RUNNING HEAD: DIURNAL PATTERNS OF FOOD CONSUMPTION

Explaining diurnal patterns of food consumption

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ABSTRACT

When questioned, people typically report that different foods are appropriate at different times of day. What is more, patterns of food consumption tend to exhibit marked diurnal/circadian variations in many parts of the world too. The question addressed in this review is what factors help to explain these temporal differences in food consumption. While it has been suggested that our nutritional needs may differ somewhat over the course of the day, cultural conventions, marketing-led interventions, atmospheric (e.g., think only of changes in ambient temperature and/or daily light levels), perceptual (i.e., threshold) and/or hedonic changes, as well as psychological factors have also been suggested to play a role. Taken together, though, the evidence reviewed here would appear to support the view that cultural and psychological factors, not to mention the ubiquitous influence of food marketing, may be the most important factors in terms of helping to explain why it is that so many of us choose to eat different foods at different times of the day. Relevant psychological factors here include everything from the purported depletion of self-restraint resources over the course of the day through to the fulfilment of different psychological needs (e.g., functional or hedonic) associated with different mealtimes. Given the unhealthy foods typically associated with breakfast in many western countries (e.g., think only of sugar-laden breakfast cereals), gaining a better understanding of the factors underpinning current temporal patterns of food consumption may potentially help those wanting to nudge consumers toward making healthier food choices in the future.

KEYWORDS: DIURNAL; CIRCADIAN; CULTURE; PSYCHOLOGICAL FACTORS; MARKETING.

1. Introduction

Nowadays, the majority of people around the world would appear to believe that different foods are appropriate for different times of day (e.g., Birch, Billman, & Richards, 1984; Kramer, Rock, & Engell, 1992). Certainly, in many parts of the world, patterns of food consumption exhibit diurnal/circadian[1] variations, with clear differences being reported in the kinds of food that people choose to eat over the course of the day (de Castro, 1987; McLeod, James, & Witcomb, 2020; see Spence, 2017a, for a review of breakfast foods). The aim of this review is to assess those factors that may help to explain these predictable temporal variations in the pattern of food consumption that are associated with different meal occasions (Leech, Worsley, Timperio, & McNaughton, 2015).

Considering this issue some years ago, Birch et al. (1984, p. 114) wrote that: *"Although these changes in acceptability with time of day are uniquely human, these data do not exclude the possibility that such cultural rules may be influenced by underlying circadian variations in physiological biases that predispose the selection of foods varying, for example, in the balance of carbohydrate, fat and protein they contain. Humans exhibit prominent circadian rhythms in plasma insulin and glucagon, among other variables known to influence eating behavior (Armstrong, 1980), which could contribute to such systematic shifts with time of day in food acceptability and, in turn, to the development of cultural rules consistent with such biases."* After all, as Peter Ungar, a professor of paleoanthropology specializing in diet (Ungar, 2017) noted recently: *"No other primate has discrete mealtimes. Meals are distinctly and uniquely human things."* (quoted in Rumbelow, 2019, p. 2).

It has been reported that our nutritional choices, and it is presumed also our nutritional needs, differ over the course of the day (e.g., Guan, Probst, Neale, Batterham, & Tapsell, 2018; Krok-Schoen, Jonnalagadda, Luo, Kelly, & Taylor, 2019; McLeod et al., 2020; Phan & Chambers IV, 2018). Cultural norms and conventions (presumably consolidated by means of associative learning; McLeod et al., 2020), not to mention marketing-led interventions, likely also play an important role here too in terms of helping to maintain (and, on occasion, to modify) particular food practices (e.g., de Castro, Bellisle, Feunekes, Dalix, & De Graaf,

1 Bear in mind here that the term 'circadian' should only be used when a study is conducted under constant environmental conditions (i.e. constant darkness or a constant routine protocol). If a study is conducted under natural or light/dark conditions then the term 'diurnal' should be used instead. This distinction is important as it helps to distinguish between those rhythms that are controlled by the endogenous molecular clock versus those rhythms that are entrained exogenously by the environment (Conroy & Mills, 1970).

1997; Marshall, 1993; Rozin, 2015; Warde & Hetherington, 1994). At the same time, however, atmospheric (e.g., think only of changes in ambient temperature and/or light levels), perceptual (i.e., threshold) and/or hedonic changes,[2] not to mention psychological factors have also been suggested to play a role too.

However, after reviewing the evidence, the argument put forward in this review will be that cultural conventions/norms, marketing-led interventions, as well as psychological factors would all appear to play a rather more important role than nutritional, atmospheric, perceptual and/or hedonic factors in helping to explain why it is that so many of us choose to eat different foods at different times of the day. Relevant psychological factors here include everything from the purported depletion of self-restraint resources over the course of the day to the improvement in mood that has been documented across the day. However, as well these predictable psychological changes, the research suggests that people also have distinct psychological needs that they try to fulfil (e.g., functional vs. hedonic) at different mealtimes (e.g., Phan & Chambers IV, 2018).

Given the unhealthy foods that are currently associated with specific mealtimes (e.g., consider only the sugar-laden breakfast in many western countries currently; Spence, 2017a), gaining a better understanding of the factors underpinning people's food choices at different times of day may ultimately help us to nudge people toward healthier food choices in the future. First, though, let us take a look at the peer-reviewed published evidence concerning different patterns of consumption (both qualitative and quantitative) over the course of the day, presumably reflecting differences in both our nutritional needs as well as cultural conventions/norms, supported by marketing-led interventions.

2. Varying patterns of food consumption over the course of the day

2.1. Qualitative changes in consumption over the course of the day

A large body of observational research suggests that both energy and macronutrient intake follows a circadian pattern, with breakfast being relatively high in carbohydrates while dinner

2 After all, given the numerous diurnal/circadian changes that have been reported (e.g., Aschoff, 1960, 1965; Colquhoun, 1971; De Castro, 1987; Halberg, Haus, & Cornelissen, 1995; Monk, Fookson, Moline, & Pollak, 1985; Monk, Leng, Folkard, & Weitzman, 1983; Rajaratnam & Arendt, 2001), it would not seem surprising were our perception of the taste (and flavour) of food and drink might not also vary too.

tends to be relatively high in fats (see Westerterp-Plantenga, 1999, for a review). That being said, according to De Castro (1987), there may be some relevant sex differences here too, with the proportion of macronutrients (such as fat and carbohydrate) in a meal decreasing over the course of the day for males while it tends to increase for females. Meanwhile, a large North American survey of 17,361 middle-aged and older adults recently revealed that the intake of grain, milk, and dairy food groups were highest at breakfast, while the intake of protein food group were highest at lunch and dinner (Krok-Schoen et al., 2019; see also Visser, 1991).

