Relationships between food groups and eating time slots according to diabetes status in adults from the UK National Diet and Nutrition Survey (2008–2017)

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ABSTRACT

Time of eating has been shown to be associated with diabetes and obesity but little is known about less healthy foods and specific time of their intake over the 24 hours of the day. In this study we aimed to identify potential relationships between foods and their eating time, and see whether these associations may vary by diabetes status. The National Diet and Nutrition Survey (NDNS) including 6802 adults (age $\geq$ 19 years old) collected 749,026 food recordings by a 4-day-diary. The contingency table cross-classifying 60 food groups with 7 pre-defined eating time slots (6-9am, 9am-12pm, 12-2pm, 2-5pm, 8-10pm, 10pm-6am) was analyzed by Correspondence Analysis (CA). CA biplots displaying the associations were generated for all adults and separately by diabetes status (self-reported, pre-diabetes, undiagnosed-diabetes, and non-diabetics) to visually explore the associations between food groups and time of eating across diabetes strata. For selected food groups, odds ratios (OR, 99% confidence intervals, CI) were derived of consuming unhealthy foods at evening/night (8pm-6am) vs. earlier time in the day, by logistic regression models with generalized estimating equations. The biplots suggested positive associations between evening/night and consumption of puddings, regular soft drinks, sugar confectioneries, chocolates, spirits, beers, ice cream, biscuits, and crisps for all adults in the UK. The OR (99% CIs) of consuming these foods at evening/night were respectively 1.38 (1.03, 1.86), 1.74 (1.47, 2.06), 1.92 (1.38, 2.69), 3.19 (2.69, 3.79), 11.13 (8.37, 14.80), 7.19 (5.87, 8.82), 2.38 (1.79, 3.15), 1.91 (1.67, 2.16), 1.55 (1.27, 1.88) vs. earlier time in the day. Stratified biplots found that sweetened beverages, sugar-confectioneries appeared more strongly associated with evening/night among un-diagnosed diabetics. Foods consumed in the evening/night time tend to be highly processed, easily accessible, and rich in added sugar or saturated fat. Individuals with undiagnosed diabetes are more likely to consume unhealthy foods at night. Further longitudinal studies are required to ascertain the causal direction of the association between late-eating and diabetes status.

INTRODUCTION

28 The timing of energy intake has been shown to be associated with obesity and diabetes. (Almoosawi
29 et al., 2016) Specifically, eating late at night or having a late dinner was found to be related to higher
30 risk of obesity (Xiao et al., 2019; Yoshida et al., 2018), hyperglycemia (Nakajima and Suwa, 2015),
31 metabolic syndrome (Kutsuma et al., 2014), diabetes (Mattson et al., 2014), and poorer glycemic control
32 among diabetics (Sakai et al., 2017). However, the relationship between food choice and the time of
33 food consumption during the day is left largely unknown. Shiftworkers have an increased risk of obesity
34 (Balieiro et al., 2014; Barbadoro et al., 2013), and diabetes (Pan et al., 2011), possibly due to limited
35 availability of healthy food choice during their night shifts (Bonnell et al., 2017; Balieiro et al., 2014).
36 Identifying those unhealthy foods that might be chosen during late night time would be helpful when
37 guiding people to change their eating habit for the purpose of either weight loss or glycemic control.
38 Dietary diary recordings from national surveys can provide detailed food choice data for exploration of the
39 relationships between food groups and their time of consumption in the general population.

40   In this study, we aimed to describe the relationship between food groups and the time of day when they
41 were consumed, and how such relationships may vary by status of type 2 diabetes using the data published
42 by the Rolling Programme of the UK National Diet and Nutrition Survey from 2008 to 2017 as this survey
43 includes diet diaries providing detailed information on the time of day of food intake.

