Study 2 debrief

4.7.1 Initial debrief

UNIVERSITY OF CAMBRIDGE

Public Health and Primary Care
The Primary Care Unit

Short-term effects of glucose on cognitive performance

Thank you very much for taking part in this study, exploring the short-term effects of glucose on cognitive performance. We can give you more information about the study aims via email, once all participants have completed the study. If you have any questions or concerns about this, please do not hesitate to contact one of the research team using the details below.

CONTACT DETAILS:
If you have any questions or concerns about the study, please contact:

Prof. Theresa Marteau   *or*   Tess Langfield
Email:
Tel:
Address: Institute of Public Health, Robinson Way, Cambridge, CB2 0SR, UK

UNIVERSITY OF CAMBRIDGE
Public Health and Primary Care
The Primary Care Unit

Impact of glass shape on drinking time: a laboratory-based replication study exploring mechanism

Thank you very much for taking part in this study. Your participation has been valuable in helping us to understand more about drinking behaviour. You were originally told that the purpose of the study was to investigate the effect of glucose on cognitive performance. Now that the study is complete, we would like to inform you of the true purpose of the research.

Those taking part received 330ml glass of Appletiser ® served in glass that was (a) straight-sided, or (b) outward-sloped.

To examine drinking behaviour in detail, we took video recordings of the study sessions. These recordings will only be available to the study researchers, and are for research purposes only. Recordings will be destroyed after 2 years.

The purpose of the study was to determine whether aspects of our drinking environment (in this case, the glass used) affect drinking speed, and other drinking behaviours such as sip size. These findings have possible implications as to the design of glassware, in efforts to reduce consumption of sugary and alcoholic drinks. We withheld the true aims of the study from you because we did not want you to be conscious of your drinking behaviour during the task. For example, knowing that we were interested in your drinking behaviour may have caused you to speed up or slow down your drinking.

All data will be stored anonymously and securely. However, if you are unhappy about your information being used in relation to the study aim described above, please let us know, and we can withdraw it from the study immediately. You have the right to withdraw from the study, at any time, without having to give a reason, up until the data is shared as "open data" (when we will no longer be able to identify which data is yours).

To stay up to date with our research group and its publications, please visit our website: http://bhru.iph.cam.ac.uk/.

CONTACT DETAILS:

If you have any questions or concerns about the study, please contact:

Prof. Theresa Marteau   *or*   Tess Langfield
Email:
Tel:
Address: Institute of Public Health, Robinson Way, Cambridge, CB2 0SR, UK.

Appendix for Chapter 5

5.1. Study 3 pre-registered study protocol

Langfield, T., Pechey, R., Pilling, M., & Marteau, T. M. (2019). Study protocol: Impact of glass shape on consumption of a soft drink during a bogus taste test.

Available at: https://osf.io/t9bvw/.

Impact of glass shape on consumption of a soft drink during a bogus taste test: study protocol

Tess Langfield, Rachel Pechey, Mark Pilling, Theresa Marteau

Abstract

Background

Glassware design may influence drinking behaviour, with some studies suggesting faster drinking from outward-sloped glasses than straight-sided ones. It is as yet unclear whether drinking from these different glass shapes leads to differences in amount consumed, and what factors might be driving the differences, with candidate mechanisms including affordance of micro-drinking behaviours and perception of volume. The present study will investigate the effect of glass shape on amount consumed for a soft drink, as well as the effect of glass shape on a micro-drinking behaviour (number of sips), and perceptual judgments (midpoint bias).

Method

In a between-subjects internal-pilot design, 72 participants will be recruited to taste and rate four drinks (all actually diluted Teisseire 'passion fruit le sirop'). They will be randomised to one of two conditions, and served these four drinks (total 660ml) in either a) outward-sloped martini glasses (n = 36) or b) straight-sided prosecco flutes (n = 36), during a single-session. The primary outcome is total amount consumed during the 10-min bogus "taste-test". To assess mechanisms for hypothesised effects, number of sips will be coded from video recordings of drinking during the "taste-test", and midpoint bias will be assessed using a task pouring liquids, conducted after the "taste-test".

Analysis

The primary analysis will predict total amount consumed (ml) from glass shape, adjusting for relevant covariates (baseline thirst, gender, maximum oral capacity, and drink enjoyment). Secondary analyses will predict number of sips and midpoint bias from glass shape, and explore whether number of sips and midpoint bias are associated with amount consumed.

Discussion

This study aims to add to growing evidence exploring the impact of glassware design on drinking behaviours. The evidence from this study - in conjunction with evidence from other studies - will inform interventions to reduce consumption of health-harming drinks.

Background

Glassware design may influence drinking behaviour (e.g., Hollands et al., 2015; Pechey et al., 2016; Spence & Wan, 2015). In particular, there is some evidence that different glass shapes – i.e., outward-sloped vs straight-sided - may cue

different drinking speeds, although results to date are mixed. Two studies show faster drinking from outward-sloped glasses than straight-sided ones (Attwood et al., 2012; Langfield et al., 2018). One of these found the effect only for beer, and not a lemonade soft drink (Attwood et al., 2012). One other found an effect for a fizzy apple soft drink (Langfield et al., 2018). A third study found no evidence for a difference in overall drinking speed for the same fizzy apple drink (Langfield et al., in prep).

One limitation common to these three glass shape studies is the potentially 'noisy' measure of 'total drinking time', reflecting drinking speed. Typically, participants are asked to consume a single drink of a pre-specified volume while watching a documentary. Total time spent drinking thus may be influenced by a number of variables (including interest in the documentary, a desire to finish the study more quickly, and so on). Further, it is as yet unclear how predictive drinking time is of amount consumed, a critical measure for assessing whether glassware design can be used to reduce consumption of health harming drinks.

Beyond 'total drinking time', there is evidence that glass shape may influence patterns of micro-drinking behaviours. For example, there is evidence that drinking trajectories within a standardised period differ between glass shapes, with a more decelerated pattern from outward-sloped glasses than straight-sided ones (Langfield et al., in prep), a pattern that has also been found for wide-rimmed vs narrow-rimmed straight-sided glasses (Cliceri et al., 2018). In addition, a lower number of sips (or larger average sip sizes) were taken from outward-sloped glasses, as compared to straight-sided ones, in all three previously mentioned studies on glass shape (Attwood et al., 2012; Langfield et al., 2018; Langfield et al., in prep), though the latter two studies were underpowered for this analysis, and only found trends in this direction.

Glass shape also affects perception of volume, with greater bias in midpoint estimation for outward-sloped glasses (Attwood et al., 2012; Troy et al., 2017; Langfield et al., 2018; in prep). These findings suggest that individuals systematically underestimate the true midpoint ("midpoint bias") to a greater degree for outward-sloped glasses than for straight-sided ones, consistent with using height as a cue for volume. However, only one study has found an association between midpoint bias and drinking speed (Attwood et al., 2012), with two studies finding no association (Langfield et al., 2018; Langfield et al., in prep). It remains unclear whether midpoint bias is an important mechanism determining drinking behaviours, including drinking speed and amount consumed.

The existing evidence suggests that people do consume differently from glasses which slope outwards, and those which are straight-sided. Thus far, effects on drinking behaviours have been shown using tall beer glasses (Attwood et al., 2012) and short tumblers (Langfield et al., 2018; in prep), suggesting that differences in drinking behaviour may be cued regardless of the exact glassware used (given certain common properties: in this instance, wall slope). Together, these findings have the potential to inform interventions designed to reduce consumption of sugary drinks and alcohol. However, it should be noted inferring reductions in amount consumed from slower drinking speeds, different drinking trajectories, or smaller sip sizes requires some assumptions to be made (namely, that these drinking behaviours are good 'proxies' for consumption, or are associated with reduced intake). As such, additional studies with measures of *amount* consumed (in addition to other drinking behaviours) are warranted.

The present study will explore the effect of glass shape on *ad libitum* consumption in a laboratory setting, using wide-rimmed, outward-sloped martini-style glasses and narrow-rimmed, straight-sided champagne glasses. Participants will be asked to taste and rate soft drinks while intake is covertly measured. The 'bogus taste test' is a validated paradigm, with consumption during these tests correlating with other measures of intake (e.g., Jones et al., 2016 for alcohol; Robinson et al., 2017 for food). The present study will also explore two possible underlying mechanisms, namely micro-drinking behaviours (number of sips) and perceptual judgments (midpoint bias).

Research Questions

Do glassware shapes of "outward-sloped wide" vs "straight-sided narrow" influence:
    (1) Amount consumed (ml)?
    (2) Number of sips?
    (3) Midpoint bias?

Is amount consumed associated with:
    (1) Number of sips?

283

(2) Midpoint bias?

Study Setting

The proposed study will take place in a testing room in central Cambridge (BCNI, Sir William Hardy Building, Downing Site, Cambridge, CB2 3EB).

Study Design

In a between-subjects experiment, participants will be randomised to one of two groups, receiving drinks to consume in either:

(1) Martini style glasses (wide and outward-sloped); or
(2) Champagne style flutes (narrow and straight-sided).

Primary outcome
The primary outcome measure is total volume consumed (ml) within a 10-minute period (as in previous bogus taste test studies, e.g., Maynard et al., 2017; Vasiljevic et al., 2018).

Secondary outcomes
Secondary outcome measures are:
(1) Micro-drinking behaviours (number of sips);
(2) Perceptual judgments (bias in midpoint estimation).

Gender, thirst, max oral capacity, and drink enjoyment will be measured to be adjusted for in the main analysis.

Participants and recruitment

A convenience sample of 72 (50% female) participants will be recruited from students and staff at the University of Cambridge, as well as the general population. Potential participants will be informed about the study through mailing lists, flyers, and word of mouth. Participants will be reimbursed £7 for their time and to cover any expenses.

Eligibility will be assessed at the start of the study session, and requires that individuals meet the following criteria:

- Have not taken part in my previous two experiments;
- Are over 18 years old;
- Are prepared to consume drinks that contain sugar;
- Have no known allergies to any of the following ingredients:
  - Fruit Juices from Concentrate 38% (20% Passion Fruit, 18% Lemon)
  - Glucose-Fructose Syrup
  - Flavourings
  - Colours: Lutein, Paprika Extract
  - Stabiliser: E445

Sample size determination

Internal pilot

The study sample size of N = 72 is primarily driven by pragmatic considerations *i.e.,* time and cost, is in line with convention (Lancaster et al, 2004), and represents an 'internal pilot', forming part of an adaptive design (see Wittes &

Britain, 1990). Internal pilot data is combined with subsequently collected data (if the study progresses) after an interim sample size re-estimation has occurred, in a final analysis. Given that previous studies have largely focused on the effects of glass shape on speed rather than consumption, we do not know what the effect size on consumption might be. As such, this internal pilot (n = 72) will provide the necessary parameters (effect size & p value) for a sample size calculation. This adaptive design allows for the following stopping rules for recruitment:

(1) If $p < 5\%$ at the internal pilot analysis, further recruitment is not required. This is the *efficacy (utility) stopping criterion*.