It has been suggested we have different nutritional requirements at different times of day (e.g., Booth, 1982; Halberg, 1983). In the morning, for instance, we may need to load up on energy-dense foods (specifically high protein and carbohydrate-rich foods) in order to help prepare us for the exertions of the day ahead (e.g., Adolpus, Lawton, & Dye, 2013; Jakubowicz, Froy, Wainstein, & Boaz, 2012; see also Tietyen & Fleming, 1995). Many people also come to crave caffeine to help maintain their levels of alertness (e.g., Brice & Smith, 2002; Fukuda & Aoyama, 2017). Neither of these attributes are presumably high on the agenda when deciding what to consume at night though (Drake, Roehrs, Shambroom, & Roth, 2013; Spence, 2017a). By contrast, the consumption of alcohol has been reported to increase later in the day.[3]

2.2. Quantitative changes in consumption over the course of the day

According to de Castro (2004), when we eat is also linked to how much we consume, with breakfast tending to be the smallest meal in the day (Chao & Vanderkooy, 1989; Fricker, Giroux, Fumeron, & Apfelbaum, 1990). The greater total consumption documented at lunch and dinner, as compared to breakfast, does not, by-and-large, occur because of increased energy density of those foods consumed later in the day, but rather because larger meals of longer duration are consumed as the day goes on (de Castro, 2004), perhaps reflecting the fact that many people have more free time once our daily duties have been completed. To put the difference in consumption into perspective, de Castro (1987) suggested that 150% more food energy is ingested in the evening relative to the morning. As will be discussed later,

3 Differing patterns of stress and craving have been reported across the course of the day in those consume moderate amounts of alcohol (Mayhugh, Rejeski, Petrie, Laurienti, & Gauvin, 2018).

dining also becomes more sociable as the day goes on, and this is relevant because the number of people eating together also has a marked influence on consumption (e.g., de Castro & Brewer, 1992; de Castro, Brewer, Elmore, & Orozco, 1990; Spence, 2017b), hence potentially also helping to explain the increased consumption documented later in the day.

At the same time, however, it is also important to note that diary self-report data shows that people tend to obtain more satiety from a given amount of food earlier in the day (i.e., at breakfast) than at either lunch or dinner, with the lowest satiety per amount of food being conferred by whatever is consumed in the evening (de Castro, 1987). According to De Castro (1987, p. 437): *"this represents eating which anticipates the overnight fast"*, while de Graff, (2000) has argued that dinner is nutritionally the most important meal occasion in North America and UK. Such quantitative changes over the course of the day certainly go against the popular suggesting from nutritionist Adelle Davis, that we should all: *"Eat breakfast like a king, lunch like a prince and dinner like a pauper."* (Sifferlin, 2013). A growing body of nutritional research now suggests that the health costs associated with skipping breakfast are far worse for us than those associated with missing either lunch or dinner (Cahill, Chiuve, Mekary, Jensen, Flint, Hu, & Rimm, 2013; Wilson, Blizzard, Gall, Magnussen, Oddy, Dwyer, et al., 2019; see Spence, 2017a, for a review).

At the same time, however, negative health consequences, including weight gain and increased body fat, not to and an increased risk of mortality amongst certain groups of individuals, are also associated with eating too much late in the day (e.g., Allison, Goel, & Ahima, 2014; Halberg, 1983; Garaulet & Gómez-Abellán, 2014; LeCheminant, Christenson, Bailey, & Tucker, 2013; McHill, Phillips, Czeisler, Keating, Yee, Barger, et al., 2017; Rumbelow, 2019; Wang, Patterson, Ang, Emond, Shetty, & Arab, 2014). According to the available research, people gain more weight when eating isocaloric meals 12 hrs after waking than when consumed for breakfast (Cornelissen, 2012; Halberg, Haus, & Cornelissen, 1995). It has also been reported that people have less self-constraint resources available later in the day (Hofmann, Friese, & Roefs, 2009; Hofmann, Vohs, & Baumeister, 2012; Kouchaki & Smith, 2013), meaning that they may find it harder to resist the temptations associated with less-healthy foods as the day wears on (Haynes, Kemps, & Moffitt, 2016). Consistent with such a suggestion, North American food survey data reveals that snacking tends to be most common in the afternoon, and least common in the morning (see Cross, Babicz, & Cushman, 1994; Vatanparast, Islam, Masoodi, Shafiee, Patil, Smith, & Whiting, 2020). However, over-and-above any differences in the quantity and types of foods eaten during different meal occasions, what is also important is their timing during the day.

2.3. Chronotype and individual differences in meal timing

Marked individual differences have been reported in chronotype, with some individuals being classified as 'owls' and others as 'larks' (e.g., Bailey & Heitkemper, 2001; Duffy, Cain, Chang, Phillips, Münch, Gronfier, et al., 2011; see also Patkai, 1971). According to the results of large-scale research, something like 30% of the population can be classified as owls, 40% as larks, with the rest falling somewhere in-between (e.g., Jones, Lane, Wood, van Hees, Tyrrell, Beaumont, et al., 2019). Intriguingly, researchers have managed to identify a heritable component to the timing of food intake, based on a twin study (N = 53 pairs of twins) that was conducted in Spain (Lopez-Minguez, Dashti, Madrid-Valero, Madrid, Saxena, Scheer, Ordoñana, & Garaulet, 2019). The results of the latter study revealed that genetic factors contributed more to the timing of breakfast (56%), less to the timing of lunch (38%), and was non-significant as far as the timing of dinner was concerned. In other words, in the case of lunch and dinner timing, environmental factors appeared to play a more important role than genetic factors.

Given that eating later in day has a number of negative health consequences, this might be related to poorer health amongst 'owls' (see Garaulet & Gómez-Abellán, 2014). Indeed, according to Harb, Levandovski, Oliveira, Caumo, Allison, Stunkard, and Hidalgo (2012), night eating and chronotypes are correlated with binge eating behaviours. Eveningness does appear to be associated with a higher BMI and an increase in disinhibited eating (Schubert & Randler, 2008), including increased consumption of fast food (Fleig & Randler, 2009), possibly linking to the depletion of self-regulatory resources later in the day (see below). That all being said, it is worth noting that Flein and Randler (2009) failed to find any difference in the consumption of fruit, vegetables, or sweets between these two groups (chronotypes) in an adolescent sample.

Cultural factors/norms may also play a role in helping to dictate the average timing of meals. A recent survey of changes in eating in more than 60,000 North American adults (aged 20-74 years) over a 40-year period between 1971 and 2010 revealed that breakfast and lunch timing had moved somewhat later in the day (Kant & Graubard, 2015). The timing and regularity of meals is important, especially given evidence suggesting that the irregularity in breakfast consumption, as well as variability in daily meal timing patterns, are both associated with body weight status and inflammation (Guinter, Campbell, Patel, & McCullough, 2019).

2.4. Interim summary

Given the large body of evidence supporting the claim that people do indeed tend to consume different types (and amounts) of food at different times of day, the next question becomes one of explaining the factors underlying such temporal variation in our consumption of food. The most obvious place to start is with cultural conventions and beliefs about the appropriate foods to eat at different times of day. The role of food marketing, and the associative conditioning of specific cultural food practices (Birch et al., 1984; Booth, 1990; de Castro et al., 1997; Fjellström, 2004; Kramer et al., 1992), in terms of establishing, and then subsequently helping to maintain, different patterns of food consumption at different times of day are also discussed (see also de Castro, 2001).

3. Cultural basis of meal occasions

The ability to eat different foods at different times of day undoubtedly speaks to a food-rich landscape, one in which the traditional constraints on availability (such as would once have been provided by access to the seasonal harvest) are no longer all that relevant. That is, in the increasingly globalized food marketplace (Sobal, 1999), many of the most popular foods are now available on a year-round basis (see Spence, submitted, for a review). As such, one might wonder why it is that people do not simply eat their most preferred foods throughout the day, rather than what seems to be the case, changing their food choices according to the meal occasion. Certainly, if one goes back far enough (e.g., to the medieval period in England, say), then the evidence would appear to suggest that people used to consume a far more restricted diet than they do today. In fact, the limited availability of food might itself have necessitated that people consume the same foods regardless of the time of day (Dunne, Chapman, Blinkhorn, & Evershed, 2019). There may, in other words, once have been less opportunity to vary one's diet over the course of the day.[4]

At what point in our history, then, did it start to become common practice for us (in the west) to eat different foods at different times of day. According to contemporary commentators, the introduction of a clear distinction in the type (and not just the quantity; de Castro, 1987) of food consumed at breakfast as compared to other times of day first became standard practice as workers increasingly moved from the country to the city during the industrial revolution (see also Seiga-Riz, Popkin, & Carson, 1998, for breakfast trends over the latter half of the 20th Century).[5] But what role does food marketing play in helping to introduce/maintain specific food behaviours?