METHODS

44 6802 adults (2810 men and 3992 women) and 749026 food recordings collected by the UK National Diet
45 and Nutrition Survey Rolling Programme (NDNS RP 2008-17) were analyzed in the current study (MRC
46 Elsie Widdowson Laboratory and NatCen Social Research, 2018). The survey comprised a cross-section
47 representative sample of the UK adult population taken over the period 2008-2017. The sample was
48 randomly drawn from a list of all addresses in the UK, clustered into postcode sectors. Details of the
49 rationale, design and methods of the survey can be found in the previously published official study reports
50 (Bates et al., 2014; Roberts et al., 2018). Time of the day was categorized into 7 slots: 6-9 am, 9-12 noon,
51 12-2 pm, 2-5 pm, 5-8 pm, and 10 pm - 6 am. Foods recorded were classified into 60 standard food groups
52 with 1 to 10 subgroups each: the details are given in Appendix R of the NDNS official report (NatCen Social
53 Research, MRC Elsie Widdowson Laboratory, Univeristy College London. Medical School., 2018). We
54 focused on the 60 standard food groups in the current analysis. Diabetes status was defined as: 1) healthy
55 if fasting glucose was lower than 6.10 (mmol/L), hemoglobin A1c (HbA1c) was less than 6.5 (%), and
56 without self-reported diabetes and treatment for diabetes (n = 2626); 2) pre-diabetic if fasting glucose was
57 lower between 6.10 and 6.99 (mmol/L, inclusive) but without self-reported diabetes and without treatment
58 for diabetes (n = 133); 3) undiagnosed diabetic if either fasting glucose was higher or equal to 7.00
59 (mmol/L) or HbA1c higher or equal to 6.5 (%) but without self-reported diabetes and treatment for diabetes
60 (n = 99); 4) diabetic if participant had self-reported diabetes or was under treatment for diabetes (n = 227).
61 Consequently, there was also a large number of adults (3717 adults of whom 1519 men and 2198 women)
62 whose diabetes status did not fall in one of above categories and could not thus be confirmed; these were
63 retained in the whole sample (unstratified) analyses. In addition, the National Statistics Socio-economic
64 Classification (Rose and Pevalin, 2005) was applied in the survey and accordingly, the socio-economic
65 status of participants was classified in one of 8 categories.

66   Correspondence analysis (CA) (Greenacre, 2017; Chapman et al., 2017; Palla et al., 2020) was used as a
67 tool for data mining, visualization and hypotheses generation using half of the randomly selected NDNS
68 diary entries data. Specifically, the contingency table generated by cross-tabulating 60 food groups and 7
69 time slots were analyzed by CA. Through CA, the 60 categories of standard foods and the 7 time slots
70 were projected on biplots, i.e. onto two dimensional plots that could jointly contain large percentage of the
71 χ^2 deviation (or inertia) of the contingency table. Biplots that graphically show the association between
72 time of day and food groups were derived for all adults and separately according to their diabetes status. To
73 account for the hierarchical structure of the data (food recorded by the same individuals who lived within
74 the same area/sampling units) and to calculate population average odds ratios (OR), logistic regression
75 models with generalized estimating equations (GEE) were subsequently used to test the associations that
76 were first suggested by visual inspection of biplots generated by CA, using the remaining half of the
77 diary entries data. The marginal ORs and their 99% confidence intervals (CI) were derived of consuming
78 unhealthy food groups (selected by CA) later in the day (8 pm - 6 am, i.e. in the evening and night)
79 compared to earlier in the day (in the morning or afternoon). CA and biplots were conducted and generated
80 by the following packages under R environment (R Core Team, 2019): `FactoMineR`, `factoextra`,
81 `ggplot2`, `ggrepel` (Lê et al., 2008; Kassambara and Mundt, 2019; Wickham, 2016; Slowikowski,
82 2019) Logistic regression models with GEE were performed with SAS procedure `GENMOD` (SAS Institute,
83 2013) adjusted for age, sex, and socio-economic levels, which were deemed the main potential confounders
84 of the associations.

RESULTS

85 The dataset consisted of 2810 (41.3%) men and 3992 (58.7%) women aged older than or equal to 19 years
86 old with the mean age of 49.9 years (standard deviation, SD = 17.6). Of these individuals 22.6 % were
87 current smokers, 24.3 % were past smokers. The average body mass index (BMI) was 27.7 kg/m^2 (SD =
88 5.41). Among the food recordings collected (n = 749026), 56.9% were recorded during traditional breakfast
89 (6 am - 9 am: 14.3%), lunch (12 noon - 2 pm: 18.5%), or dinner (5 pm - 8 pm: 24.1%) time slots. Table 1.
90 shows the top 37 food groups that contributed to 90% of the total calories consumed by adults in NDNS
91 RP. These food groups accounted for 478028 of the total diary entries (63.8 %). The random process split
92 the whole set of food recordings into a hypothesis generating dataset of 374682 and a testing dataset of
93 374344 entries.