(2) If the sample size required to demonstrate $p < 5\%$ is unfeasible (feasibility will be determined at the time of the calculation – based on time and cost) the trial will be stopped. This is the *futility stopping criterion*.

Together, these criteria represent early stopping rules.

If the trial is stopped based on the futility stopping criterion, the data from the sample of 72 participants will be written up as a pilot study.

Randomisation

Participants will be randomised by gender strata into one of the two conditions, using a random number generator (with each condition containing 36 participants, made up of 18 females and 18 males).

Materials

Glassware
The martini glass is the "Olympia Campana", sourced from Nisbets (https://www.nisbets.co.uk/olympia-campana-one-piece-crystal-martini-glass-260ml/cs497), see Figure 1a.

The prosecco flute is the "Olympia Modale", also sourced from Nisbets (https://www.nisbets.co.uk/olympia-modale-crystal-champagne-flutes-215ml/gf728), see Figure 1b.
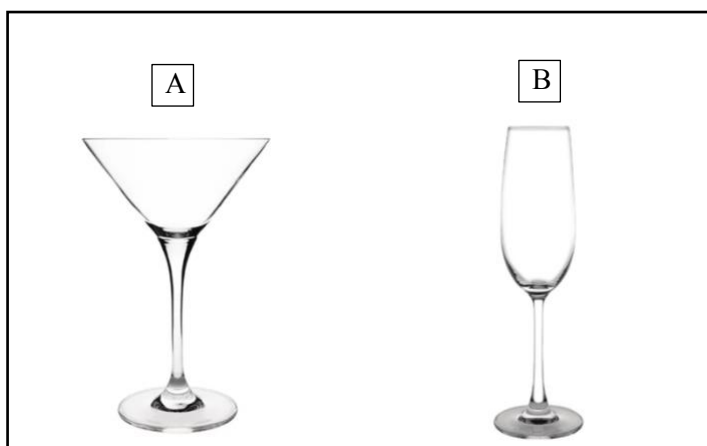
Figure 1. Images of the glassware to be used in the study. (A) outward-sloped martini glass, (B) straight-sided prosecco flute.

The glasses were chosen as they roughly match on various dimensions, while differing in shape (see Table 1 for glassware specifications).

Table 1. Properties of glassware used in the study

	Product name	Height	Weight	Rim diameter	Material	Maximum capacity
Martini glass	Olympia: Campana	18 cm	165 g	12 cm	Glass	260 ml
Prosecco flute	Olympia: Modale	23 cm	145 g	4.5 cm	Crystal	210 ml

Drink served

Participants will be served a total of 660ml (divided into four 165ml portions) of Teisseire passion fruit le sirop (Ingredients: Sugar, Fruit Juices from Concentrate 38% (20% Passion Fruit, 18% Lemon), Glucose-Fructose Syrup, Water, Flavourings, Colours: Lutein, Paprika Extract, Stabiliser: E445), 80g sugar/100ml undiluted. The drinks will be diluted 1 part syrup, 7 parts water (12.5ml syrup per 100ml served).

Measures

Primary outcome measure

Total amount consumed (ml) will be measured by weighing the four identical glasses before and after drinking, using high precision scales.

Each glass (A,B,C,D) will be weighed with 165ml inside, to provide a total in grams (which will be 165 + weight of the glass, to account for any variation in weight between glasses).

To determine volume consumed after the "taste test", the weights of the glasses after consumption will be subtracted from the initial weights. Volume consumed will be collated across the four glasses *i.e.,* individual glass consumption data, while it will be recorded, will not be analysed.

Secondary outcome measures

(1) Micro-drinking behaviour: number of sips

Number of sips will be determined from video recordings of participants' drinking during the "taste test". These video recordings will be coded for sips. Sips will be counted across all four drinks (i.e., within-glass data will not be analysed).

(2) Perceptual judgment: Midpoint bias

Midpoint bias will be measured by asking participants to complete a task involving pouring liquids, to determine their ability to estimate the halfway point of the drink they were served previously.

Participants will be presented with a 165ml portion of Teisseire passion fruit le sirop in the same style of glass they were served during the "taste test". They will be asked to pour out half of this volume (82.5ml) into a jug (containing 500ml). After the glass is weighed to determine their midpoint estimate, the glass will be emptied into the jug, and the

participant will be asked to pour from the jug now containing 665ml into the now empty glass, until they think the glass contains 82.5ml. They will estimate the halfway point six times in total (three pours from a "full" (165ml) glass into the jug, and three from the jug into an empty glass).

Other measures

Demographic characteristics (gender, age, BMI, level of education) will be collected from participants using the Qualtrics online survey platform, at the start of the study.

Baseline thirst will be measured, by asking participants to rate their thirst from 1 ("Not at all") to 10 ("Extremely").

Maximum oral capacity will be measured by asking participants to sip from a glass of water, filling their mouth with as much liquid as possible, before spitting this liquid it into a cup (see Lawless et al., 2003 for similar procedure). This will be completed three times (with the resulting liquid measured and divided by three). This liquid will not be stored, and the glass emptied and washed immediately after the weight has been determined.

Drink enjoyment will be derived from "tasty" and "pleasant" ratings measured during the bogus taste test (e.g., Maynard et al., 2017; Langfield et al., 2018).

Procedure

Participants will be invited into the laboratory to take part in a single-session study investigating taste preferences for drinks - the cover story for the study. Testing will take place between 8am-8pm in a location in central Cambridge.

To begin the study, the participant will be asked to complete a consent form, and confirm eligibility criteria via a self-reported tick list. Next, the participant will answer questions relating to demographic information and rate thirstiness (1-10). They will then be asked to wait while the experimenter prepares the drinks for the "taste test".
The experimenter will next leave the room to prepare the four drinks – which are weighed out (each with 165ml of Teisseire passion fruit le sirop), and placed on a tray. Drinks will be labelled A, B, C, or D, using card labels placed in front of each glass.

To begin the "taste test", the experimenter will place the tray in front of participant, and provide instructions for the task. Participants will be told they will have 10 minutes to taste and rate the drinks along 10 descriptors (fruity, smooth, sweet, refreshing, bitter, strong-tasting, gassy, pleasant, light, and tasty) (see Langfield et al., 2018; Maynard et al., 2017). As well as completing these ratings, participants will also be asked to note down their order of preference from 1(favourite)- 4(least favourite), to reinforce the cover story. They will be told they can drink as much or as little of the drinks as they like to assist their ratings. The camera will be switched on, and participants reminded they will be video recorded during the task, explaining that this is to track the order in which drinks are consumed.

During the "taste test", the experimenter will leave the room for 10 minutes, before returning and removing the drinks from in front of participant. The camera will be switched off at this stage.

The participant will next complete the midpoint pouring task (involving six poured estimates of 82.5ml). After the pouring task, the participant will be asked to guess the purpose of the study, using an open-ended question on the Qualtrics platform on the computer. Finally, participants will be asked to fill their mouth to full capacity by sipping from a cup filled with water, and spitting this into an empty cup (weighed before and after to gauge volume).

Participants will then be debriefed and reimbursed £7 for their time and expenses (approximately 45 minutes). After the participant has left, the experimenter will weigh the glasses to determine total amount consumed.

Analysis Plan

Stage 1 (Internal pilot – to estimate effect size):

287

Total amount consumed (transformed if skewed, or similar) will be compared between glass shapes. This analysis will be conducted with and without adjustment for relevant covariates (gender, baseline thirst, maximum oral capacity, and drink enjoyment).

The resulting effect size (Cohen's d) and p value will be used to calculate the required sample size for the full trial.

At this stage, given the primary purpose is to estimate effect size of glass shape on consumption, secondary outcomes (number of sips, midpoint bias), split by condition, will simply be summarised unless the trial is stopped.

Stage 2 (Full trial – full analyses):

After the full sample has been recruited - either (1) the internal pilot was sufficient to detect a difference (utility stopping criterion), or (2) further participants are recruited based on the sample size calculation - full analyses will be conducted. These will incorporate *all* the data collected (i.e., at both stages if further participants are recruited). This is an 'adaptive design' (for more info see Kairilla et al., 2012).

The primary analysis will predict amount consumed from glass shape, adjusting for specified covariates. Secondary analyses be conducted, predicting number of sips and midpoint bias from glass shape. The relationships between amount consumed and number of sips/midpoint bias will also be explored. Sensitivity analyses will also be conducted with/without individuals who correctly guess the true purpose of (1) the study (to examine the effect of glass shape on amount consumed), and (2) the taste test (to measure how much is consumed).

References

Hollands, G. J., Shemilt, I., Marteau, T. M., Jebb, S. A., Lewis, H. B., Wei, Y., ... & Ogilvie, D. (2015). Portion, package or tableware size for changing selection and consumption of food, alcohol and tobacco. *The Cochrane database of systematic reviews*, (9).

Pechey, R., Couturier, D. L., Hollands, G. J., Mantzari, E., Munafò, M. R., & Marteau, T. M. (2016). Does wine glass size influence sales for on-site consumption? A multiple treatment reversal design. *BMC public health*, *16*(1), 390.

Spence, C., & Wan, X. (2015). Beverage perception and consumption: The influence of the container on the perception of the contents. *Food quality and preference*, *39*, 131-140.

Attwood, A. S., Scott-Samuel, N. E., Stothart, G., & Munafò, M. R. (2012). Glass shape influences consumption rate for alcoholic beverages. *PloS one*, *7*(8), e43007.

Langfield, T., Pechey, R., Pilling, M., & Marteau, T. M. (2018). Impact of glass shape on time taken to drink a soft drink: A laboratory-based experiment. *PloS one*, *13*(8), e0202793.

Langfield, T., Pechey, R., Pilling, M., & Marteau, T. M. (in prep).

Cliceri, D., Petit, E., Garrel, C., Monteleone, E., & Giboreau, A. (2018). Effect of glass shape on subjective and behavioral consumer responses in a real-life context of drinking consumption. *Food Quality and Preference*, *64*, 187-191.