3.1. Food marketing

According to Mayyasi and Priceonomics (2016), prior to the introduction of breakfast cereal: *"in mid-1800s America, breakfast was not all that different from other meals."* (see also Dyson, 2000). However, the powerful and hugely successful marketing drive by the likes of Kellogg's to promote what were once called 'pre-digested' cereal seems to have had a profound effect on our food behaviours in the west since the closing years of the 19th Century (Gitlin & Ellis, 2012; Graber & Twilley, 2015; Scott & Crawford, 1995; Severson, 2016).[6] While Kellogg's Corn Flakes were advertised as 'The Sunshine Breakfast' from the 1960s-1990s, the packaging makes no specific reference to breakfast nowadays. consistent with the suggestion that traditional food-to-mealtime associations are increasingly starting to blur (see Foster & Lunn, 2007).

The food marketers were also responsible for encouraging many North American (as well as other western) consumers to drink orange juice for breakfast too (Hisano, 2019). That things were once so very different is brought home by the following quote from Classen, Howes,

4 According to researchers, the evening meal was once the main meal of the day (Walker, Walker, & Adam, 2003), presumably implying that a greater amount of food might have been consumed at this meal occasion.

5 Here, though, it is perhaps worth noting that those anthropologists who have chosen to study eating, and who have tried to decipher the structure, and meaning, of the western meal, have seemingly given little thought to the peculiarities of breakfast (e.g., Douglas, 1972; Douglas & Nicod, 1974; Visser, 1991).

6 Note here that the suggestion that breakfast *is "the most important meal of the day"* originates from a 1944 marketing campaign from General Foods, the manufacture of Grape Nuts (see Mayyasi & Priceonomics, 2016).

and Synnott (1994, p. 68) who note that: *"coffee is so much the smell and taste of morning for us now, that it is odd to think that, before its advent, beer was the common breakfast drink in Europe. With the introduction of coffee, tea and chocolate, Europe sobered up."*

In the contemporary era, there is a sense in which many people try to make a healthy start to the day (Anon., 2010; Hisano, 2019; Phan & Chambers IV, 2018). A likely explanation may lie in the advertising by breakfast food companies and the efforts of nutrition educators, which tended to emphasize the importance of breakfast for good health. The cumulative effect of such campaigns could well be the basis for a form of 'cognitive stereotyping' (Booth, 1994) – namely associating breakfast with health. Relevant here, in terms of breakfast, foods such as cereals, have long been marketed as offering a healthy start to the day (Severson, 2016), this despite the fact that many breakfast cereals are anything but healthy (e.g., Environmental Working Group, 2011, 2014; Pombo-Rodrigues, Hashem, He, & MacGregor, 2017; see also Barton, Eldridge, Thompson, Affenito, Striegel-Moore, Franko, Albertson, & Crockett, 2005; Lee & Lee, 2007). Much the same criticism can also be levelled at orange juice (e.g., Bachmann, 2013; Braun, 2014).

It has been suggested that the traditional American breakfast is probably the least healthy meal, which consists basically of "disguised desserts" (Belluz & Zarracine, 2018). For example, sugar-laden or high carbohydrate foods, such as cold cereal, fruit juice and bread, are among the most common foods that American consumers have for breakfast (Langer, 2005; The NPD Group, 2013), unhealthy breakfasts have been found in children as well (Public Health England, 2016). A recent survey conducted by the Public Health England (2016) found that children under ten years of age were consuming more than 50% of their recommended daily allowance of sugar at breakfast in the form of sweetened cereals, sugary drinks, and spreads.

The growing awareness amongst consumers of the questionable health credentials of many breakfast cereals and fruit juice offerings may help to explain why sales of these traditional 'breakfast' foods have been declining for years (e.g., Ferdman, 2016; Tuttle, 2014; Wexler, 2013; though see also Haines, Guilkey, & Popkin, 1996). Nevertheless, despite these declining sales, the point remains that our association of certain foods with the breakfast meal would appear to have been heavily influenced by marketing-led interventions.

At the same time, however, it is important to stress that what counts as a typical breakfast food differs markedly across the globe (Bian & Markman, 2020a, b; de Sousa, Akutsu, Zandonadi, & Botelho, 2020; Haines et al., 1996; Howden, Chong, Leung, Rabuco, Sakamoto, Tchai, et al., 1993; Parkinson, 2019; Walloga, 2015). For example, it has been reported that while rice and beans tend to be a common feature of lunch and dinner, coffee (with milk and sugar) bread margarine/butter and to a lesser degree regional foods are a common feature of low-income Brazilian breakfasts (de Sousa, Akutsu, Zandonadi, & Botelho, 2020). Similar to American adults, U.S. children (4-5 yrs old) perceive typical breakfast foods as especially appropriate for breakfast and believe that alternatives typically consumed at lunch or dinner time are less suitable for breakfast. This leads them to be unwilling to add nutritious alternatives to their breakfast repertoire. By contrast, Chinese children are not as likely to hold these mistaken beliefs and are more motivated to try healthy alternatives at breakfast (Bian & Markman 2020a).

It is the increasing exposure of many consumers to other food cultures, where the foods eaten for breakfast versus at other times of day are perhaps not so clearly delineated, that has been suggested to be helping to break-down traditional distinctions between certain foods and specific meal occasions too (Sproesser, Imada, Furumitsu, Rozin, Ruby, Arbit, et al., 2018; Thorn, 2015). Furthermore, breakfasts in many other countries, such as Japan and Turkey, are nourishing, well-balanced and harder to distinguish from their dinner foods (cf. Sproesser et al., 2018). At the same time, however, the growing popularity of brunch has undoubtedly started to blur the boundary in the west (Spence, 2017a; see also Leading Article, 2016).

It has been suggested is that the range of options available at different mealtimes has expanded radically in the West since the war (McLeod et al., 2020). Sales of all-day breakfast have also increased at McDonalds in recent years (Peterson, 2015). In 2015, McDonalds announced that it was bringing in digital menus that would change the offerings at different times of day (Peterson, 2015). This fits with the more general claim that traditional mealtime structure may slowly be disappearing (Mestdag, 2005). Nevertheless, as we will see in the next section, many consumers still judge certain foods as being more appropriate for particular times of day.

