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Meat or meatless meals at lunch and dinner – exploring the associated factors and transition between meals

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ABSTRACT

This study aimed to explore the factors associated with the consumption of meat vs. meatless meals and to assess the applicability of a multi-state model to describe transitions between lunch and dinner. Fifteen thousand four hundred and eight main meals (lunch and dinner) from a sample of adults (18–84 years, $n=3852$) from the Portuguese Food, Nutrition and Physical Activity Survey (IAN-AF 2015–2016) were categorised as meat, fish, ovolactovegetarian or snack. Adjusted generalised-mixed-effects models were used to explore the associations and a time-homogeneous Markov-multi-state model was applied to study the transitions. Women, older and higher educated individuals presented higher odds of consuming meatless meals and lower hazard of transitioning to meat in the following main meal. Strategies for replacing meat with more sustainable foods should be specific towards different population groups. Studying transitions across main meals, using multi-state models, can support the development of feasible, realistic and group-specific strategies to replace meat and promote dietary variety.

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Meals; meat; fish; ovolactovegetarian

Introduction

The high intake of meat and meat products in Europe is a key concern due to its health and environmental implications (Westhoek et al. 2011, 2014). Reducing meat consumption and its substitution by healthier and more sustainable alternatives, such as pulses, whole grains, or even fish or eggs, as the main protein source of meals, expectedly result in desirable health and environmental benefits (Westhoek et al. 2014; Springmann et al. 2018). However, most consumers eat meat regularly, making enduring behavioural changes a challenging process (Rees et al. 2018). To effectively achieve long-term health and environmental benefits, interventions and guidelines directed to promote changes in dietary behaviours must set feasible goals. Thus, it is relevant to improve the knowledge of the factors that lead consumers to eat different food sources of protein in diverse meals.

Concerning meals, most meat products, as well as fish and seafood, eggs, vegetables and pulses, are most commonly consumed at the main meals, namely at lunch and dinner (De Oliveira Santos et al. 2015; Myhre et al. 2015; Sui et al. 2017; Murakami et al. 2022). Furthermore, meals reflect a structured eating behaviour, showing the relevance of studying meals rather than food groups by themselves. It has also been suggested that meal-based dietary advice and guidelines are effective in promoting dietary behaviour change (Leech et al. 2015; Sui et al. 2017; Schwedhelm et al. 2019). Nonetheless, there is scarce information about the factors associated with having a specific meal category (i.e. meat, fish, eggs, pulses or meat-substitutes), and about the shifts in the foods eaten across consecutive meal occasions (i.e. explaining what will a person that ate a meat-based lunch eat at dinner). Shifting the consumption of foods across meal occasions may be used as a proxy of diet

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diversity which is shown to be associated with nutrient adequacy and diet quality (Nair et al. 2016). Multi-state models describe processes that encompass several states. Thus, they can be useful to address these issues. These models estimate the probability of transition from one state to another within a specific period adjusted for several covariates (Hougaard 1999; Meira-Machado et al. 2009). These aspects are relevant when studying meals, as meals are time-dependent variables, allowing to understand the influence of several variables in the changes between meal categories across consecutive meal occasions.

The present study used data from the Portuguese Food, and Physical Activity Survey 2015–2016 (IAN-AF 2015–2016), and the main aim was to investigate the sociodemographic and health-related factors associated with the consumption of meal categories (i.e. meat, fish, ovolactovegetarian and snack) in lunch and dinner, in a representative sample of Portuguese adults. Furthermore, it was also intended to assess the applicability of a multistate model to describe the pathways of transition between meal categories across lunch and dinner.