Troy, D. M., Attwood, A. S., Maynard, O. M., Scott-Samuel, N. E., Hickman, M., Woods, A., & Munafò, M. R. (2018). Effect of glass shape on the pouring accuracy of liquid volume. *PloS one*, *13*(10), e0204562.

Jones, A., Button, E., Rose, A. K., Robinson, E., Christiansen, P., Di Lemma, L., & Field, M. (2016). The ad-libitum alcohol 'taste test': secondary analyses of potential confounds and construct validity. *Psychopharmacology*, *233*(5), 917-924.

Robinson, E., Haynes, A., Hardman, C. A., Kemps, E., Higgs, S., & Jones, A. (2017). The bogus taste test: Validity as a measure of laboratory food intake. *Appetite*, *116*, 223-231.

Maynard, O. M., Langfield, T., Attwood, A. S., Allen, E., Drew, I., Votier, A., & Munafò, M. R. (2017). No impact of calorie or unit information on ad libitum alcohol consumption. *Alcohol and Alcoholism*, *53*(1), 12-19.

Vasiljevic, M., Couturier, D. L., Frings, D., Moss, A. C., Albery, I. P., & Marteau, T. M. (2018). Impact of lower strength alcohol labeling on consumption: A randomized controlled trial. *Health Psychology*.

Lancaster, G.A., Dodd, S., & Williamson, P.R. (2004). Design and analysis of pilot studies: recommendations for good practice. *J Eval Clin Pract*, 10, 307–312.

Wittes, J., & Brittain, E. (1990). The role of internal pilot studies in increasing the efficiency of clinical trials. *Statistics in Medicine*, *9*(1-2), 65-72.

Kairalla, J. A., Coffey, C. S., Thomann, M. A., & Muller, K. E. (2012). Adaptive trial designs: a review of barriers and opportunities. *Trials*, *13*(1), 145.

Lawless, H. T., Bender, S., Oman, C., & Pelletier, C. (2003). Gender, age, vessel size, cup vs. straw sipping, and sequence effects on sip volume. *Dysphagia*, *18*(3), 196-202.

5.2. Study 3 recruitment

5.2.1 Flyer used for recruitment

UNIVERSITY OF CAMBRIDGE

Taste preferences study

We are looking to recruit participants for a study on taste preferences.

You would be eligible to take part if you:

- Have **not** taken part in my previous two experiments;
- Are over 18 years old;
- Are prepared to consume drinks that contain sugar;
- Have no known allergies to any of the following ingredients:
    - Fruit Juices from Concentrate 38% (20% Passion Fruit, 18% Lemon)
    - Glucose-Fructose Syrup
    - Flavourings
    - Colours: Lutein, Paprika Extract
    - Stabiliser: E445

The study involves tasting and rating four drinks, as well as completing some questionnaires and short tasks. The entire session should last around 45 minutes, and you would be reimbursed **£7** for your time and expenses. Testing takes place in the BCNI, Sir William Hardy Building, Downing Site, Cambridge, CB2 3EB.

5.2.2 Email used for mailing lists

Subject line: Invitation to participate in a study on taste preferences

Dear All,

I am currently conducting a study on taste preferences. I am looking for participants who:

- Have <u>not</u> taken part in my previous two experiments;
- Are over 18 years old;
- Are prepared to consume drinks that contain sugar;
- Have no known allergies to any of the following ingredients:
    - Fruit Juices from Concentrate 38% (20% Passion Fruit, 18% Lemon)
    - Glucose-Fructose Syrup
    - Flavourings
    - Colours: Lutein, Paprika Extract
    - Stabiliser: E445

The study involves tasting four soft drinks, and completing some questionnaires and other short tasks. It should last about 45 minutes, and you would be reimbursed with £7 for your time and expenses.

The study takes place in the BCNI, Sir William Hardy Building, Downing Site, Cambridge, CB2 3EB.

If you would like to take part, please email me on ▮▮▮▮▮▮▮▮▮▮▮▮ or sign up to a slot directly here: <insert SONA link>.

Participant Information Sheet: Taste preferences study

You are being invited to take part in a research study. Before you decide to take part it is important for you to understand why the research is being done and what it will involve. Please take time to read the following information carefully and discuss it with others if you wish. A member of the team can be contacted if there is anything that is not clear or if you would like more information. Take time to decide whether or not you wish to take part.

Purpose of the study

This study will investigate taste preferences for drinks which have been bottled in different containers. You will be asked to attend a single session of approximately 45 minutes, in which you would be served four soft drinks for you to taste and rate. You would also complete some questionnaire measures, and some further tasks involving pouring the drinks.

Why have I been chosen?

You have been invited to take part as you expressed an interest in this study.

Do I have to take part?

It is up to you whether you decide to take part. If you do decide to take part, you will be asked to sign a consent form prior to commencing the study. If you change your mind, withdrawal will involve no penalty or loss, now or in the future.

What will happen to me if I take part?

You will be asked to come to a testing room in the BCNI in Downing Site for a single 45-minute session. If you are eligible to take part, you will be asked to sign a consent form. After an initial questionnaire, you would be asked to taste four soft drinks. These drinks have been bottled and stored in different containers. You will be asked to rate the drinks according to a given criteria. You would be asked to consume as much or as little as you like, in order to make your ratings. You would have 10 minutes to complete the ratings, and you would be videotaped during this time. You would complete an exercise on perceptions that involves pouring liquids. You would also be asked to complete a water taste test. After finishing the study, you would then be reimbursed £7.

Are there possible disadvantages and/or risks in taking part?

There are no major risks associated with taking part, though you should ensure you are prepared to consume drinks that contain sugar, and that you have no allergies to the following ingredients: Fruit Juices from Concentrate 38% (20% Passion Fruit, 18% Lemon); Glucose-Fructose Syrup; Flavourings; Colours: Lutein, Paprika Extract; Stabiliser: E445.

What are the possible benefits of taking part?

There are no direct benefits of taking part in this research study and your participation is entirely voluntary.

What will happen to my personal information?

We will be using any personal information you give us in order to undertake this study and the University of Cambridge will act as the data controller for this purpose. The legal basis for using your personal information is to carry out academic research in the public interest. We will keep identifiable information about you for as long as necessary for the study. Your rights to access, change or move your information are limited, as we need to manage your information in specific ways in order for the research to be reliable and accurate. If you withdraw from the

study, we will keep the information about you that we have already obtained. To safeguard your rights, we will use the minimum personally-identifiable information possible.

For further general information about the University of Cambridge's use of your personal data as a participant in a research study, please see https://www.information-compliance.admin.cam.ac.uk/data-protection/research-participant-data.

What will happen to the results of the research project?

Once the study is complete, the data will be analysed and written up for publication in journals. Results may also be presented at conferences. Your personal responses during the study would not be identifiable in any way, as data will be aggregated. If you would like a copy of the final paper, you may request that this be sent to you once it is published.

Video recordings will be identified only by a code, and will only be available to those on the research team. They will be stored securely in line with departmental regulations. Recordings will be destroyed after 1 year.

At the end of the study your data would become "open data", so that anyone who is interested in the research is able to conduct their own analyses. However, all data will be anonymised before being made publicly available, so there would be no way to identify you personally.

Can I withdraw my data?

Yes. If you decide that you do not want your data to be used you can withdraw your data at any time after the study, for any reason, up until the data is shared as "open data". After this, all links between your personal information and the research data would be destroyed. Thus we would not be able to withdraw your data because we would not be able to identify which data came from you.

Who is organising and funding the research?

This study is being organised by the Behaviour and Health Research Unit at the University of Cambridge, and funded by a PhD grant from the Medical Research Council.

Ethical review of the study

The project has been reviewed by the University of Cambridge Psychology Research Ethics Committee (reference: PRE.2018.122).

Contact for further information

For any questions or concerns about the study, please contact Tess Langfield at ████████████████ or Professor Theresa Marteau at ██████████████████████ or on ██████████. Alternatively, please write to us at: Institute of Public Health, Robinson Way, Cambridge, CB2 0SR, UK

CONSENT FORM

Taste preferences study

Please confirm that you agree to the following statements, by writing your <u>initials</u> in each box.

PLEASE CONFIRM THAT YOU:

<u>**INITIALS**</u>

Have read and understand the Information Sheet;	
Have had satisfactory answers to any questions asked about the study;	
Understand that all personal information will remain confidential and all efforts will be made to ensure you cannot be identified (except as might be required by law);	
Agree that data gathered in this study may be stored anonymously and securely, and may be used for future research;	
Understand that this study will be recorded, and that video recordings will not be made available beyond the research team (recordings will be kept securely for 1 year before being destroyed);	
Understand that participation is voluntary and that you are free to withdraw at any time without having to give a reason;	
Have not taken part in my previous two experiments;	
Are at least 18 years of age;	
Are prepared to consume drinks that contain sugar, and have no known allergies to the following ingredients: 　▪　Passion fruit juice; Lemon juice; Glucose-Fructose Syrup; Flavourings; Colours (Lutein; Paprika extract); Stabiliser: E445.	
Agree to take part in this study.	

BY SIGNING THE BELOW BOX, I AGREE WITH ALL POINTS LISTED ABOVE. I HEARBY FULLY AND FREELY CONSENT TO MY PARTICIPATION IN THIS STUDY

Date					Signature of the participant:
	Day	Month	Year		Print name: Signature of the investigator:

293

5.4. Study 3 online questionnaire

UNIVERSITY OF
CAMBRIDGE

Participant information

Please answer the following questions about yourself.

Gender

Male

Female

Other

Prefer not to say

Age

Handedness

Right

Left

Ambidextrous

What is the highest level of education you have completed?

GCSE/O Level

AS/A Level

Undergraduate degree

Postgraduate degree (e.g. Masters, PhD)

None of the above

Height and Weight

Height can be given in cm, m, feet, inches, etc. Weight can be given in kg, pounds, stone, etc.

If you don't know, please give a reasonable guess!

Please specify which measurement you are using (e.g. 165cm / 5 ft 10 / 1.8 m / 55 kg / 9 stone 8)

Height

Weight

Now, thinking about how you feel now, how thirsty are you? (1 = Not at all, 10 = Extremely)

| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |

Taste test

You will have **10 minutes** to taste and rate four drinks, which have been previously bottled in different containers.

The drinks are labelled **A, B, C,** and **D.** You may taste them in any order, but please make sure your ratings apply to the correct question below.

Please drink as much, or as little, as you would like, in order to make your ratings.