3.2. *On the acceptability/appropriateness of different foods for different meals*

The participants in an early study reported by Birch, Billman, and Richards (1984) exhibited high levels of agreement in terms of categorizing the foods that had been selected as suitable either for breakfast (Cheerios, scrambled eggs, and orange juice, OJ) or dinner (pizza, green beans, & macaroni and cheese). The two other foods tested in this study (whole wheat bread and sliced banana) were somewhat less strongly associated with breakfast. Birch et al. (1984, p. 109) write: *"Particularly in affluent western cultures, time of day has a major impact on food availability and selection, as a result of culturally based rules that designate foods as appropriate or inappropriate for particular mealtimes (see Rodin, 1980 for a discussion of this issue). For example, in the United States people typically do not eat pizza and green salad at breakfast time or cold cereal and orange juice at dinner time."*

However, given that Birch et al.'s (1984) study was conducted more than 35 years ago with both children and adults, different results might well be expected were the study to be repeated in a different country, such as France or Poland with an adult population (e.g., see Jaeger, Roigard, Le Blond, Hedderley, & Giacalone, 2019). That said, a pre-survey of 19 individuals conducted by Kramer et al. (1992) also demonstrated that those questioned had clear/strong beliefs about the sorts of foods that were most appropriate for breakfast (e.g., scrambled eggs, oatmeal, blueberry muffin, wheat toast, and bacon) versus lunch (e.g., turkey sandwich, macaroni and cheese, baked beans, and mixed vegetables; see also Rodin, 1980). In the west, for example, many people consider cereal or wheat toast appropriate for breakfast, while pasta (i.e., macaroni & cheese, or a turkey sandwich) is typically judged as more appropriate for lunch or dinner.[7] Here, it is interesting to note how there would appear to be more of a distinction between breakfast foods and those consumed at other times of day (e.g., the foods that are appropriate for lunch and dinner feel largely interchangeable). That said, the rise of brunch (Spence, 2017a; though see also Chamlee, 2016; Cloake, 2017) blurs the distinction between those foods that are appropriate for different times of day.[8] According to the latest research with British consumers, the latter are more willing to accept breakfast foods at lunchtime than vice versa (McLeod et al., 2020).

At the same time, however, McLeod et al. (2020) recently demonstrated that while 215 adults whom they quizzed – the latter were shown eleven well-known foods via online

7 Note, though, how some foods, like bread, are rated as appropriate no matter the meal occasion.

8 According to Baertlein (2015): *"A 2014 survey by the National Restaurant Association showed 72% of U.S. adults wished restaurants would offer breakfast items all day."*

questionnaire asked about previous consumption and mealtime appropriateness, the majority of whom were British (80%) held distinct associations between those foods that were deemed appropriate for breakfast versus lunch. As the authors conclude: *"The results revealed a clear distinction between different food-to-mealtime associations. Porridge, Special K, Cheerios and Rice Krispies were considered breakfast foods and chicken salad, chicken sandwich, spaghetti Bolognese, cheese and tomato pasta, lasagne, and fish, chips and peas were considered lunch foods. A bacon sandwich was the only food option with strong previous consumption and appropriateness associations with both breakfast and lunch. Comparing the participant responses for a bacon sandwich and a chicken sandwich is of great interest as the content of both sandwiches is very similar (meat within two pieces of bread) but the responses differed greatly regarding previous consumption and consumption appropriateness at breakfast and lunch. This highlights the process of associative learning that underpins food-to-mealtime associations."* (McLeod et al., 2020, p. 17).

3.3. Interim summary

The research reviewed in this section has highlighted the role played by cultural conventions/norms, likely maintained by associative learning, and marketing-led interventions in helping to associate specific foods with particular times of day. What is clear is that many consumers deem certain foods appropriate for specific meal occasions, though, which specific foods are associated with particular times of the day undoubtedly differs by culture, as well as over the centuries (at least in the west). So, having established the importance of cultural norms and marketing to establishing the association between particular foods and different mealtimes, I next want to look at the evidence relevant to assessing the role of atmospheric factors on people's food consumption behaviours.

4. Atmospheric influences of food behaviour over the course of the day

Environmental conditions change more-or-less predictably over the course of the day, with ambient outdoor temperatures tending to be higher during the middle part of the day than at night. Ambient light levels also change predictably over the course of the day. The ambient humidity and barometric air pressure may also change too (see also Schulte-Fortkamp, 2010).

Could such environmental changes exert any meaningful influence over food perception and hence help to explain any part of the variations in our food behaviour at different times of day? Potentially relevant here, recent research from Japan has shown that warmer ambient temperatures tend to decrease people's self-reported liking for savoury foods (Motoki, Saito, Nouchi, Kawashima, & Sugiura, 2018). In this study, 52 participants reported their preferences for various categories of foods in a room that was either warmer (28.9°C) or cooler (21.8°C) than the holding room in which they had been introduced to the study. Groups of participants were shown ten pictures of foods from each of four categories: vegetables, fruits, sweets, and savoury foods. They rated their liking for the foods shown in the images, as well as how tasty, healthy, and hot they looked (all on 7-point scales). The results revealed a selective reduction in the preference for savoury foods under warmer ambient conditions, at least when the participants' attention had been drawn to the warmth of the foods that they were evaluating. Intriguingly, the decrease in preference was greater for those savoury foods that were rated as 'hotter'.

Given the predictable daily variation in ambient temperature, it would be interesting to consider whether such environmental changes might also not influence people's everyday food choices. That said, it should also be noted that the majority of the world's population now lives an urban existence (see UN-Habitat, 2010; United Nations Department of Economic and Social Affairs, 2018) spending an estimated 90-95% of their time indoors (Klepeis, Nelson, Ott, Robinson, Tsang, Switzer, et al., 2001; Ott & Roberts, 1998; Velux YouGov Report, 2018; Wargocki, 2001). As such, they are presumably more likely to be insulated from any diurnal ambient variations in temperature. Indeed, the evidence suggests that average indoor temperatures now tend to vary much less over the course of the day than they did even just a few decades ago (see Healy, 2008; Mavrogianni, Johnson, Ucci, Marmot, Wardle, Oreszczyn, & Summerfield, 2013; cf. Lynch, 1972).

Note also that seemingly contrary to contemporary food trends, Motoki et al.'s (2018) findings would also lead to the suggestion that hot savoury foods ought to be more popular for breakfast (because the ambient temperature is likely cooler) than in the heat of the day (cf. Thompson & Harsha, 1984a, b), though that is not obviously the case. Here, though, it is important to note that our response to indoor thermal cues may be qualitatively different than when experienced outdoors (see Spence, submitted). At the same time, however, it has also been suggested that on our behaviour nowadays may still be influenced by evolutionary older adaptations to the hot temperatures that would once have been experienced early in the afternoon. Indeed, according to Thompson and Harsha (1984a, b), we all experience a dip in performance in the afternoon from c. 2pm onwards.[9] While this is often attributed to the 'post-lunch' dip (Korkki, 2007; see Monk, 2005, for a review), they notice that similar dips do not occur after breakfast or dinner which are sometimes heavier (i.e., more calorific). What is more, shifting the time of lunch between 10am, 12 noon, and 2pm had no effect on the timing or severity of this dip. Thompson (a social anthropologist) and Harsha (a physical anthropologist) instead ascribe it to our evolutionary past (what they call our 'tropical heritage') in Africa, and the afternoon heat, which reaches its peak roughly from one to three hours after noon. It is for this reason that Thompson and Harsha advised workers to shift their lunch from noon to 2pm, in order to coincide with this dip in alertness (and so optimize their productivity at work).

The brightness (and colour, or colour temperature) of the ambient lighting also exhibits a predictable diurnal variation (Collins, 1965). What is more, there is evidence to suggest that brighter ambient lighting is associated with stronger taste experiences (Gal, Wheeler, & Shiv, 2007; Xu & LaBroo, 2014). For instance, Gal et al. reported that people who liked strong coffee drank more of the hot beverage under bright lighting, while Xu and LaBroo reported that people tended to order spicier chicken wings under brighter lighting. However, just as for the ambient temperature example mentioned a moment ago, the ubiquity of indoor lighting may well serve to minimize any such daily environmental effects on our food behaviours (though see also Bschaden, Dörsam, Cvetko, Kalamala, & Stroebele-Benschop, 2020).