Methods

Study population

A thorough description of the IAN-AF 2015–2016 protocol and methodology is published elsewhere (Lopes et al. 2017, 2018). Briefly, this survey considered a representative sample of the Portuguese general population, aged between 3 months and 84 years old. The sample was selected from the National Health Registry, by multistage sampling, in each Portuguese geographical region (NUTS II), and weighed according to sex and age group (<1 year, 1–2 years, 3–9 years, 10–17 years, 18–34 years, 35–64 years, 65–74 years and 75–84 years). A total of 5811 individuals from all age groups completed two dietary assessment interviews. For this study, we only considered the adult population, aged ≥18 years old, comprising a total of 3852 individuals. From these, 89% reported four main meals (lunch and dinner), 10% reported three and about 1% reported less than three main meals. No exclusions were made based on the number of reported main meals.

Dietary assessment

Data on food consumption were collected according to European guidelines (EFSA 2014), through one year, from October 2015 to September 2016, to account for seasonal variability. Dietary assessment was performed by a trained dietitian using an electronic platform ("You eAT&Move") that included a validated assessment tool for 24-hours recall (eAT24) (Goios et al. 2020). The eAT24 software was used to collect detailed food consumption data. Dietary intake was obtained by two non-consecutive 24-hour recalls, 8–15-days apart.

Detailed information and quantification of foods, recipes and supplements reported by the participants were collected and converted into nutrients at the ingredient level by the eAT24 software, using the Portuguese food composition table (Instituto Nacional de Saúde Doutor Ricardo Jorge (INSA) 2007), which was adapted and updated during the survey fieldwork, using mostly data from the European Food Information Resource (EuroFIR) network databases (Roe et al. 2013). Recipes were disaggregated into their food items, and the food items were categorised into food groups and subgroups.

Meal definition and characteristics

We considered the meals empirically identified as Lunch or Dinner by the IAN-AF 2015–2016 participants as main meals. Breakfast was deliberately not considered in these analyses due to its specific characteristics in Portuguese culture, reflected in our data. Typically, in Portugal, breakfast is composed of coffee (59%), milk or milk substitute (54%) and a cereal component (72%) that usually is bread with different possible fillings. Only about 10% of breakfast meals include meat, and less than 1% include fish. The breakfast meat meals include mainly small portions of cooked ham consumed in sandwiches.

First, each main meal was categorised according to its energy amount. All lunches and dinners that presented less that 250 kcal were considered as lighter meals and classified as *snacks*, as 250 was approximately half of the median energetic content of all observed meals. Then, the categorisation was done according to the food products consumed. A meal was categorised as *meat* if it included any meat product, *fish* if it included any fish or seafood product, or "*ovolactovegetarian*" if no meat or fish was part of the meal consumed (including vegan meals and meals with dairy or eggs as the main protein source). Whenever meat and fish were simultaneously part of the same meal, we classified it according to the food item amount. The *ovolactovegetarian* meals included meals with eggs, pulses, dairy or meat substitutes, cereals and vegetables. The variables used to characterise meals were the meal occasion (restricted in this analysis to "lunch" or "dinner"), day type (weekdays, weekend days), season

(Winter, Spring, Summer and Autumn), as well as the meal content in energy (kcal), protein (g), fat (g), carbohydrates (g), fibre (g) and salt (g).

Other variables

In the IAN-AF 2015–2016 survey, participants' data on socioeconomic and sociodemographic characteristics, health-related information and behavioural traits were collected by interviewer-administered questionnaires.

For the present study, the socioeconomic and demographic variables used were sex, age (in years), educational level (none or primary, secondary or post-secondary, tertiary/higher), household income (number of minimum wages (MW), earned by the household), marital status (married, unmarried) and food insecurity status of the household, measured by a Portuguese adapted version of the questionnaire developed by Cornell/Radimer (Radimer et al. 1990; Alarcão et al. 2020).

Health-related data were assessed as participants self-reported previous diagnoses of chronic disease. Body mass index (BMI) was calculated using data on weight and height, measured by trained researchers and using standardised procedures (The International Society for the Advancement of Kinanthropometry 2001). For BMI categorisation, cut-offs were assumed, according to the World Health Organization (WHO) (World Health Organization 2000): underweight ($<18.5\,kg/m^2$), normal weight ($18.5–24.9\,kg/m^2$), overweight ($25.0–29.9\,kg/m^2$) and obese ($\geq 30.0\,kg/m^2$). Due to the underrepresentation of the underweight class, underweight and normal weight were merged into a single variable class for analytical purposes.