Rating drink **'A'** - please judge it along the following criteria.

Give your answers from 1 to 10, where 1 represents **'Not at all'** and 10 represents **'Extremely'**.

| | 1 = 'Not at all' | | | | | | | | | 10 = 'Extremely' |
	1	2	3	4	5	6	7	8	9	10
Fruity	○	○	○	○	○	○	○	○	○	○
Smooth	○	○	○	○	○	○	○	○	○	○
Sweet	○	○	○	○	○	○	○	○	○	○
Refreshing	○	○	○	○	○	○	○	○	○	○
Bitter	○	○	○	○	○	○	○	○	○	○
Strong tasting	○	○	○	○	○	○	○	○	○	○
Gassy	○	○	○	○	○	○	○	○	○	○
Pleasant	○	○	○	○	○	○	○	○	○	○
Light	○	○	○	○	○	○	○	○	○	○
Tasty	○	○	○	○	○	○	○	○	○	○

Rating drink **'B'** - please judge it along the following criteria.

Give your answers from 1 to 10, where 1 represents **'Not at all'** and 10 represents **'Extremely'**.

| | 1 = 'Not at all' | | | | | | | | | 10 = 'Extremely' |
	1	2	3	4	5	6	7	8	9	10
Fruity	○	○	○	○	○	○	○	○	○	○
Smooth	○	○	○	○	○	○	○	○	○	○
Sweet	○	○	○	○	○	○	○	○	○	○
Refreshing	○	○	○	○	○	○	○	○	○	○
Bitter	○	○	○	○	○	○	○	○	○	○
Strong tasting	○	○	○	○	○	○	○	○	○	○
Gassy	○	○	○	○	○	○	○	○	○	○
Pleasant	○	○	○	○	○	○	○	○	○	○
Light	○	○	○	○	○	○	○	○	○	○
Tasty	○	○	○	○	○	○	○	○	○	○

Rating drink **'C'** - please judge it along the following criteria.

Give your answers from 1 to 10, where 1 represents **'Not at all'** and 10 represents **'Extremely'**.

| | 1 = 'Not at all' | | | | | | | | | 10 = 'Extremely' |
	1	2	3	4	5	6	7	8	9	10
Fruity	○	○	○	○	○	○	○	○	○	○
Smooth	○	○	○	○	○	○	○	○	○	○
Sweet	○	○	○	○	○	○	○	○	○	○
Refreshing	○	○	○	○	○	○	○	○	○	○
Bitter	○	○	○	○	○	○	○	○	○	○
Strong tasting	○	○	○	○	○	○	○	○	○	○
Gassy	○	○	○	○	○	○	○	○	○	○
Pleasant	○	○	○	○	○	○	○	○	○	○
Light	○	○	○	○	○	○	○	○	○	○
Tasty	○	○	○	○	○	○	○	○	○	○

Rating drink **'D'** - please judge it along the following criteria.

Give your answers from 1 to 10, where 1 represents **'Not at all'** and 10 represents **'Extremely'**.

	1 = 'Not at all'									10 = 'Extremely'
	1	2	3	4	5	6	7	8	9	10
Fruity	○	○	○	○	○	○	○	○	○	○
Smooth	○	○	○	○	○	○	○	○	○	○
Sweet	○	○	○	○	○	○	○	○	○	○
Refreshing	○	○	○	○	○	○	○	○	○	○
Bitter	○	○	○	○	○	○	○	○	○	○
Strong tasting	○	○	○	○	○	○	○	○	○	○
Gassy	○	○	○	○	○	○	○	○	○	○
Pleasant	○	○	○	○	○	○	○	○	○	○
Light	○	○	○	○	○	○	○	○	○	○
Tasty	○	○	○	○	○	○	○	○	○	○

Please place the four drinks in your order of preference by dragging the options up and down (1 = favourite, 4 = least favourite).

Drink A

Drink B

Drink C

Drink D

To what extent can you taste differences between the four drinks?

Not at all

Somewhat

Extremely

Unsure

299

VOLUME PERCEPTION TASK

The aim of this task is to measure your ability to perceive liquid volumes. You will be asked to judge where you think the midpoint of the drink is - that is, where **half of the portion** is.

The liquid volume you will be judging will be the same as you were served in the taste test.

You will be asked to pour from the glass into the jug, leaving half of the liquid in the glass. You will then be asked to pour from the jug into the glass, again, where you think half of the full portion is.

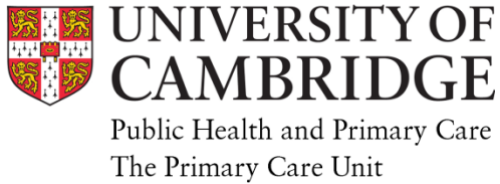**You'll do each pouring task 3 times each, so 6 pours of the midpoint in total.**

Next

Please indicate what you think the *main* purpose of the study was, in your own words?

Please click 'Next'.

Next

5.5 Study 3 debrief

5.5.1 Initial debrief

UNIVERSITY OF CAMBRIDGE
Public Health and Primary Care
The Primary Care Unit

Taste preferences study

Thank you very much for taking part in this study, exploring taste preferences for drinks previously bottled in different containers. We can give you more information about the study aims via email, once all participants have completed the study. If you have any questions or concerns about this, please do not hesitate to contact one of the research team using the details below.

CONTACT DETAILS:
If you have any questions or concerns about the study, please contact:

Prof. Theresa Marteau   *or*   Tess Langfield
Email:
Tel:
Address: Institute of Public Health, Robinson Way, Cambridge, CB2 0SR, UK

5.5.2 Final debrief

Impact of glass shape on *ad libitum* consumption of a soft drink in a bogus taste test

Thank you very much for taking part in this study. Your participation has been valuable in helping us to understand more about drinking behaviour. You were originally told that the purpose of the study was to investigate taste preferences stored in different containers. Now that the study is complete, we would like to inform you of the true purpose of the research.

Those taking part received 660ml of Teisseire passion fruit le sirop, served in four glasses. You were told these drinks had been previously stored in different bottles, which may have affected taste. In fact, the drinks all came from identical glass bottles. However, half of you were served your drinks in glasses that were straight-sided (prosecco flutes), and the other half were served drinks in glasses that were outward-sloped (martini glasses). You also completed a task where you poured liquid into the glass, to estimate the halfway point. The study aimed to see whether glass shape affected drinking behaviours (including amount consumed and number of sips), as well as ability to accurately perceive volume (the pouring task).

To examine drinking behaviour in detail, we took video recordings of the study sessions. These recordings will only be available to the study researchers, and are for research purposes only. Recordings will be destroyed after 1 year.

The purpose of the study was to determine whether aspects of our drinking environment (in this case, the glass used) affect amount consumed, and other drinking behaviours such 'micro-drinking behaviours' (e.g., sipping behaviours). These findings have possible implications as to the design of glassware, potentially to be used in efforts to reduce consumption of sugary and alcoholic drinks. We withheld the true aims of the study from you because we did not want you to be conscious of your drinking behaviour during the task. For example, knowing that we were interested in your drinking behaviour may have caused you to consume more or less of the drinks served to you.

All data will be stored anonymously and securely. However, if you are unhappy about your information being used in relation to the study aim described above, please let us know, and we can withdraw it from the study immediately. You have the right to withdraw from the study, at any time, without having to give a reason, up until the data is shared as "open data" (when we will no longer be able to identify which data is yours).

To stay up to date with our research group and its publications, please visit our website: http://bhru.iph.cam.ac.uk/.

CONTACT DETAILS:
If you have any questions or concerns about the study, please contact:

Prof. Theresa Marteau   *or*   Tess Langfield
Email:
Tel:
Address: Institute of Public Health, Robinson Way, Cambridge, CB2 0SR, UK.

Appendix for Chapter 6

6.1. Study 4 pre-registered study protocol

Langfield, T., Gilchrist, P., Norberg, M., Pilling, M., & Marteau, T. M. (2019). Study protocol: Impact of glass shape on amplitude of activity in *orbicularis oris* and sip size: an electromyography study

---

Study protocol: Impact of glass shape on amplitude of activity in *orbicularis oris* and sip size: an electromyography study

Background
There is increasing evidence that the shape and size of glassware can influence drinking behaviours for soft drinks and alcohol, including drinking speed, volume consumed, and micro-drinking behaviours such as sip size. One proposed mechanism which may elucidate these effects is affordance. For example, glasses may afford certain patterns of micro-drinking behaviours based on physical characteristics of the container and the resulting flow of liquid when tipped. Relatedly, it is possible that glasses of different shapes may afford different embouchures (the positioning of lip muscles), which may, in turn, influence sip size. This hypothesis awaits testing.

Method
In a within-subjects design, a minimum of 40 participants will taste and rate four drinks, (all identical 165ml servings of Teisseire 'passion fruit le sirop'). These will be served in A) straight-sided prosecco glasses and B) outward-sloped martini glasses, with order of presentation counterbalanced (ABAB or BABA), with participants randomised equally to the two orders. They will take three sips from each drink, while the activity of their lip muscles (orbicularis oris) is measured using non-invasive surface electromyography (EMG). The primary outcome measure will be mean amplitude of activity in orbicularis oris, expressed as a percentage of maximum voluntary contraction – a proxy for embouchure. The secondary outcome measure will be sip size, measured using concealed weighing scales detecting change in weight after each sip.

Analysis
The primary analysis will investigate the effect of glass shape (outward-sloped vs straight-sided) on embouchure. Analyses will also be conducted to determine the extent to which embouchure predicts sip size.

Discussion
The present study will investigate whether different glass shapes (outward-sloped, straight-sided) cue differences in embouchures (measured using EMG). Through exploring the possible affordances of glassware design on embouchures, and, in turn, whether these impact micro-drinking behaviours, the study will elucidate underlying mechanisms potentially driving effects of glassware design on consumption. Exploring mechanism in this way may ultimately inform the optimal design of glassware to reduce consumption of health-harming drinks.

Research questions

303

1. Does glass shape (outward-sloped vs straight-sided) affect embouchure (amplitude of activity in orbicularis oris)?

2. Does embouchure predict sip size?

Study design

In a within-subjects design, participants will be presented with four soft drinks to taste, varying only in the glass shape they are served in (2 identical straight-sided prosecco glasses and 2 identical outward-sloped martini glasses). The order of presentation will be counterbalanced (i.e., ABAB or BABA, with A representing the straight-sided glass shape and B representing the outward sloped glass shape), with participants randomised equally to the two orders.