Interestingly, De Castro (2004, p. 110) has also brought an evolutionary consideration to the impact of diurnal changes in ambient light levels on people's consumption of food, noting that: *"Intake late in the day does not appear to be particularly satiating. Earlier in our evolutionary history, the advent of night greatly restricted activity. In modern times, however, the widespread use of artificial lighting has allowed people to remain active and eating late into the night. Could it be that obesity in the modern world results in part from the extension of the active period into the night when satiety mechanisms appear to be weak? The present results that intake in the late night period are associated with higher overall daily intake supports this speculation."*

9 Folkard (1975) reports that logical reasoning performance improves from 08.00 to 14.00 and then falls off fairly rapidly (see also Blake, 1967; Pink, 2018).

Any changes in barometric air pressure and humidity over the course of the day may also exert a limited effect on people's olfactory perception. For instance, it has been reported that thresholds for butanol are lower in humid as compared to dry air conditions According to research from Kuehn, Welsch, Zahnert, and Hummel (2008), olfactory sensitivity at threshold, but not suprathreshold odour discrimination (picking the odd one out from three odorants), was impaired in a hypobaric, as compared to a hyperbaric, milieu. At the same time, however, null results of variations in humidity (20-55%) and ambient temperature (18-26°C) on olfactory thresholds (for detection of rose-like odour of phenyl ethyl alcohol) have been reported under somewhat less realistic (ecologically-valid) testing conditions (Philpott, Goodenough, Passant, Robertson, & Murty, 2004). Taken together, it would seem likely that those of us living a primarily urban existence (hence spending something like 90-95% of our time indoors), are less likely to be influenced in our food choices by changes in weather than our ancestors might once have been (though see also De Castro, 2004; Thompson & Harsha, 1984a, b).

While environmental conditions (such as outdoor light levels and temperature) do change in a more-or-less predictable manner over the course of the day, the impact of such changes on our multisensory flavour perception and food behaviours/choices would seem to be fairly minimal, and hence unlikely to play much role in biasing consumers towards choosing different foods at different times of day. Next, I review the evidence concerning any circadian/diurnal changes in our sensory-discriminative response to food stimuli.

5. Perceptual changes in response to food-related stimuli over the course of the day

In this section, I want to review the literature concerning any perceptual changes in the sensory-discriminative aspects of chemosensory and visual responses to food stimuli as a function of the time of day. The limited evidence that has been published on this topic to date highlights the existence of modest fluctuations in perceptual sensitivity to basic tastants and orthonasally-presented olfactory stimuli that might, in some small way, help to explain why it is that people choose to eat different foods at different times of day. There is also some preliminary evidence concerning daily variations in our response to food-related visual cues as well.

5.1. Circadian/diurnal variation in gustatory perception

Nakamura, Sanematsu, Ohta, Shirosaki, Koyano, Nonaka, et al. (2008) demonstrated a diurnal variation in human sweet taste recognition thresholds. In their study, sweet taste thresholds for sucrose, glucose, and saccharin were lowest (indicating an increased sensitivity to the presence of sweet taste) in the morning and highest (c. 20% higher) at 22.00 hrs. A total of 91 young non-obese participants took part in the study with psychophysical testing taking place between 08.00 and 22.00 hrs. However, given that threshold assessment was carried out using the staircase method for each of seven tastants separately, this presumably means that Nakamura et al. actually measured gustatory detection, rather than recognition, thresholds (cf. Gomez, Cassís-Nosthas, Morales-de-León, & Bourges, 2004), as the authors suggest in their paper. Intriguingly, circulating plasma leptin levels, which paralleled the changes in the sweet taste thresholds, were also found to be around 50% higher in the evening. (Note that leptin is a hormone that is primarily produced in adipose cells.) By contrast, no such circadian variation was detected in the threshold for any of the other four basic tastes, assessed using solutions of sodium chloride (NaCl), citric acid, quinine, and monosodium glutamate (MSG).

It should, however, be noted that in contrast to the latter results, an earlier Japanese study in healthy participants had already demonstrated that recognition (detection?) thresholds for salt taste (as well as salivary sodium concentrations) showed a circadian variation, being lowest in the afternoons (Fujimura, Kajiyama, Tateishi, & Ebihara, 1990; see also Irvin & Goetzl, 1952). However, while this kind of research demonstrates that perceptual thresholds for specific tastants sometimes change systematically over the course of the day, it is by no means clear what the implications of such observations might be for the everyday food preferences/flavour perception of consumers. What is more, it should also be remembered that the majority of what we consider to be taste is actually derived from retronasal olfactory cues (see Spence, 2015, for a review). As such, it might well be argued that any circadian variation in olfactory perception would be much more relevant in terms of helping to explain the changes in the kinds of foods that we consume (and the flavours we favour) as a function of the time of day (at least when addressing the question from a perceptual standpoint).

5.2. Circadian/diurnal variation in olfactory perception

Early research suggested the existence of circadian/diurnal variations in olfactory acuity in normal individuals, often linked to the consequences of food intake (e.g., Goetzl, Abel, & Ahokas, 1950; Goetzl & Stone, 1947; Guild, 1956; Hammer, 1951; and see Koelega, 1994, for a critical review of the early literature on the effects of food intake on olfactory sensitivity).[10] Indeed, meal timing has been shown to exert a significant influence over the circadian rhythm (Wehrens, Christou, Isherwood, Middleton, Gibbs, Archer, et al., 2017). While it has been argued that there is minimal evidence of olfactory perception during the hours of sleep (Carskadon & Herz, 2004), the limited research that has been conducted in those participants who have been awake at the time of testing has mostly revealed null results, suggesting that olfactory thresholds do not appear to change much over the course of the day. For instance, Lötsch, Nordin, Hummel, Murphy, and Kobal (1997) reported that while orthonasal olfactory detection threshold for hydrogen sulphide (H_2S) did not change over the day, they did become somewhat noisier in the five healthy male participants who were tested in this study. That is, variance was increased, being lowest at 4.00 am and peaking at around 4.00 pm. By contrast, no change in either the threshold, or threshold variability, was reported for the painful trigeminal stimulant carbon dioxide (CO_2). The increased variability of orthonasal olfactory thresholds documented in this study was put down to the varied environmental sensory stimulation that was likely to have been encountered by the participants during the course of the day.

There are, however, a couple of salient points to note as far as the interpretation of Lötsch et al.'s (1997) findings are concerned. First, orthonasal (not retronasal) olfactory thresholds were assessed. Second, hydrogen sulphide is not a food-relevant odorant. Although it has yet to be demonstrated, one might, *a priori,* have expected any diurnal variation in olfactory performance to be more pronounced for food-related odorants than for unambiguously non-food odours (see also Duclaux, Feisthauer, & Cabanac, 1973; Koelega, 1994, on this point). And, while there are many similarities between orthonasal and retronasal olfaction (e.g., Heilman & Hummel, 2004), only retronasal olfaction is constitutively involved in multisensory flavour perception (see Spence, Smith, & Auvray, 2015). By contrast, orthonasal olfaction is more relevant in terms of setting our flavour expectations (Stevenson, 2009). As such, it is presumably by no means certain that just because orthonasal olfactory detection thresholds for non-food odours remain stable over the course of the day, that

10 Note that a role for hunger was suggested by a number of early researchers (Janowitz & Grossman, 1949; Kaplan & Powell, 1969; Yenson, 1959), but the idea certainly has not been accepted by everyone (Berg, Pangborn, Roessler, & Webb, 1963).

retronasal olfactory detection thresholds for food-relevant odorants will necessarily show the same pattern (cf. Koza, Cilmi, Dolese, & Zellner, 2005; Rozin, 1982; Small, Veldhuizen, Felsted, Mak, & McGlone, 2008). It is therefore perhaps somewhat surprising that no one has yet investigated whether there is a circadian/diurnal rhythm in retronasal olfactory perception, given that it is retronasal (not orthonasal) olfaction that directly (i.e., constitutively) contributes to multisensory flavour perception (see Spence, 2015).