For the behavioural traits data, we used the variable physical activity level categorised according to the estimated weekly metabolic equivalent energy expenditure ("inactive": <600 metabolic equivalent minutes (MET) per week, "minimally active": 600–3000 MET per week and "very active": >3000 MET per week) and assessed by the International Physical Activity Questionnaire (IPAQ) short-form (Craig et al. 2003; IPAQ Research Committee 2005) and the variable smoking status ("never smoked", "former smoker" and "current smoker").

Statistical analysis

We described the meal categories using mean and standard deviation for numerical variables, and absolute and relative frequencies for categorical variables. Since there is a dependency between observations, there was more than one observation per individual; mixed-effects models and generalised mixed-effects (GLME) models, respectively for Gaussian and binomial variables, were performed to compare means and proportions according to the meal category.

To assess the magnitude of the association between meal categories and the socioeconomic, health-related and behavioural factors, we estimated adjusted odds ratio (OR) and the respective 95% confidence intervals (95%CI), using GLME models adjusted for sex, age and educational level. Three separate GLME models were estimated, one comparing *meat* with *fish* meals, one comparing *meat* and *ovolactovegetarian* meals and one comparing *meat* and *snack* meals, all using *meat* as the reference category in both models.

Then, a time-homogeneous Markov multi-state model was applied to study the transitions between-meal categories across lunch and dinner occasions. Accordingly, we considered a three-state model that described how each participant changes between meal categories across lunch and dinner. There were 16 possibilities for transition, as graphically depicted in Figure 1. The two interviews of each participant resulted in four main meals and three studied transitions (Lunch (d1) → Dinner (d1) → Lunch (d2) → Dinner (d2)). To assess the effect of the covariates in the meal occasion transitions, the multi-state model estimated the crude and adjusted for sex, age and educational level hazard ratios (HRs) for each socioeconomic, health-related and behavioural variable (Supplementary Material). Furthermore, a final multivariate model is presented including all the covariates for which HRs remained significant for at least one possible transition when they were all included in the model. As the second transition included in the model: "Dinner (d1) → Lunch (d2)" was not consecutive, we conducted a sensitivity analysis, separating the transitions that were consecutive (Lunch → Dinner) and the ones that were not consecutive (Dinner → Lunch) to assess the impact of this limitation.

We performed all statistical analyses using R software version 3.4.1 for Windows (R Foundation for Statistical Computing, Vienna, Austria) (R Core Team 2018) and used the "msm" R library (Jackson 2011) to create the multi-state model. We assumed a significance level of .05.

Results

Description of meals

Table 1 presents the characteristics of the meals consumed by the 3852 IAN-AF 2015–2016 participants aged ≥18 years old, according to the categories: *meat*,