The primary outcome measure is:
-   Mean amplitude of muscular activity (mV) in the left orbicularis oris (superior and inferior), expressed as a % of maximal voluntary contraction, detected during sipping.

Other measures will include sip size (ml), gender, baseline thirst, and maximum oral capacity (the latter three of which will be included as covariates for analyses involving sip size).

Study setting

Bar-laboratory, Macquarie University, Balaclava Rd, Macquarie Park, NSW 2109, Australia.

Participants and recruitment

A convenience sample will be recruited, with the aim to test a minimum of 40 female participants, based on pragmatic constraints, and in line with previous studies (e.g., Carr, Winkielman, & Oveis, 2013; Larsen, Norris, & Cacioppo, 2003; Wu et al., 2015).

Potential participants will be informed about the study through mailing lists, flyers, and word of mouth, and those who express an interest will be sent more information in advance of attending a session. Participants will be informed that the study involves assessing taste preferences for drinks when served in different containers. They would be informed that they would be reimbursed 10 AUD for their time and expenses.

Eligibility will be assessed at the start of the study session, and requires that individuals meet the following criteria, that they:

-   Are female;
-   Are over 18 years old;
-   Have not eaten or drunk anything (including water) for 30 minutes prior to the test session;
-   Have not smoked within 30 minutes of the test session;
-   Have had no surgical procedures performed on the lips (e.g., cleft lip surgery or cosmetic reconstruction);
-   Do not have highly sensitive skin (the skin will be gently exfoliated with abrasive gel and an abrasive pad, which may irritate highly sensitive skin);
-   Are prepared to remove their facial make up prior to the task;

- Are prepared to consume drinks that contain sugar;
- Have no known allergies to any of the following ingredients:
    o Fruit Juices from Concentrate 38% (20% Passion Fruit, 18% Lemon)
    o Glucose-Fructose Syrup
    o Flavourings
    o Colours: Lutein, Paprika Extract
    o Stabiliser: E445

Materials

Drinking glasses and drink served

Participants will be served 660ml of passion fruit syrup mixed with water (Teisseire passion fruit le sirop). The syrup ingredients are listed as follows: Sugar, Fruit Juices from Concentrate 38% (20% Passion Fruit, 18% Lemon), Glucose-Fructose Syrup, Water, Flavourings, Colours: Lutein, Paprika Extract, Stabiliser: E445). The syrup contains 80g sugar/100ml undiluted. The drinks will be diluted 1 part syrup, 7 parts water (i.e., 12.5ml syrup per 100ml served).

The 660ml served to participants will be divided between four glasses (two outward-sloped, and two straight-sided), each containing 165ml.

The outward-sloped martini glass is the "Olympia Campana", sourced from Nisbets, Australia (https://www.nisbets.com.au/olympia-campana-one-piece-crystal-martini-glass-260ml/cs497)   see Figure 1a.

The straight-sided prosecco flute is the "Olympia Modale", also sourced from Nisbets, Australia (https://www.nisbets.com.au/olympia-modale-crystal-champagne-flutes-215ml/gf728), see Figure 1b.
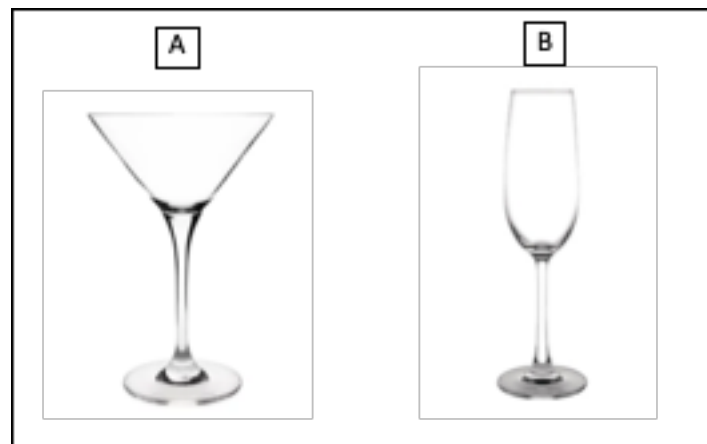

Figure 1. Images of the glassware to be used in the study. (A) outward-sloped martini glass, (B) straight-sided prosecco flute.

Electrodes and electrode placement

Four surface electrodes will be attached to the upper and lower lips on the left side of the face. For the lower left quadrant, one electrode will be placed 1cm below the cheilion (corner of mouth), and the paired electrode placed 1cm medial and slightly below (corresponding to the edge of the mouth). The

305

upper left quadrant will follow the same pattern (see Fridlund & Cacioppo, 1986 and van Boxtel, 2010 for recommended placement of electrodes for facial EMG). The ground electrode will be placed on the temple (as recommended in the BIOPAC webinar on facial EMG measurement, 2018).

Prior to attaching the electrodes, the skin will be prepared for placement. Any make up in the area of electrode placement will be removed using a make-up remover wipe (Simple). The skin will then be gently exfoliated with an abrasion pad, and then brushed with a small amount of abrasive gel on the end of a cotton bud.

The surface electrodes will be filled with electrode prep gel to encourage good signal conductivity and reduce artifacts, prior to being affixed to skin with adhesive discs. All wires coming from the electrode site will be taped behind the ear and clipped to the chair to ensure they do not pull from the skin.

Impedance (signal conductivity) will be checked for each electrode using an Impedance checker prior to beginning the taste test. If impedance is too high (i.e., greater than 30 kO) even after 10 minutes of waiting, the electrodes will be removed and re-affixed.

Figure 2. Placement of surface electrodes on the face.

Measures

Facial EMG Measurement: Embouchure

The primary outcome measure in this study is embouchure. Embouchure will be measured using electrodes which detect the amplitude of activity in the upper and lower lips. Higher amplitudes of activity will be seen as a proxy for a more 'pursed' embouchure. A BIOPAC machine, connected to a computer with Acknowledge software, and to the participant via electrodes, will record the electromyographic (EMG) signals from the lip muscles in real time.

Raw amplitudes of activity will be transformed in the Acknowledge software using a script which generates a rectified and integrated copy of the data over a period of 250ms and then rescales the channel so that this runs from 0-100%, with an individual's maximum voluntary contraction representing 100%. Standardising activity in this way has been recommended for facial EMG measurement (van Boxtel et al., 2010). To determine each individual's maximum voluntary contraction, maximal lip compression trials will be run, involving participants pursing their lips as hard as possible three times (as in Murray et al., 1998). The signal with the highest amplitude (from the three maximum lip compression attempts) will be selected to be used for each participant's maximum voluntary contraction. The amplitudes selected for maximum voluntary contraction may differ across lip sites (upper/lower).

Both aggregated (i.e., mean embouchures (%) for each participant, across the six sips taken from each glass) and individual-level (i.e., embouchure at each sip) data will be obtained.

Sip size (ml)

In order to explore the association between embouchures and sip sizes (ml), individual sip volumes will be measured. Repeated measures data will be obtained (i.e., values for each of the six sips taken from each glass shape). Sip sizes will be calculated by using concealed weighing scales. The weight of each glass will be measured before consumption (i.e., with 165ml drink inside) and after each sip is taken during the drinking task. To determine sip sizes, the difference in weight will be calculated.

Other measures

Demographic information will be collected once electrodes have been affixed. This will include gender, age, level of education, and BMI. A baseline thirstiness rating (1-10) will also be obtained by asking participants rate from 1(Not at all) to 10(Extremely) their current level of thirst, after the demographic questionnaire.

Maximum oral capacity will be measured – disguised as a palate cleanser – prior to placement of electrodes. Participants will be asked to fill their mouth with water (as much as physically possible) and spit their bolus into a jug. The jug will be weighed before and after to determine the maximum oral capacity.

Procedure

Participants will be invited to take part in a 45 minute experiment in a 'bar lab' at Macquarie University, Sydney, Australia. The laboratory is designed to mimic a real-life drinking environment. Participants will be recruited via mailing lists, posters, flyers, and word of mouth, and invited to take part in a study investigating preferences for and reactions to soft drinks stored in different containers (see Vasiljevic et al., 2018 for a similar cover story). The procedure will be adapted from a standard bogus taste test paradigm (Jones et al., 2016).

At the start of the study, the participant will first be invited to read to the Information Sheet, and to complete a consent form, confirming via self-report that they meet the eligibility criteria.

Once informed consent has been obtained and eligibility checked, participants will be asked to 'cleanse their palate' – the task measuring maximum oral capacity. They will be asked to fill their mouth with as much water as they physically can, and to spit this into a jug (as in Langfield et al., in prep). Next, the skin will be prepared for electrode placement. The skin of the electrode sites (upper and lower lips, and temple) will first be wiped with a make-up remover wipe to remove any surface debris and oils. Next these areas will be gently exfoliated with an abrasive pad and a cotton bud with a little abrasive gel on the tip.

Next, the electrodes will be prepared for placement. After sticking adhesive disks to the surface of the electrodes, the cavities inside each electrode will be filled with electrode gel. Two electrodes will then be placed onto the upper lip, followed by two onto the lower lip, and one on the temple (the ground electrode). All trailing wires would be taped on the neck to leave slack and avoid pulling. The wires will then be clipped behind the participant to their chair.

Next, the participant will be asked to fill out questionnaires (i.e., demographic information and thirstiness rating). During this time, impedance of each electrode site will be checked periodically (using the Impedance Checker). The drinking task will not begin until at least 10 minutes has passed, even if the participant has finished the questionnaires (allowing time for the electrodes to settle, minimising noise and maximising conductivity). Once impedance is satisfactory (i.e., less than 30 kO), the main task of the experiment (the taste test) will begin.

The order that participants will be instructed to taste the four drinks (i.e., from two outward-sloped glasses and two straight-sided glasses) will be counterbalanced (in the order ABAB or BABA). Participants will taste each drink in four regimented stages, three times (i.e., there will be three sips taken from each drink, with each sip being divided into four stages). The initiation of each of the four stages will be demarcated by words on the screen ("Relax", "Prepare", "Remove", "Swallow"; adapted from Murray et al., 1998). The action to be elicited for each word would be next be explained, as follows:

Step 1 – "Relax": "Please relax, keeping your lips at rest"

Step 2 – "Prepare": "Please lift the glass and hold it in front of your mouth"

Step 3 – "Remove": "Now raise the glass to your lips and take a sip"

Step 4 – "Swallow": "Swallow the sip in one swallow"

Participants will practise these stages first by sipping from a glass of water. Once they are confident with the steps, they would then begin the taste test, taking sips from each glass three times (with 15 second gap to follow the "swallow" stage, and prior to the initiation of the next sip). After tasting each drink three times, the participant would be shown a 10-item questionnaire. These questions have been used in previous studies using bogus taste tests (e.g., Maynard et al., 2017; Langfield et al, in prep). Participants would be asked to rate the drink, from 1(Not at all) to 10 (Extremely), on 10 descriptors, included as filler questions ("fruity", "smooth", "sweet", "refreshing", "bitter", "strong-tasting", "gassy", "pleasant", "light", and "tasty"). They would then be asked to rate, from 1-10, how much they enjoyed the experience of consuming their drink from that glass. These represent filler questions. The participant would then be presented with the second drink (in the alternate glass), and the previous steps would be repeated. These stages would then be repeated twice more (once again from each glass).