In the years since Lötsch et al. (1997) published their seminal study, a number of other researchers have also looked for any circadian/diurnal variation in olfactory perception. For instance, Goel and Grasso (2004) also failed to find any difference in odour discrimination ability in a large sample of 169 young women and men tested either in the morning (08.00-10.00 hrs) or evening (18.00-20.00 hrs). In this case, the participants were given pairs of olfactory stimuli to sniff. They had to judge whether the second stimulus was weaker, stronger, or the same as the first. The olfactory stimuli used in this study consisted of an unscented control and five lavender scents differing in terms of their intensity. Given the preceding discussion, it is perhaps worth noting that lavender does occasionally appear in a food context (even if Koelega, 1994, and a number of other sensory scientists, have chosen to categorize it as a non-food odour): Think here only of lavender biscuits and the 'herbes de Provence' seasoning (e.g., McGee, 2004, p. 403). That said, the scent of this seasonal plant is more commonly experienced in nature, and in fragranced products (Kirk-Smith, 2003a, b; Mitchell, Konigsbacher, & Edman, 1964; cf. Trivedi, 2006), than in food, hence its status as a food aroma is somewhat ambiguous.

In contrast to these null results, however, several other studies have demonstrated circadian changes in orthonasal olfactory sensitivity. So, for example, Fikentscher, Kielwagen, Laukner, and Roseburg (1977) reported enhanced sensitivity for two of the six odorants (namely, eugenol and benzylacetate) when tested later rather than earlier in the day in a sample of 82 participants. Similarly, a recent study conducted in adolescents also reported that olfactory sensitivity is influenced by circadian timing (Herz, Van Reen, Barker, Hilditch, Bartz, & Carskadon, 2018). In particular, Herz et al. tested a group of 37 adolescents (21 male), with a mean age of 13.7 yrs. These researchers assessed orthonasal olfactory detection thresholds for phenylethyl alcohol (PEA, which smells like rose), as well as four-alternative forced choice identification, and performance in picking the odd one out of three "Sniffin' Sticks" (note that scores on these three tasks were combined). Using a 28-hr forced desynchronization protocol, and testing participants over nine consecutive days, Herz et al. were able to demonstrate that olfactory sensitivity does indeed vary with circadian phase, with the lowest threshold occurring slightly after the onset of melatonin production (at just after 9 pm; i.e., what would normally be the early biological night). While Herz and her colleagues acknowledge considerable individual variability, their results nevertheless do highlight the fact that peak olfactory acuity never occurred between 2.22 am and 10.10 am.

Interestingly, Herz et al. (2018, pp. 49-50) put forward an evolutionary account for their findings suggesting that: *"...the finding that olfactory sensitivity tended to be best in the early night may have evolutionary significance for the detection of predators. After the evening meal, which anthropological records indicate has been the main meal of the day (Walker et al. 2003), carnivorous animals may be especially drawn to human groups. The ability to detect the presence of predators through odor cues when visual cues are less effective due to dusk and darkness would be adaptive. Relatedly, heightened olfactory acuity for the main meal of the day may have aided with satiation—greater olfactory sensitivity increases flavour perception and satiation (Ruijschop et al. 2010)—which would be beneficial when limited resources were available. Another evolutionary explanation for olfactory acuity in early night may be related to the selection of reproductive mates."* Given the earlier discussion, it is perhaps worth noting that several of the odorants used by Herz et al. were food-relevant (e.g., banana, lemon, peppermint, and cinnamon).

Moving on from perceptual to more neurophysiological measures, Nordin, Lötsch, Murphy, Hummel, and Kobal (2003) reported evidence of a circadian rhythm and desensitization in chemosensory event-related potentials (ERPs) in response to pure olfactory and trigeminal stimulants. Chemosensory event-related potentials were assessed in response to the pure odorant H_2S and the pure (painful) trigeminal stimulus CO_2 in five young men at four-hourly intervals over the 24 hr cycle (these are presumably the same participants who were tested in Lötsch et al.'s, 1997, study mentioned earlier). A circadian rhythm was documented, with ERP amplitudes being largest at 16.00 hrs and smallest at 04.00 hrs (see also Lötsch, Hummel, Kraetsch, & Kobal, 1998). It is, though, unclear what the implications of such neural differences might be for people's food perception/consumption behaviour over the course of the day. (Note that Nordin et al.'s study was conducted more in the context of a methods paper concerning those factors influencing olfactory ERPs than specifically to study any circadian changes in food behaviour).

5.3. Circadian/diurnal changes in neural response to visual food cues

Neuroimaging research from Masterson, Kirwan, Davidson, and LeCheminant (2016) revealed that neural responses to visual food cues that are, note, also relevant to setting our food/flavour expectations (Wang, Volkow, Telang, Jayne, Ma, Rao, Zhu, Wong, Pappas, Geliebter, et al., 2004; see Spence, Okajima, Cheok, Petit, & Michel, 2016, for a review), differ depending on the time of day. In particular, these researchers reported that the neural response (as assessed by functional magnetic resonance imaging, fMRI) to both low- and high-energy visual food pictures in women was reduced in several areas of the brain (related to reward and visual processing) during the evening hours (5.00-7.00 pm) as compared to the morning (6.30-8.30 am). Some of the variations in response to food cues over the course of the day presumably reflect the differences that result from hunger/having eaten (e.g., Seibt, Häfner, & Deutsch, 2007).

5.4. Interim summary

The limited psychophysical and neuroimaging evidence that has been published to date demonstrates a number of perceptual and neurophysiological differences in people's responses to various food-related cues (both chemosensory and visual) as a function of the time of day when those stimuli happen to be presented. Although the data is somewhat mixed, it would appear that orthonasal olfactory sensitivity is enhanced later in the day (Fikentscher et al., 1977; Herz et al., 2018), while neural responses to visual food stimuli (at least in women) may be suppressed (Masterton et al., 2016). Sensitivity to sweetness has been reported to decline towards end of day (Nakamura et al., 2008), whereas sensitivity to saltiness may increase in the afternoon (Fujimura et al., 1990; though see also Nakamura et al., 2008). In addition to these perceptual changes, systematic changes in intra-oral temperature have also been reported over the course of the day (Moore, Watts, Hood, & Burritt, 1999).