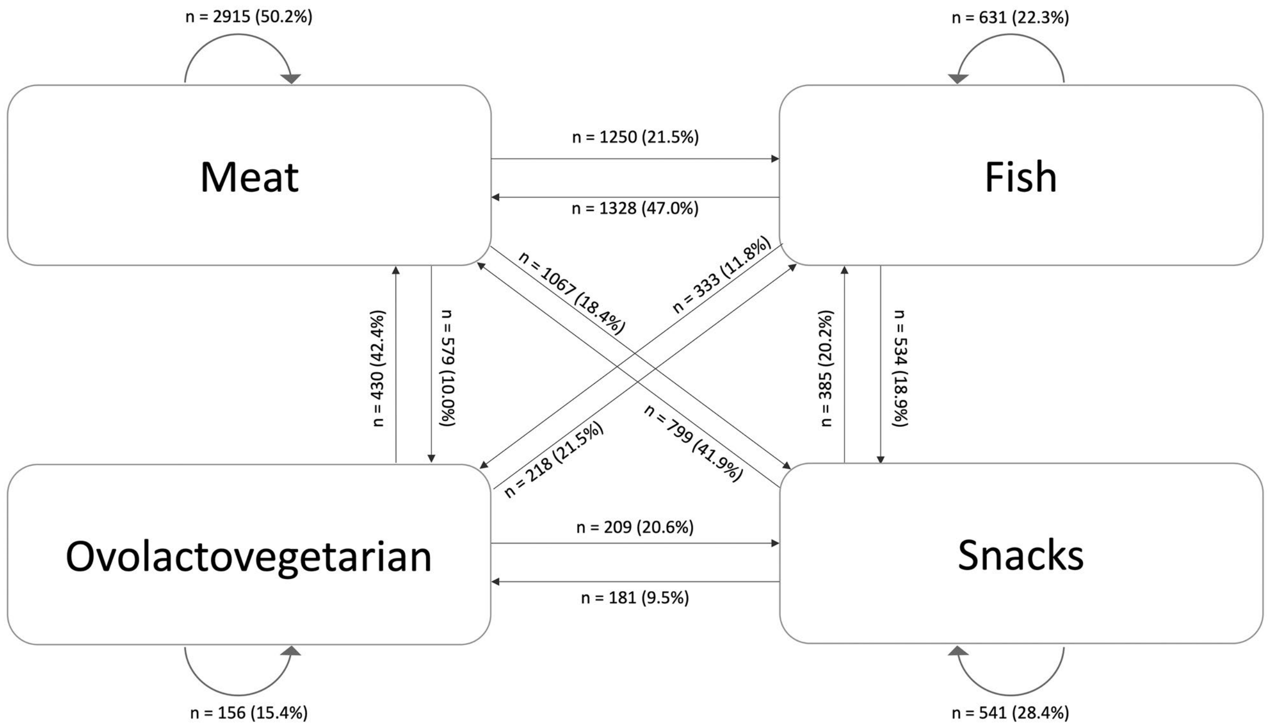

Figure 1. Graphical representation of the transitions model and the observed transitions (*n*, %) between the meal categories: meat, fish, ovolactovegetarian and snack, across the main meal occasions (lunch and dinner) in IAN-AF 2015–2016 sample.

Table 1. Characterisation of the Portuguese Food and Physical Activity Survey 2015–2016 (IAN-AF 2015–2016) reported meals according to its categories: meat, fish, ovolactovegetarian and snack.

	Meal category				
Variable	Meat (M) (*n* = 7489, 48.6%)	Fish (F) (*n* = 3586, 23.3%)	Ovolactovegetarian (O) (*n* = 1513, 9.8%)	Snack (S) (*n* = 2820, 18.3%)	*p* Values[a]
Meal occasion, *n* (%)					
Lunch	4107 (53.3)	2096 (27.2)	538 (7.0)	963 (12.5)	<.001 for all pairs,
Dinner	3382 (43.9)	1490 (19.3)	975 (12.7)	1857 (24.1)	except O vs. S: .22
Days, *n* (%)					
Weekdays	6020 (47.7)	3052 (24.2)	1257 (10.0)	2301 (18.2)	M vs. F: <.001
Weekend days	1469 (52.9)	534 (19.2)	256 (9.2)	519 (18.7)	M vs. O: .01
					M vs. S: .31
					F vs. O: .08
					F vs. S: <.001
					O vs. S: .20
Season, *n* (%)					
Winter	1967 (49.5)	879 (22.1)	341 (8.6)	785 (19.8)	M vs. F: .07
Spring	2530 (47.4)	1242 (23.3)	567 (10.6)	997 (18.7)	M vs. O: .02
Summer	2365 (48.6)	1197 (24.6)	488 (10.0)	814 (16.7)	M vs. S: .16
Autumn	627 (50.7)	268 (21.7)	117 (9.5)	224 (18.1)	F vs. O: .21
					F vs. S: .004
					O vs. S: .002
Energy[1] (kcal)					
Mean (SD)	724 (404)	643 (338)	502 (254)	133 (81)	<.001 for all pairs
Protein[b] (g)					
Mean (SD)	40.5 (25.3)	33.4 (18.6)	16.3 (10.4)	6.6 (7.1)	<.001 for all pairs
Fat[b] (g)					
Mean (SD)	26.1 (19.6)	21.7 (16.3)	17.4 (14.1)	4.1 (3.6)	<.001 for all pairs
Total carbohydrates[b] (g)					
Mean (SD)	69.8 (46.9)	65.2 (44.6)	61.6 (36.2)	15.8 (12.1)	<.001 for all pairs
Fibre[b] (g)					
Mean (SD)	6.0 (4.4)	6.6 (4.6)	6.8 (4.8)	2.5 (2.0)	<.001 for all pairs, except F vs. O: .81
Salt[b] (g)					
Mean (SD)	3.1 (2.2)	3.6 (2.5)	2.2 (1.6)	0.8 (0.7)	<.001 for all pairs