Once both drinks had been tasted and rated, the participant would be asked to complete the maximal lip compression tasks (which will be used to standardise amplitude of activity into a percentage of maximum activity). They would be asked to "squeeze your lips together as hard as you can, so they protrude as far as possible". They will do this 3 times, as prompted by the on-screen instructions.

Finally, electrodes will be removed from the participant, and make-up remover wipes and tissues offered. Participants would then be asked to describe what they believe to be the purpose of the study. They would finally be debriefed, reimbursed 10 AUD, and asked to sign a form stating receipt of the reimbursement.

Statistical Plan

Descriptive summaries will be used to assess whether data can be aggregated by glass type or whether the glass number may be required in analysis.

The primary analysis will predict embouchure (% muscle activity used) from glass shape, adjusting for order effects, using a linear mixed effects model.

The secondary analysis will involve predicting sip size (ml) from embouchure (% muscle activity used), adjusting for pre-specified covariates (order effects, gender, baseline thirst, maximum oral capacity), and with glass shape as a fixed effect, in a linear mixed effects model.

Sensitivity analyses will also be conducted with/without individuals who correctly guessed the true purpose of the study.

References

Attwood, A. S., Scott-Samuel, N. E., Stothart, G., & Munafò, M. R. (2012). Glass shape influences consumption rate for alcoholic beverages. *PloS one*, *7*(8), e43007.

Basmajian, J. V., & White, E. R. (1973). Neuromuscular control of trumpeters' lips. *Nature*, *241*(5384), 70.

Bennett, J. W., Van Lieshout, P. H., Pelletier, C. A., & Steele, C. M. (2009). Sip-sizing behaviors in natural drinking conditions compared to instructed experimental conditions. *Dysphagia*, *24*(2), 152-158.

Cannon, P. R., Li, B., & Grigor, J. M. (2017). Predicting subjective liking of bitter and sweet liquid solutions using facial electromyography during emptying, swirling, and while thinking about the taste.

Carr, E. W., Winkielman, P., & Oveis, C. (2014). Transforming the mirror: Power fundamentally changes facial responding to emotional expressions. *Journal of Experimental Psychology: General*, *143*(3), 997.

Cliceri, D., Petit, E., Garrel, C., Monteleone, E., & Giboreau, A. (2018). Effect of glass shape on subjective and behavioral consumer responses in a real-life context of drinking consumption. *Food Quality and Preference*, *64*, 187-191.

Fridlund, A. J., & Cacioppo, J. T. (1986). Guidelines for human electromyographic research. *Psychophysiology*, *23*(5), 567-589.

Gotouda, A., Yamaguchi, T., Okada, K., Matsuki, T., Gotouda, S., & Inoue, N. (2007). Influence of playing wind instruments on activity of masticatory muscles. *Journal of oral rehabilitation*, *34*(9), 645-651.

Hollands, G. J., Bignardi, G., Johnston, M., Kelly, M. P., Ogilvie, D., Petticrew, M., ... & Marteau, T. M. (2017). The TIPPME intervention typology for changing environments to change behaviour. *Nature Human Behaviour*, *1*(8), 0140.

Hollands, G. J., Marteau, T. M., & Fletcher, P. C. (2016). Non-conscious processes in changing health-related behaviour: a conceptual analysis and framework. *Health Psychology Review*, *10*(4), 381-394.

Hollands, G. J., Shemilt, I., Marteau, T. M., Jebb, S. A., Kelly, M. P., Nakamura, R., ... & Ogilvie, D. (2013). Altering micro-environments to change population health behaviour: towards an evidence base for choice architecture interventions. *BMC public health*, *13*(1), 1218.

Jones, A., Button, E., Rose, A. K., Robinson, E., Christiansen, P., Di Lemma, L., & Field, M. (2016). The ad-libitum alcohol 'taste test': secondary analyses of potential confounds and construct validity. *Psychopharmacology*, *233*(5), 917-924.

Langfield, T., Pechey, P., Pilling, M., & Marteau, T. M. (in prep). Glass design and drinking behaviours: A review of impact and mechanisms using a new typology of drinking behaviours.

Langfield, T., Pechey, R., Pilling, M., & Marteau, T. M. (2018). Impact of glass shape on time taken to drink a soft drink: A laboratory-based experiment. *PloS one*, *13*(8), e0202793.

Larsen, J. T., Norris, C. J., & Cacioppo, J. T. (2003). Effects of positive and negative affect on electromyographic activity over zygomaticus major and corrugator supercilii. *Psychophysiology*, *40*(5), 776-785.

Lawless, H. T., Bender, S., Oman, C., & Pelletier, C. (2003). Gender, age, vessel size, cup vs. straw sipping, and sequence effects on sip volume. *Dysphagia*, *18*(3), 196-202.

Marteau, T. M. (2018). Changing minds about changing behaviour. *The Lancet*, *391*(10116), 116-117.

Marteau, T. M., Hollands, G. J., & Fletcher, P. C. (2012). Changing human behavior to prevent disease: the importance of targeting automatic processes. *science*, *337*(6101), 1492-1495.

Maynard, O. M., Langfield, T., Attwood, A. S., Allen, E., Drew, I., Votier, A., & Munafò, M. R. (2017). No impact of calorie or unit information on ad libitum alcohol consumption. *Alcohol and Alcoholism*, *53*(1), 12-19.

Murray, K. A., Larson, C. R., & Logemann, J. A. (1998). Electromyographic response of the labial muscles during normal liquid swallows using a spoon, a straw, and a cup. *Dysphagia*, *13*(3), 160-166.

Robinson, E., Haynes, A., Hardman, C. A., Kemps, E., Higgs, S., & Jones, A. (2017). The bogus taste test: Validity as a measure of laboratory food intake. *Appetite*, *116*, 223-231.

Vaiman, M., & Eviatar, E. (2009). Surface electromyography as a screening method for evaluation of dysphagia and odynophagia. *Head & face medicine*, *5*(1), 9.

Vaiman, M., Eviatar, E., & Segal, S. (2004). Surface electromyographic studies of swallowing in normal subjects: a review of 440 adults. Report 1. Quantitative data: timing measures. *Otolaryngology-Head and Neck Surgery*, *131*(4), 548-555.

Vaiman, M., Nahlieli, O., & Eliav, E. (2006). Oynophagia in patients after dental extraction: surface electromyography study. *Head & face medicine*, *2*(1), 34.

Van Boxtel, A. (2010, August). Facial EMG as a tool for inferring affective states. In *Proceedings of measuring behavior* (pp. 104-108). Wageningen: Noldus Information Technology.

Vasiljevic, M., Couturier, D. L., Frings, D., Moss, A. C., Albery, I. P., & Marteau, T. M. (2018). Impact of lower strength alcohol labeling on consumption: A randomized controlled trial. *Health Psychology*.

White, E. R., & Basmajian, J. V. (1973). Electromyography of lip muscles and their role in trumpet playing. *Journal of Applied Physiology*, *35*(6), 892-897.

Wu, Y., van Dijk, E., & Clark, L. (2015). Near-wins and near-losses in gambling: a behavioral and facial EMG study. *Psychophysiology*, *52*(3), 359-366.

Zaretsky, E., Pluschinski, P., Sader, R., Birkholz, P., Neuschaefer-Rube, C., & Hey, C. (2017). Identification of the most significant electrode positions in electromyographic evaluation of swallowing-related movements in humans. *European Archives of Oto-Rhino-Laryngology*, *274*(2), 989-995.

6.2. Study 4 recruitment

6.2.1 Flyer used for recruitment

EARN $10 FOR A 45 MINUTE STUDY

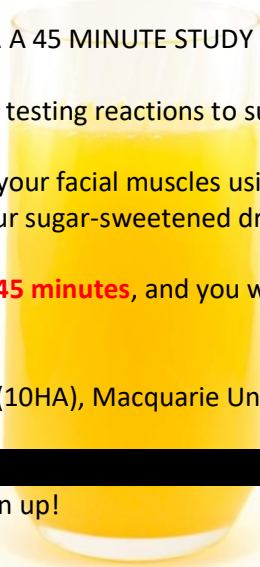We are looking for females for a study testing reactions to sugar-sweetened drinks.

The study will measure the activity of your facial muscles using non-invasive electrodes – while you taste and rate your preferences for four sugar-sweetened drinks.

The entire session should last around **45 minutes**, and you would be reimbursed **$10 cash** for your time and expenses.

Testing takes place in Simulation Hub (10HA), Macquarie University Campus.

Contact Tess ▮▮▮▮▮▮▮▮▮▮▮▮▮▮▮▮▮▮▮▮▮▮▮▮▮▮▮▮ for more information (including eligibility criteria) and to sign up!

6.2.2 Email used for mailing lists

Subject line: Invitation to participate in a study on taste preferences

Dear All,

We are looking to recruit females for a study testing reactions to sugar-sweetened drinks.

The study will measure the activity of your facial muscles using non-invasive electrodes – while you taste and rate your preferences for four sugar-sweetened drinks.

The entire session should last around 45 minutes, and you would be reimbursed **$10** for your time and expenses.

You would be eligible to take part if you:
- Are female;
- Are over 18 years old;
- Have had no surgical procedures performed on the lips (e.g., cleft lip surgery or cosmetic reconstruction);
- Do not have highly sensitive skin (the skin will be gently exfoliated with abrasive gel and an abrasive pad, which may irritate highly sensitive skin);
- Are prepared to remove facial make up prior to the task;
- Do not consume any food, drink (including water), or tobacco, for 30 minutes prior to testing;
- Are prepared to consume drinks that contain sugar;
- Have no known allergies to any of the following ingredients:
    o Fruit Juices from Concentrate 38% (20% Passion Fruit, 18% Lemon)
    o Glucose-Fructose Syrup
    o Flavourings
    o Colours: Lutein, Paprika Extract
    o Stabiliser: E445

Testing takes place in the Simulation Hub, 10 Hadenfeld Avenue, Macquarie University, NSW 2109, Australia.