94   Figure 1-5 present the CA biplots that visually summarize the associations between 60 food groups and
95 the time of their consumption in the entire sample and then stratifying by their diabetes status. In Figure 1,
96 the horizontal axis explains 68.9 % of the association structure (inertia) between food and time while the
97 vertical axis reflects 15.3 % of the same relationship. Therefore, a total of 84.2 % of the inertia between
98 food and time were captured in this figure which shows a visual summary of how those two categorical
99 variables are related. Specifically, time slots later than 8 pm are shown in the upper side of the plot closer
100 to alcoholic products (beers and spirits) or highly processed/energy-dense foods (sugar confectioneries,
101 chocolates, biscuits, regular softdrinks, ice cream, crisps); times earlier than noon appear in the left hand
102 side together with typical breakfast foods (cereals, milk, bread, etc.).

103   To visualize the potentially different associational patterns between food groups choice and time slots
104 according to diabetes status, Figure 2-5 display the CA biplots in subsets of the data. Depending on different
105 diabetes status, these biplots explained between 76.3% and 84.1% of the inertia in the data. Similarly
106 to the biplot created from the total sample (Figure 1), later time in the day (8 pm and later) are shown
107 in the upper side of each figure and suggested an association with the alcoholic beverages and highly
108 processed or energy-dense food groups. Additionally, some food groups and time slots also flagged up

109 associations potentially different by diabetes status. For example, puddings seemed to be closer to later
110 time in the day among undiagnosed diabetics (Figure 4) while for diagnosed diabetic patients (Figure
111 3) they were closer to traditional dinner time (5 pm to 8 pm) or earlier in the day. Furthermore, sugar
112 confectioneries/chocolates/biscuits/regular soft drinks appeared to be associated with later time in the day
113 (8 pm or later) more strongly among undiagnosed diabetics (Figure 4) than the other participants.

114 Based on the findings suggested from Figure 1-5, we decided to focus on puddings, regular soft drinks,
115 confectioneries, chocolates, spirits, beers, ice cream, biscuits, crisps as these foods either showed a
116 particularly strong association with time of the day or a different pattern of association across different
117 strata of the survey sample; hence, we tested the following null hypotheses using logistic regression models
118 (adjusted for age, sex, and socio-economic levels) with GEE: that the odds of consuming each selected
119 food at later time of the day (8 pm - 6 am) is the same compared to earlier in the day; and the associations
120 of the above-mentioned food groups and time slots are the same among participants with different diabetes
121 status (i.e. no interaction between the time of food intake and diabetes status). The results are summarized
122 in Table 2.

123 The listed food groups were found to have higher odds to be consumed between 8 pm and 6 am with
124 higher odds compared to earlier time. The OR (99% CIs) main effects of consuming these foods at
125 evening/night were for puddings 1.38 (1.03, 1.86), for regular soft drinks 1.74 (1.47, 2.06), for sugar
126 confectioneries 1.92 (1.38, 2.69), for chocolates 3.19 (2.69, 3.79), for spirits 11.13 (8.37, 14.80), for beers
127 7.19 (5.87, 8.82), for ice cream 2.38 (1.79, 3.15), for biscuits 1.91 (1.67, 2.16), for crisps 1.55 (1.27, 1.88)
128 vs. earlier time. Opposite directions of the association for puddings were detected across diabetes status:
129 the ORs (99% CIs) of consuming puddings at night time (8 pm or later) compared to earlier time were 1.50
130 (1.10, 2.07), 0.89 (0.16, 4.87), 1.81 (0.41, 7.98), and 0.58 (0.14, 2.43) for healthy, prediabetic, undiagnosed
131 diabetic, and diabetic participants, respectively. Furthermore, undiagnosed diabetic patients were found to
132 have particularly high odds of consuming regular soft drinks (OR: 2.72; 99% CI: 1.44, 5.14), and sugar
133 confectioneries (OR: 13.07; 99%CI: 4.59, 37.24) during night time periods compared to participants with
134 other diabetes status.

DISCUSSION

135 The present study described the potential relationships between food groups and time of their consumption
136 in a representative sample from the NDNS RP. Many unhealthy foods emerged from CA were found to
137 be more likely to be consumed after 8 pm. These included alcoholic/sweetened beverages, chocolates
138 and other foods rich in added sugars and saturated fats such as biscuits and ice cream. Foods chosen in
139 the evening/night time slots tend to be highly processed and easily accessible. Specifically, undiagnosed
140 patients might be at a higher risk of worsening their condition as they were found to have higher odds to
141 choose a number of less healthy foods after 8 pm (sugar confectioneries, regular soft drinks) than diabetics
142 and non-diabetics. Those foods might need to be targeted when designing intervention to those who might
143 be at risk of being diabetics.