[a]*p* Values for the differences between all combinations of meal categories obtained by mixed-effects and generalised mixed-effects models (for gaussian and categorical variables, respectively). Meal categories are represented by their initials – meat (M), fish (F), ovolactovegetarian (O) and snack (S).
[b]Average nutritional content of reported meals, according to each category.
[1]Significant values are considered for $p < .05$.

fish, ovolactovegetarian or snack. A total of 15,408 main meals were considered. From these, 48.6% of the meals were classified as *meat* ($n = 7489$), 23.3% as *fish* ($n = 3586$), 18.3% as *snack* ($n = 2820$) and lastly, 9.8% as *ovolactovegetarian* ($n = 1513$). Snack meals represent a wide diversity of meals, but the vast majority consist of vegetable soup accompanied by fruit, dairy or sandwiches with small amounts of meat or fish products.

Independent of the meal occasion, *meat* meals are the most frequently consumed meals (53.3% of meals at lunch, 43.9% of meals at dinner). However, the second most frequent meal category depends on the meal occasion, *fish* at lunch (27.2%) and *snack* meals at dinner (24.1%).

On weekdays, the proportion of *fish* meals was higher when compared to weekends (24.2% vs. 19.2%), and the opposite is found for *meat* meals (47.7% vs. 52.9%, at weekdays and weekends, respectively) ($p < .001$).

Meat meals presented higher energetic value, protein, fat and carbohydrate content compared to all other meal categories ($p < .001$) and higher salt content than ovolactovegetarian and snack meals ($p < .001$). *Ovolactovegetarian* and *fish* meals presented higher fibre content than *meat* and *snack* meals ($p < .001$). Fish meals were the ones with the highest salt content ($p < .001$).

Socioeconomic, behavioural and health-related factors associated with the consumption of meal categories

Table 2 presents the associations between the consumption of meal categories with socioeconomic, behavioural and health-related factors. The odds of consuming a *fish* meal instead of a *meat* meal significantly increased as age increased by 10 years (OR/10 y: 1.19, 95%CI: 1.15–1.23). Additionally, for this model, the odds of having a *fish* meal rather than a *meat* meal were significantly lower among the individuals in the lower educational level category, in people with food insecurity and current smokers. Increasing the household income by one MW seems to increase the odds of having a *fish* meal instead of *meat*, despite this association is only marginally significant.

Table 2. Odds ratio (OR) for the factors associated with the consumption of fish, ovolactovegetarian and snack meals compared to meat meals (reference).