If you would like to take part, please email a member of the research team on ▮▮▮▮▮▮▮▮▮▮▮▮▮▮▮▮▮▮▮ or sign up to a slot directly here: <insert link>.

6.3. Study 4 participant information and consent

Department of Psychology

Faculty of Human Sciences

MACQUARIE UNIVERSITY   NSW   2109

Phone: ████████████

Fax: ███████████████

Email: ████████████████████

Macquarie University Supervisor's Name & Title: Philippe Gilchrist, Ph.D.

Participant Information and Consent Form

HREC Project Number: 5415

Name of Project: **Taste preferences study**

You are invited to participate in a study examining taste preferences for, and reactions to, sugar-sweetened drinks served in different containers.

This Participant Information Sheet/Consent Form tells you about the research project, and what is involved. Knowing what is involved will help you decide if you want to participate. Please read this information carefully. Ask questions about anything that you don't understand or want to know more about. Before deciding whether or not to take part, you might want to talk about it with a relative or friend or local doctor. Participation in this research is voluntary. If you don't wish to take part, you don't have to.

1. What is the purpose of this research?

The purpose of the study is to better understand people's reactions to, and preferences for, sugar-sweetened beverages served in different containers. We will use questionnaire ratings and psychophysiological measures of the activity of facial muscles to measure this. This will help fill a gap in knowledge regarding the factors that may influence palatability of sugar-sweetened beverages.

The study is being conducted by collaborators from Macquarie University and the University of Cambridge. Ms. Tess Langfield ████████████████████ will conduct the experiment under the supervision of Dr. Philippe Gilchrist ████████████████████, Department of Psychology, ████████████████, and A/Prof. Melissa Norberg. Tess Langfield is a Visiting Scholar at Macquarie University. She is a PhD Student at the Department of Public Health and Primary Care, University of Cambridge, UK. Her PhD is supervised by Prof Theresa Marteau (████████████████████), Department of Public Health and Primary Care, University of Cambridge, UK.

2. What does participation in this research involve?

If you decide to participate, you would be required to abstain from eating, drinking (including water), and smoking, for 30 minutes prior to your allocated test session. You would be invited to attend a testing room on the Macquarie University campus. After checking you are eligible to take part, you would be asked to cleanse your palate, by swirling water in your mouth, and spitting it out. Your skin would then be prepared for the non-invasive surface electrodes. We would ask you to wipe your skin with a make-up remover wipe, in the locations of electrode placement. We'd then very gently exfoliate the skin with an abrasive pad and mild abrasive gel. Some people may feel some minor discomfort in this process. Next we would attach the surface electrodes to your skin using adhesive discs. These would be placed in three locations (one on the temple, and two on the lower portion of the face). While we wait for the electrode signal to improve, you would answer some questions about yourself, including demographic information. You would then be asked to taste and rate four soft drinks, taking three sips from each. You would rate them along various criteria (e.g., how 'tasty' you think they are). After finishing the study, the electrodes would be removed carefully. This process feels a bit like removing a band aid. The full study lasts about 45 minutes. You would receive $10 AUD for your participation.

3. Other relevant information about the research project

Any information or personal details gathered in the course of the study are confidential, except as required by law. No individual would be identifiable in any publication of the results. Members of the immediate research team (Dr. Philippe Gilchrist, Prof Theresa Marteau, Dr. Melissa Norberg, Dr Mark Pilling, and Ms Tess Langfield) will have access to the anonymised study data. Your personal responses during the study would not be identifiable in any way, as data will be aggregated. A summary of the results of the study can be made available to you on request once it is published, if you make such a request to us by email. The data from this study may also be used to inform future Human Research Ethics Committee-approved projects in the Department of Psychology at Macquarie University and the Department of Public Health and Primary Care at the University of Cambridge.

4. Do I have to take part in this research project?

Participation in any research project is voluntary. If you do not wish to take part, you do not have to. If you decide to take part and later change your mind, you are free to withdraw from the project at any stage without any negative consequences.

If you do decide to take part, you will be given this Participant Information and Consent Form to sign for us, and you will be given a copy to keep as well. Your decision whether to take part or not to take part, or to take part and then withdraw, and will not affect your relationship with Macquarie University.

5. What are the possible benefits of taking part?

There are no direct benefits of taking part in this research study and your participation is entirely voluntary. However, possible benefits may include learning and insight into experimental psychology research methodology.

6. What are the possible risks and disadvantages of taking part?

There are no risks associated with the physiological measurement procedures in this study. Some people may experience some minor discomfort when preparing skin for electrode placement. This process involves exfoliating the skin to ensure the electrodes can detect activity of your facial muscles. Further, when removing the electrodes, you may also feel some minor discomfort – similar to removing a band aid. You should also ensure you are prepared to consume drinks that contain sugar, and that you have no allergies to the following ingredients: Fruit Juices from Concentrate (Passion Fruit, Lemon); Glucose-Fructose Syrup; Flavourings; Colours: Lutein, Paprika Extract; Stabiliser: E445.

7. What if I withdraw from this research project?

There are no negative consequences to withdrawing, at any time. If you decide that you do not want your data to be used you can withdraw your data at any time during or after the study, for any reason, up until the data is shared as "open data". After this, all links between your personal information and the research data would be destroyed. Thus we would not be able to withdraw your data because we would not be able to identify which data came from you.

8. What will happen to information about me?

By signing the consent form you consent to the research team to collect and use personal information about you for the research project. Any information obtained in connection with this research project that can identify you (e.g., your name and contact details) will remain confidential. Participants will be assigned participant IDs, and the link between your identifiable information and this ID will be stored securely (on the encrypted Secure Data Hosting Service). All data you provide for this study (e.g., answers to online questionnaire, psychophysiological measurements) will only be identified by participant ID.

At the end of the study your data would become "open data", so de-identified data will be stored on a public repository in order to promote open science. This enables anyone who is interested in the research to conduct their own analyses. However, all data will be anonymised before being made publicly available, so there would be no way to identify you personally. The link between your contact details and participant ID will be destroyed at this stage.

It is anticipated that the results of this research project will be published and/or presented in a variety of forums. In any publication and/or presentation, information will be provided in such a way that you cannot be identified. Your name or any information that might identify you will not be used in any publications which stem from this research. Any

313

information obtained for the purpose of this research project that can identify you will be treated as confidential and securely stored (i.e., this consent form). All participant consent forms and any paper data will be stored under lock and key at Macquarie University during and following the research study until which time they will be destroyed after 7 years. It will be disclosed only with your permission, or as required by law.

We will be using any personal information you give us in order to undertake this study and the University of Cambridge will act as the data controller for this purpose. The legal basis for using your personal information is to carry out academic research in the public interest. We will keep identifiable information about you for as long as necessary for the study. Your rights to access, change or move your information are limited, as we need to manage your information in specific ways in order for the research to be reliable and accurate. If you withdraw from the study, we will keep the information about you that we have already obtained. To safeguard your rights, we will use the minimum personally-identifiable information possible.

For further general information about the University of Cambridge's use of your personal data as a participant in a research study, please see https://www.information-compliance.admin.cam.ac.uk/data-protection/research-participant-data.

9. Who is organizing and funding this research?

This study is being organised by researchers at the Behaviour and Health Research Unit at the University of Cambridge, and in the Department of Psychology at Macquarie University. The study is funded by a PhD grant from the Medical Research Council, administered to Tess Langfield. Facilities are provided by Macquarie University.

10. Who has reviewed the research project?

This project has been reviewed by the Macquarie University Research Ethics Committee (REF: 5201954159069) and the University of Cambridge Psychology Research Ethics Committee (REF: PRE.2019.030).

11. Further information and who to contact

The person you may need to contact will depend on the nature of your query. If you want any further information concerning this project or if you have any problems which may be related to your involvement in the project, you can contact any of the named researchers below:

Chief Investigator (Macquarie University): Philippe Gilchrist, Ph.D.
Phone:
Email:

Co-supervisor: Melissa Norberg, Ph.D.
Phone:
Email:

Chief Investigator: Theresa Marteau, Ph.D.
Phone:
Email:

Experimenter (Visiting Scholar): Tess Langfield B.Sc.
Email:

If you decide you want to take part in the research project, you will be asked to sign the consent section.

You will be given a copy of the Participant Information and Consent Form to keep.

CONSENT FORM
Please write your INITIALS in each box, to confirm that you:

Have read and understand the Information Sheet;	
Consent to the tests and research that are described;	
Understand that all personal information will remain confidential and all efforts will be made to ensure you cannot be identified (except as might be required by law);	
Agree that data gathered in this study may be stored anonymously and securely, and may be used for future research;	
Understand that participation is voluntary and that you are free to withdraw at any time without having to give a reason;	
Are female;	
Are at least 18 years of age;	
Have had no surgical procedures performed on the lips (e.g., cleft lip surgery or cosmetic reconstruction);	
Do not have highly sensitive skin (the skin will be gently exfoliated with abrasive gel and an abrasive pad, which may irritate highly sensitive skin);	
Are prepared to remove facial make up prior to the task;	
Have not consumed any food, drink (including water), or tobacco for 30 minutes prior to test session;	
Are prepared to consume drinks that contain sugar, and have no known allergies to the following ingredients: Passion fruit juice; Lemon juice; Glucose-Fructose Syrup; Flavourings; Colours (Lutein; Paprika extract); Stabiliser: E445.	
Consent to take part in this study.	

BY SIGNING THE BELOW, I AGREE WITH ALL POINTS LISTED ABOVE.

I, _____, have read and understand the Information Sheet and any questions I have asked have been answered to my satisfaction. I agree to participate in this research, knowing that I can withdraw from further participation in the research at any time without consequence, up until the data from this study is made "open data". I have been given a copy of this form to keep.

Participant's Name:_____
  (Block letters)

Participant's Signature: _____ Date:_____

Investigator's Name:_____
  (Block letters)

Investigator's Signature: _____ __ Date:_____

The ethical aspects of this study have been reviewed by the Macquarie University Human Research Ethics Committee and the Cambridge University Psychology Research Ethics Committee.

If you have any complaints or reservations about any ethical aspect of your participation in this research, you may contact the Macquarie Committee through the Director, Research Ethics & Integrity (telephone (02) 9850 7854; email ethics@mq.edu.au). Any complaint you make will be treated in confidence and investigated, and you will be informed of the outcome.