144 These findings are concerning considering previous research that have indicated that quality of
145 macronutrient intake in the evening is likely to influence fasting glucose levels and glycaemic response
146 to subsequent meals in the morning. (Wolever et al., 1988) More recently, a randomized controlled trial
147 indicated that consuming carbohydrates at dinner irrespective of glycaemic index raised postprandial
148 glucose response to breakfast producing what is known as a second meal effect (Haldar et al., 2020).
149 Similar observation have been made by Nitta and colleagues who observed that eating sweet snacks
150 post-dinner worsened glycaemic excursions in the evening and at subsequent breakfast (Nitta et al., 2019).

151 Added to this is evidence that suggests that the late-night dinners induce post-prandial hyperglycemia in
152 patients with type 2 diabetes and that interventions at this eating occasions can result in a profound impact
153 on post-prandial glycaemia. On the balance of this evidence, targeting and improving the timing and quality
154 of foods in evening eating occasions provides a unique opportunity to design intervention to those who
155 might be at risk of being diabetics.

156   A compelling finding of our study is the observation that diabetes patients were found to be potentially
157 controlling their choice of food groups such as avoiding puddings at night. However, higher odds of
158 consuming alcoholic beverages and energy condensed foods such as chocolates and sugar confectioneries
159 at night among individuals with diabetes suggests that their food choice might need further modifications.

160   Assessing the relationships between food groups and timing of eating by diabetes status can be considered
161 as a first step towards identifying specific public health targets for behavior change/intervention. This is
162 important as most current public health strategies and dietary recommendations do not provide targeted
163 advice that takes into considerations specific eating occasions while targeted advice is more likely to result
164 in sustainable behavioural change. Our findings are consistent with previous evidence that has found that
165 both sweetened and alcoholic beverages are responsible for large portion of energy consumption at night in
166 other populations (Hassen et al., 2018).

167   However, an important limitation in this study is the cross-sectional study design. The inability to assess
168 the temporal relationship between timing of food intake and diabetes status means that a cause-effect
169 relationship between time of unhealthy food intake and diabetes status cannot be established. Hence, further
170 prospective studies are warranted to investigate the causal relationship between diabetes and both quality
171 and timing of eating. Moreover, the current study assumes that mis-reporting occurred equally amongst all
172 eating occasions. This limitation has been reported by previous literature as an important methodological
173 limitation of chrononutrition (Fayet-Moore et al., 2017); in fact further investigation would be warranted
174 to assess the effect of differential misreporting on epidemiological studies in chrono-nutrition in order to
175 suggest possible corrections, e.g. for differential under-reporting at different times of the day (e.g. main
176 meals vs. snack times).

CONCLUSION

177 In summary, our study indicates that foods consumed in the evening/night time tend to be highly processed,
178 easily accessible, and rich in added sugar or saturated fat, whatever the diabetic status. . Individuals
179 with undiagnosed diabetes are more likely to consume specific unhealthy foods at night. The survey
180 cross-sectional nature warrants further investigations by longitudinal cohort studies to establish the causal
181 relation between time of eating of unhealthy foods and diabetes.

DISCLOSURE/CONFLICT-OF-INTEREST STATEMENT

182 The authors declare that they have no competing interests.

AUTHOR CONTRIBUTIONS

183 CW, SA, and LP: designed research and had primary responsibility for final content; CW and LP performed
184 statistical analysis; and all authors: wrote the manuscript, read and approved the final manuscript.

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AVAILABILITY OF DATA AND MATERIALS

187 Original data used in this study can be accessed upon request to the UK Data Service (`https://www.`
188 `ukdataservice.ac.uk`) for academic usage (Study Number: 6533).

TABLES

Table 1. The numbers of food recordings contributed to the total calories consumed by adults in the UK adults. (NDNS RP 2008-2017).