To date, though, there is little evidence to suggest meaningful (in the sense of biasing our decisions between different foods, or food groups) changes in how food tastes as a function of circadian/diurnal patterns in perceptual sensitivity. Furthermore, in most cases, it is unclear whether the modest changes in sensory perception that have been documented over the course of the day are endogenously-driven by circadian rhythms or else are exogenously-driven by diurnal variations. Nevertheless, regardless of the cause, the nature and magnitude of the changes that have been reported do not appear to be of the type that can readily explain the daily variations in our food choices that have already been highlighted in this review. What is more, a number of non-food evolutionary explanations (in terms of avoiding predators and selecting mates) have also been put forward to explain the enhanced orthonasal olfactory sensitivity that Herz et al. (2018) have observed at the end of the day. Having taken a look at the nature of any sensory-discriminative changes in perception over the course of the day, I now wish to take a closer look at any changes in people's hedonic responses to specific foods as a function of the time of day.

6. Hedonic ratings of food at different times of the day

The limited evidence that has been published to date concerning any differences in hedonic ratings of (or responses to) foods as a function of the time of day are quite mixed.[11] Birch et al. (1984) reported that people's food preferences changed as a function of the time of day when they were tested: 08.00-10.00 am vs. 3.30-5.30 pm. In this early study, children's (N = 30 3- & 4-year-olds) and adults' (N = 25) hedonic ratings of several breakfast and non-breakfast foods were assessed after tasting samples of each of the foods. As mentioned earlier, the three breakfast foods consisted of Cheerios, scrambled eggs, and orange juice, while the dinner foods consisted of pizza, green beans, and macaroni and cheese. According to Birch et al., these foods were rated as tasting slightly, but significantly, more acceptable (that is, they were preferred) when sampled at the appropriate (rather than at the inappropriate) time of day.[12]

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11 Such changes, note, occurring over-and-above the oft-documented hedonic changes for specific odorants that are observed as a hungry individual consumes certain foods to satiety (Duclaux et al., 1973; Small, Zatorre, Dagher, Evans, & Jones-Gotman, 2001).

12 Note that while judgments of food-mealtime appropriateness, discussed earlier, and hedonic ratings of food at different times of day are presumably linked, it is important to stress that they are, in some sense at least, potentially orthogonal judgments. So, for example, those living in the UK would presumably strongly associate the Full English Breakfast with the start of the day, no matter whether they happen to like this particular breakfast dish or not.

By contrast, however, null results of time of day on people's taste ratings have subsequently been reported by Kramer and colleagues (1992). The latter researchers conducted three studies, primarily in young men, that showed no difference in hedonic ratings, nor in the consumption of breakfast / lunch foods as a function of whether they happened to be served at breakfast or lunchtime. It is, though, worth noting, in passing, that the participants consumed significantly fewer calories of the 'breakfast' meals than of the 'lunch' meals regardless of the time of day at which they were served. While there is no clear answer as to why different results should have been reported in these two studies (Birch et al., 1984; Kramer et al., 1992), the fact that mostly female participants were tested in Birch et al.'s study, whereas only young males (military types) were tested in Kramer et al.'s study. Furthermore, the food exemplars also differed between these two studies, hence also potentially helping to explain the differences.

Nevertheless, what little evidence has been published to date concerning hedonic responses to different foods as a function of the time of day, fails to provide any clear evidence that this is what is driving our choice of different foods at different times of day. At this point, it is important to note that what people choose to eat at different times of day is not only determined by their nutritional needs (in terms of different food groups), nor solely by culture, marketing and/or changing atmospheric conditions over the course of the day. Nor, as we have just seen, can any sensory-discriminative and/or hedonic differences in people's responses to different foods at different times of day necessarily provide a satisfactory explanation either. Instead, it turns out that people's choice of what to eat when may sometimes help to fulfil some psychological need instead. What is more, our ability to resist temptation (i.e., to stop ourselves from snacking and eating those foods that are obviously less healthy) also declines over the course of the day. Perhaps, therefore, some part of the explanation for why we choose to consume different foods at different times of day may be as much psychological as anything else.

7. Psychological factors influencing food choices at different times of day

7.1. Do daily variations in our mood influence our choice of food?

At a group level, predictable fluctuations in people's mood (primarily positive affect rather than negative) have been documented over the course of the day (e.g., Clark, Watson, &

Leeka, 1989; de Castro, 1987). According to Clark et al., all components of positive affect (including enthusiasm, energy level, mental alertness, interest, joy, and determination) tend to rise from early morning through to noon. They then remain relatively constant until 9 pm, before falling off rapidly thereafter. Consistent with such a view, as a group, the young men in Goel and Grasso's (2004) study, mentioned earlier, reported themselves to be in a slightly better mood in the evening as compared to the morning (though no such change was observed in the women who were tested). More generally, it would appear that it is positive, rather than negative, mood, or depression, that is affected by the time of day. Mood has also been shown to influence people's taste perception and food behaviour (e.g., Gardner, Wansink, Kim, & Park, 2014; Noel & Dando, 2015; Platte, Herbert, Pauli, & Breslin, 2013; Spence, 2017c). For instance, according to Gardner et al., people tend to make healthier longer-term food choices when they are in a good mood, while tending to choose less healthy foods when they are in a bad mood. Such a mood-based account might therefore suggest that people should make healthier food choices later in the day. As we will see momentarily, however, the opposite would actually seem to be closer to the truth.

7.2. Daily depletion of self-regulatory resources

The evidence shows pronounced psychological variations that might, in some small way, help to explain why it is that people choose to eat different foods at different times of day. For one thing, many people feel more virtuous in the morning, whereas their resolve may have been weakened somewhat by the end of the day, especially given the range of temptations that so many of us find ourselves trying to resist on a daily basis (Haynes et al., 2016). Certain of the differences in food behaviour that occur over the course of the day may, then, be attributed to a depletion of mental resources (specifically self-control/self-regulation, or what has been termed 'ego-depletion'; Boland, Connell, & Vallen, 2013; Sproesser, Strohbach, Schupp, & Renner, 2011; cf. Hofmann et al., 2009, 2012; Kouchaki & Smith, 2013) rather than to any more fundamental perceptual changes in taste/flavour perception or nutritional needs. That said, it should also be born in mind here that the concept of 'ego depletion' has not gone unchallenged in the academic literature (e.g., Hagger, Chatzisarantis, Alberts, Anggono, Batailler, Birt, et al., 2016; see also Sanders, Shirk, Burgin, & Martin, 2012).

Support for the depletion of self-regulation resources account comes from a study reported by Haynes et al. (2016). These researchers conducted a study on 304 female undergraduates presenting a single-category Implicit Association Test (IAT) at different times of day (with testing spread out at hourly intervals between 9.00 am and 5.00 pm). The participants had to respond to food images (unhealthy food images, including pictures of chocolate, cake, ice-cream, chips, pizza, and hamburger) by pressing one of two response keys coded “I like” and “I dislike”. These response keys were also used to respond to a randomly-presented sequence of positive and negative words such as, for example, ‘sunlight’ and ‘evil’. The results revealed that unhealthy foods were implicitly evaluated more positively, with the participants exhibiting a decreased ability to inhibit their positive reactions to the food images. They were, in other words, more likely to incorrectly respond “I like” on those trials where the food image actually happened to be paired with the “I dislike” response) if they happened to be tested later in the day. However, it is worth noting that time of day was confounded order of testing, meaning that some kind of practice effect might also be used to explain the results of this study.

Results such as these fit with observations from North American participants suggesting that snacking is more common in the afternoon (defined as between 3-8pm in one of the studies) than in the morning (defined as before 10 am; Cross et al., 1994; Vatanparast et al., 2020). It would certainly be intriguing to see whether these findings could somehow be linked to the neuroimaging findings reported by Masterton et al. (2016).