(PARTICIPANT'S [or INVESTIGATOR'S] COPY – SIGN AND DATE BOTH COPIES)

315

6.4. Study 4 online questionnaire

UNIVERSITY OF CAMBRIDGE

Participant information

Please answer the following questions about yourself.

Gender

Male

Female

Other

Prefer not to say

Age

What is your nationality?

What is the highest level of education you have completed?

School Certificate or equivalent

Higher School Certificate or equivalent

Diploma or Associate degree

Bachelors degree

Masters degree

Doctoral degree (e.g. PhD)

None of the above

Height and Weight

Please give height in cm or m, and weight in kg.

If you don't know, please give a reasonable guess!

Height

_____

Weight

_____

Now, thinking about how you feel now, how thirsty are you? (1 = Not at all, 10 = Extremely)

| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |

Please click 'Next'.

Electrode preparation

The experimenter will attach the facial electrodes. Please be patient as this process will take several minutes.

Next

Taste test

You are going to be asked to taste and rate four drinks, served in different containers. We are interested in how the drinks taste. You will be asked to rate each drink after you have tasted it.

Please familiarise yourself with the questions you will be asked about the drinks, below.

You can also see the questions on a printed sheet in front of you.

Rating drink **X** - please judge it along the following criteria.

Give your answers from 1 to 10, where 1 represents **'Not at all'** and 10 represents **'Extremely'**.

| | 1 = 'Not at all' | | | | | | | | | 10 = 'Extremely' |
	1	2	3	4	5	6	7	8	9	10
Fruity	O	O	O	O	O	O	O	O	O	O
Smooth	O	O	O	O	O	O	O	O	O	O
Sweet	O	O	O	O	O	O	O	O	O	O
Refreshing	O	O	O	O	O	O	O	O	O	O
Bitter	O	O	O	O	O	O	O	O	O	O
Strong tasting	O	O	O	O	O	O	O	O	O	O
Gassy	O	O	O	O	O	O	O	O	O	O
Pleasant	O	O	O	O	O	O	O	O	O	O
Light	O	O	O	O	O	O	O	O	O	O
Tasty	O	O	O	O	O	O	O	O	O	O

How much did you enjoy the drink?

Give your answer from 1 to 10, where 1 represents **'Not at all'** and 10 represents **'Extremely'**.

	1	2	3	4	5	6	7	8	9	10
Drink X	O	O	O	O	O	O	O	O	O	O

319

Taste test

In this task, you will be asked to taste and rate 4 soft drinks.

For each drink, you will be asked to take **3 sips.** You will then answer the questions about how the drink tasted (see image below).

Instructions for sips:

We would like you to **take each sip** by following these instructions.

Step 1 – "Relax": "Please relax, keeping your lips at rest"

Step 2 – "Prepare": "Please lift the glass and hold it in front of your mouth"

Step 3 – "Sip": "Now raise the glass to your lips, and take a sip"

Step 4 – "Swallow": "Remove the glass from your lips and swallow the sip in a single swallow"

Please note you can drink as much or as little as you would like, with every sip.

Let's practise with a glass of water.

Ready to take your first sip from **PRACTICE DRINK X**?

Click "Next" to begin.

Next

(NOTE: The below four stages represent all three sips taken for each drink. Step 1 and 2 were displayed on screen for 5 seconds each. Step 3 and 4 were displayed on screen for 3 seconds each.)

Step 1 – "Relax": Please relax, keeping your lips at rest

Step 2 – "Prepare": Please lift the glass and hold it in front of your mouth

Step 3 – "Sip": Now raise the glass to your lips, and take a sip

Step 4 – "Swallow": Remove the glass from your lips and swallow the sip in a single swallow

Ready to take your second sip from **PRACTICE DRINK X**?

Click "Next" to begin.

STEP 1 – 4 THEN PRESENTED AGAIN

Ready to take your third sip from **PRACTICE DRINK X**?

Click "Next" to begin.

STEP 1 – 4 THEN PRESENTED AGAIN

Rating drink (**PRACTICE DRINK X**) - please judge it along the following criteria.

Give your answers from 1 to 10, where 1 represents '**Not at all**' and 10 represents '**Extremely**'.

	1 = 'Not at all'									10 = 'Extremely'
	1	2	3	4	5	6	7	8	9	10
Fruity	○	○	○	○	○	○	○	○	○	○
Smooth	○	○	○	○	○	○	○	○	○	○
Sweet	○	○	○	○	○	○	○	○	○	○
Refreshing	○	○	○	○	○	○	○	○	○	○
Bitter	○	○	○	○	○	○	○	○	○	○
Strong tasting	○	○	○	○	○	○	○	○	○	○
Gassy	○	○	○	○	○	○	○	○	○	○
Pleasant	○	○	○	○	○	○	○	○	○	○
Light	○	○	○	○	○	○	○	○	○	○
Tasty	○	○	○	○	○	○	○	○	○	○

How much did you enjoy the drink?

Give your answer from 1 to 10, where 1 represents '**Not at all**' and 10 represents '**Extremely**'.

	1	2	3	4	5	6	7	8	9	10
PRACTICE DRINK X	○	○	○	○	○	○	○	○	○	○

You are now finished with the practice task. Do you have any questions?

Click "Next" to move onto the main task.

The main task proceeded as above, with three sips taken for each of the four drinks, except drinks were named **"DRINK 1", "DRINK 2", "DRINK 3", and "DRINK 4",** *rather than* **"PRACTICE DRINK X".**

Please indicate what you think the *main* purpose of the study was, in your own words?

Please click 'Next'.

6.5. Study 4 debrief

6.5.1 Initial debrief
Department of Psychology

Faculty of Human Sciences

MACQUARIE UNIVERSITY   NSW   2109

Phone: ▮▮▮▮▮▮▮▮▮▮▮
Email: ▮▮▮▮▮▮▮▮▮▮▮▮

Experimenter and Visiting Scholar: Tess Langfield
Chief Investigator (Cambridge): Theresa Marteau, Ph.D.
Chief Investigator (Macquarie): Philippe Gilchrist, Ph.D.
Co-Investigators: Melissa Norberg, Ph.D., Mark Pilling, Ph.D.

HREC Project Number: 5415

DEBRIEF – Taste preferences study

Thank you very much for taking part in this study, exploring taste preferences for, and reactions to, sugary drinks served in different containers. We will give you more information about the study aims via email, once all participants have completed the study. If you have any questions or concerns about this, please do not hesitate to contact one of the research team using the details below.

CONTACT DETAILS:

If you have any questions or concerns about the study, please contact a member of the research team:

Tess Langfield ▮▮▮▮▮▮▮▮▮▮▮▮▮▮
Institute of Public Health, Forvie Site, Cambridge Biomedical Campus, Cambridge, CB2 0SR (UK)

Dr. Philippe Gilchrist ▮▮▮▮▮▮▮▮▮▮▮▮▮▮▮▮
Department of Psychology, 4 First Walk, Macquarie University, NSW 2019 (AUS)

Prof. Theresa Marteau ▮▮▮▮▮▮▮▮▮▮▮▮▮▮
Institute of Public Health, Forvie Site, Cambridge Biomedical Campus, Cambridge, CB2 0SR (UK)

6.5.2 Final debrief

Department of Psychology
Faculty of Human Sciences
MACQUARIE UNIVERSITY   NSW   2109

Experimenter and Visiting Scholar: Tess Langfield
Chief Investigator (Cambridge): Theresa Marteau, Ph.D.
Chief Investigator (Macquarie): Philippe Gilchrist, Ph.D.
Co-Investigators: Melissa Norberg, Ph.D., Mark Pilling, Ph.D.   HREC Project Number: 5415

FULL DEBRIEF –
Impact of glass shape on amplitude of activity in *orbicularis oris* and sip size: an electromyography study

Thank you very much for taking part in this study. Your participation has been valuable in helping us to understand more about drinking behaviour. You were originally told that the purpose of the study was to investigate taste preferences for, and reactions to, drinks served in different containers. Now that the study is complete, we would like to inform you of the true purpose of the research.

Those taking part received 660ml of Teisseire passion fruit le sirop, served in four glasses (two straight-sided prosecco flutes and two outward-sloped martini glasses). The activity of the orbicularis oris (upper and lower lip) was monitored using electrodes attached to an electromyography machine.

Some research has suggested that aspects of our drinking environment (and in particular, the glass used) can affect drinking behaviour, including amount consumed. We wanted to explore whether glasses of different shapes influences the position of lips – how pursed they are – during sipping. We were also interested in whether the position of your lips was associated with the size of sips you took. To examine your sip sizes in real time, we used a concealed weighing scales which tracked how much you had consumed after each sip.

These findings may help to understand the mechanisms underlying effects of glassware design on drinking behaviour. Together with other research, this study could have implications as to the optimal design of glassware to reduce consumption of sugary and alcoholic drinks. We withheld the true aims of the study from you because we did not want you to be conscious of your drinking behaviour during the task. For example, knowing that we were interested in your drinking behaviour and the positioning of your lips may have caused you to behave unnaturally - consuming more or less of the drinks served to you, or changing the way you approached the glasses with your lips.

All data will be stored anonymously and securely. However, if you are unhappy about your information being used in relation to the study aim described above, please let us know, and we can withdraw it from the study immediately. You have the right to withdraw from the study, at any time, without having to give a reason, up until the data is shared as "open data" (when we will no longer be able to identify which data is yours).

This study was conducted by researchers from the Behaviour and Health Research Unit at the University of Cambridge <http://bhru.iph.cam.ac.uk/>, in collaboration with the Behavioural Science Lab at Macquarie University <http://psy.mq.edu.au/bsl/>. You can keep up to date with research and publications from these research groups on their websites.

CONTACT DETAILS:
If you have any questions or concerns about the study, please contact a member of the research team:

Tess Langfield ▮▮▮▮▮▮▮▮▮▮▮▮▮▮), and **Prof. Theresa Marteau** ▮▮▮▮▮▮▮▮▮▮▮▮
Address: Institute of Public Health, Forvie Site, Cambridge Biomedical Campus, Cambridge, CB2 0SR (UK)
Phone: ▮▮▮▮▮▮▮▮▮▮

Dr. Philippe Gilchrist ▮▮▮▮▮▮▮▮▮▮▮▮▮▮
Address: Department of Psychology, 4 First Walk, Macquarie University, NSW 2019 (AUS)
Phone: ▮▮▮▮▮▮▮▮