Food group names	n	Calories	Relative Prop	Cal Prop	Cal Cum Prop
Pasta & Rice and other cereals	18353	3512069.99	2.45%	7.36%	7.36%
White Bread	18434	3245641.19	2.46%	6.80%	14.17%
Chips, fried and roast potatoes and potato products	6749	1884058.68	0.90%	3.95%	18.12%
Cakes, buns, sweet pastries, fruit pies	7806	1710594.27	1.04%	3.59%	21.70%
Vegetable (not raw)	51317	1665474.02	6.85%	3.49%	25.19%
Biscuits	13200	1662598.06	1.76%	3.49%	28.68%
Fruit	33903	1641675.02	4.53%	3.44%	32.12%
Miscellaneous unclassified foods	48597	1639024.81	6.49%	3.44%	35.56%
Chicken/turkey	8863	1617820.30	1.18%	3.39%	38.95%
Cheese	10983	1492015.32	1.47%	3.13%	42.07%
Beer lager	8199	1484001.20	1.09%	3.11%	45.19%
Semi-skimmed milk	57611	1302649.72	7.69%	2.73%	47.92%
Potatos other (in salads and dishes)	10113	1291447.61	1.35%	2.71%	50.62%
Fat spreads	37960	1215278.60	5.07%	2.55%	53.17%
Beef	4987	1124560.42	0.67%	2.36%	55.53%
High fiber breakfast cereals	8215	1072813.73	1.10%	2.25%	57.78%
Whole meal bread	7193	1070695.89	0.96%	2.24%	60.02%
Chocolate	6495	1046112.65	0.87%	2.19%	62.22%
Wine	6967	1027792.96	0.93%	2.15%	64.37%
Brown, granary and wheatgerm bread	6183	1009074.95	0.83%	2.12%	66.48%
Butter	10203	965901.11	1.36%	2.02%	68.51%
Eggs	7554	964769.19	1.01%	2.02%	70.53%
Soft drinks not diet	11387	940516.516	1.52%	1.97%	72.50%
Reduced fat spreads	12620	848834.89	1.68%	1.78%	74.28%
Crisps and savoury snacks	5664	835671.58	0.76%	1.75%	76.04%
Sausages	3025	775004.13	0.40%	1.62%	77.66%
Meat pastries	1979	744639.89	0.26%	1.56%	79.22%
Bacon and ham	8467	738727.49	1.13%	1.55%	80.77%
Yogurt	6776	665484.55	0.90%	1.40%	82.16%
Low-fiber breakfast cereals	4303	560296.32	0.57%	1.17%	83.34%
Nuts and seeds	6259	559873.88	0.84%	1.17%	84.51%
Oily fish	2610	550425.36	0.35%	1.15%	85.67%
Whole Milk	13628	530449.07	1.82%	1.11%	86.78%
White fish, shellfish	1597	498928.82	0.21%	1.05%	87.82%
Puddings	2291	459784.62	0.31%	0.96%	88.79%
Other Milk Cream	6605	434239.37	0.88%	0.91%	89.70%
Pork	1832	420503.76	0.24%	0.88%	90.58%

NDNS RP: National Diet and Nutrition Survey.

Table 2. Odds ratio (99% confidence intervals) for food groups eaten at night (8 pm - 6 am) vs. earlier time in the day, among total and according to different diabetes status, NDNS RP 2008-2017.

Selected food groups	Overall	Healthy	Pre-diabetics	Undiagnosed diabetes	Diabetes
Pudding	1.38 (1.03, 1.86)	1.50 (1.10, 2.07)	0.89 (0.16, 4.87)	1.81 (0.41, 7.98)	0.58 (0.14, 2.43)
Regular soft drink	1.74 (1.47, 2.06)	1.72 (1.43, 2.06)	1.87 (0.97, 3.57)	2.72 (1.44, 5.14)	1.38 (0.65, 2.96)
Sugar Confectionery	1.92 (1.38, 2.69)	1.63 (1.14, 2.32)	2.10 (0.52, 8.46)	13.07 (4.59, 37.24)	5.10 (2.15, 12.09)
Chocolate	3.19 (2.69. 3.79)	3.10 (2.57, 3.73)	4.07 (2.58, 3.73)	2.52 (0.95, 6.66)	5.13 (2.55, 10.30)
Spirit	11.13 (8.37, 14.80)	10.86 (8.01, 14.73)	8.48 (2.26, 31.79)	7.51 (1.99, 5.21)	36.8 (7.36, 183.66)
Beer	7.19 (5.87, 8.82)	7.49 (6.02, 9.34)	4.05 (2.00, 8.20)	7.87 (3.51, 17.63)	6.32 (2.29, 17.47)
Ice Cream	2.38 (1.79, 3.15)	2.45 (1.82, 3.31)	3.32 (0.75, 14.62)	0.98 (0.14, 7.00)	1.65 (0.54, 5.07)
Biscuit	1.91 (1.67, 2.16)	1.78 (1.55, 2.03)	3.51 (2.16, 5.71)	2.75 (1.35, 5.59)	2.44 (1.54, 3.88)
Crisp	1.55 (1.27, 1.88)	1.56 (1.27, 1.92)	1.95 (0.79, 4.78)	1.37 (0.37, 5.12)	1.16 (0.49, 2.75)

Logistic regression models with GEE were adjusted for age, sex, and social-economic levels.
NDNS RP: National Diet and Nutrition Survey.

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