7.3. Functional psychological drivers (needs) underlying eating behaviour

According to a recent series of studies by Phan and Chambers IV (2018), liking is the most important driver for eating both meals and snacks amongst North Americans consumers. However, day-time eating was primarily driven more by function-oriented factors (such as need and hunger, health, weight control, habit and price) whereas night-time eating was typically driven by psychological or emotional needs, such as the desire to socialize with people or to please oneself and others. According to the results of Phan and Chambers IV’s research, people’s breakfast choices (e.g., cereal, eggs, dairy or coffee), could all be explained in terms of satisfying hunger, and the need for food, as well as trying to make healthy choices.[13] People's choice of lunch foods tended to revolve around convenience (i.e., pre-made foods), often based on habit and price. Meanwhile, the main reasons behind people's dinner choices were pleasure, socialising, and variety of food, consumed with other people. Summarizing the results of this intriguing study, Dr. Phan suggested that they revealed that: *"Motivations for food choice changed throughout the day, with daytime eating more motivated by functional-oriented factors such as need and hunger, health, weight control, habit and price, while night-time eating was to satisfy 'psychological or emotion needs' such as to socialise with people or to please the self and others."* (quoted in Allen, 2018).

The more social aspects of dining at the end of the day identified by Phan and Chambers IV's (2018) research may relate to the increased likelihood of people having free time then too. At the end of the day, many people come home from work, and having done their chores (they might even have put their children to bed), they may then finally have time to sit down and eat, and hence there is increased scope for socialization. Given the social facilitation of food consumption (Spence, 2017c), one might also consider how breakfast is typically a less social occasion than either lunch or dinner (e.g., De Castro, 1990, 1994; Rappoport, Downey, & Huff-Corzine, 2001).

In a study reported by Rappoport et al. (2001), a convenience sample (N=157) of males and females ranging in age from 18 to 87 years rated their most recent, and their "ideal", morning, midday, and evening meals on a series of evaluative and social–emotional scales. Analysis of the combined recent and ideal meal ratings revealed that regardless of the variable contents of the meal, those meals that were consumed in the morning were generally seen as significantly less expensive, more casual, convenient and lighter, and more individual affairs, whereas evening meals were seen as more unusual, elderly, masculine and happy (see also Peters, Rappoport, Huff-Corzine, Nelsen, & Downey, 1995).

7.4. Interim summary

13 Though, ironically, as was mentioned earlier, many breakfast food choices in the West (such as breakfast cereals and orange juice) are anything but healthy, despite sometimes being marketed as such (see Belluz & Zarracine, 2018; Spence, 2017a).

The evidence that has been reviewed in this section clearly highlights the fact that various psychological factors appear to influence people's choice of what to eat at different times of day. Relevant psychological factors include everything from changes in mood (Clark et al., 1989; see also Gardner et al., 2014), and the depletion of self-regulation resources over the course of the day (Haynes et al., 2016; though see Hagger et al., 2016), through to the functional needs that we try to fulfil when choosing to eat different kinds of food at different times of day. The increased availability of free time at the end of the day, not to mention the more social aspects of meals that are consumed later in the day may also play a role. Meals eaten earlier in the day tend to be cheaper, intended to be healthier, more convenient (i.e., more functional), whereas evening meals tend to be more social, varied etc. (e.g., Phan & Chambers IV, 2018; Rappaport et al., 2001).

8. Conclusions

It does not, I think, seem to (m)any of us that foods taste different at different times of day. And yet, the evidence shows that people (and, in this review, the focus has primarily been on those living in the west) clearly believe that different foods are more appropriate for different times of day/year (e.g., Bian & Markman, 2020a, b; Birch et al., 1984; Kramer et al., 1992). What is more, analysis of food diaries shows that such differences in consumption behaviour, both what we eat, not to mention how much, is influenced by the time of day (e.g., de Castro, 1987; Kramer et al., 1992). That being said, there is some modest evidence of perceptual differences in tasting/smelling/flavour thresholds over the course of the day, involving both taste (Nakamura et al., 2008) and orthonasal olfactory changes (Herz et al., 2018). Ultimately, therefore, it would seem that the well-established differences in what people choose to eat at different times of day may well have more to do with culture/convention, marketing, and fulfilling different psychological needs than with anything else (Phan & Chambers IV, 2018; Rappaport et al., 2001) (see **Table 1** for a summary of the factors suggested to influence what people eat when).

INSERT TABLE 1 ABOUT HERE

Given the various circadian changes that have been documented in the literature (e.g., Armstrong, 1980; Aschoff, 1960, 1965), one might have expected to observe significant changes in taste/flavour perception too. However the limited research that has been published on this topic to date has largely failed to demonstrate any significant perceptual changes in taste/olfactory thresholds, or hedonic responses, over the course of the day that cannot simply be put down to fluctuations in mood (de Castro, 1987; Goel & Grasso, 2004), or perhaps to the aftereffects of the consumption of food at mealtimes (see Koelega, 1994, for a review). And, of the threshold differences in gustatory perception that remain unexplained after these factors have been taken into account, it is unclear whether they really have any relevance for real-world food choices anyway.

8.1. Nudging food behaviours in a healthier direction

Ultimately, determining the factors underpinning our daily patterns of food consumption really does matter. For, if it is merely a matter of cultural norms, consolidated by associative conditioning (e.g., Birch et al., 1984; Booth, Mather, & Fuller, 1982), rather than, say, supporting different nutritional or psychological needs, then that opens up the possibility that things could be (very) different. Indeed, given how unhealthy many breakfast foods are in the west (e.g., consider only the very high sugar/salt contents of many breakfast cereals; see Belluz & Zarracine, 2018; Spence, 2017a), one might consider whether marketing/advertising could help to encourage consumers, and perhaps especially children, to move toward consuming healthier breakfast foods (Booth, 1994; McLeod et al., 2020). Though, as we have seen, there are likely to be relevant cultural differences that need to be borne in mind here (e.g., Bian & Markman, 2020a, b), as well as changing patterns of behaviour and possible breakdown of traditional mealtime structure/associations (Mestdag, 2005). Indeed, according to Mattes (2002), thinking differently about the time of day at which foods like ready-to-eat cereals are appropriate (e.g., as a meal replacement) might also help promote weight loss strategies.

Here, it is certainly also worth recognizing how, only a century or two ago, the distinction between those foods that would have been eaten at the start, versus at other times, of the day was much less clear-cut in the west than it is today (Steel, 2008). And, as was mentioned earlier, there are some countries/cultures where, even today, the distinction between the different foods that are associated with different times of day would seem to be far weaker than in others (Sproesser et al., 2018).Of course, gaining a better understanding of the factors underpinning our choice of different foods at different times of day might help those food companies/marketers wanting to extend the popularity of certain foods beyond their traditional associations with specific times of day (consider here only the rise of the all-day breakfast; Baertlein, 2015; Peterson, 2015).

8.2. Temporal variations in food consumption at different timescales

Looking at longer timescales, there are also day-to-day variations in energy and nutrient intake that may also be worthy of further consideration (Tarasuk & Beaton, 1992). And beyond that, there is an emerging body of evidence that our patterns of consumption also vary over the course of week, the month, and of, course, the year (or seasons; see Spence, submitted, for a review). For now, however, it must remain an open question as to whether the same factors as have been outlined here (e.g., nutritional/physiological, cultural or marketing-related, atmospheric, perceptual, hedonic, or psychological) can also help to explain the patterns of consumption that have been documented at these other time-frames.

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