	OR (95%CI)[a]		
Variable	Fish	Ovolactovegetarian	Snack
		Reference: meat meals	
Sex			
Female	Ref.	Ref.	Ref.
Male	0.96 (0.87–1.05)	**0.69 (0.59–0.80)**	**0.23 (0.20–0.27)**
Age			
Per 10-year increase	**1.19 (1.15–1.23)**	**1.28 (1.22–1.36)**	**1.27 (1.21–1.33)**
Marital status			
Married	Ref.	Ref.	Ref.
Unmarried	1.03 (0.93–1.14)	**1.37 (1.17–1.61)**	**1.36 (1.18–1.57)**
Education level			
≤6 years	**0.76 (0.67–0.87)**	0.91 (0.73–1.14)	**1.41 (1.16–1.73)**
7–12 years	0.91 (0.81–1.01)	0.93 (0.77–1.13)	1.14 (0.96–1.36)
>12 years	Ref.	Ref.	Ref.
Household income			
Per 1 MW increase	1.02 (0.99–1.05)	0.97 (0.92–1.02)	**0.95 (0.90–0.99)**
Food insecurity			
No	Ref.	Ref.	Ref.
Yes	**0.80 (0.68–0.94)**	**1.27 (1.00–1.61)**	1.20 (0.97–1.48)
BMI class			
Under/normal weight	Ref.	Ref.	Ref.
Overweight	0.96 (0.86–1.07)	**0.78 (0.65–0.93)**	1.03 (0.87–1.21)
Obese	0.94 (0.83–1.06)	**0.75 (0.61–0.91)**	1.12 (0.93–1.33)
Having a chronic disease			
No	Ref.	Ref.	Ref.
Yes	1.06 (0.96–1.18)	1.06 (0.90–1.25)	**1.33 (1.15–1.54)**
IPAQ level			
Inactive	Ref.	Ref.	Ref.
Minimally active	**1.11 (1.00–1.24)**	1.08 (0.91–1.29)	1.12 (0.96–1.31)
Very active	1.06 (0.96–1.19)	1.14 (0.94–1.37)	0.99 (0.83–1.17)
Smoking status			
Never	Ref.	Ref.	Ref.
Former smoker	0.97 (0.87–1.08)	0.95 (0.80–1.14)	**0.84 (0.72–0.99)**
Current smoker	**0.86 (0.76–0.97)**	1.01 (0.83–1.23)	**0.82 (0.69–0.99)**

MW: minimum wage; BMI: body mass index; IPAQ: International Physical Activity Questionnaire; Ref.: reference category.
[a]Adjusted for sex, age and educational level; bold values are statistically significant with a confidence level of 95%.

Furthermore, we found that the odds of eating *ovolactovegetarian* meals rather than *meat* were significantly lower in men (OR: 0.69, 95%CI: 0.59–0.80), but significantly higher as age increased (OR/10 y: 1.28, 95%CI: 1.22–1.36), as well as among unmarried individuals (OR: 1.37, 95%CI: 1.17, 1.61). Overweight and obese individuals presented lower odds of having *ovolactovegetarian* meals than normal weight ones.

The odds of having *snack* meals also increased as age increased (OR/10 y: 1.27, 95%CI: 1.21–1.33), and were higher among unmarried individuals, people with lower educational level (OR: 1.41, 95%CI: 1.16–1.73) and participants with chronic diseases. On the contrary, higher income, being current (OR: 0.82 95%CI: 0.69–0.99) or former (OR: 0.84 95%CI: 0.72–0.99) smoker and male sex (OR: 0.23, 95%CI: 0.20–0.27), were associated with lower odds of having *snack* meals.

Transitions between meal categories across lunch and dinner

The observed transitions are presented in Figure 1, where it is possible to see that independent of the meal category, the most likely transition is towards the meat category in the next meal. Moreover, Table 3 presents HRs for the variables included in the meal transition multi-state model. In general, compared to women, men seem to change more from *meat* to *fish* (HR: 1.21, 95%CI: 1.07–1.37)) and vice versa (HR: 1.22, 95%CI: 1.09–1.38) in a next meal but change less to *snack* meals ($HR_{meat\text{-}snack}$: 0.45, 95%CI: 0.39–0.52; $HR_{fish\text{-}snack}$: 0.48, 95%CI: 0.39–0.58). Increasing age is associated with higher likelihood of changing to *ovolactovegetarian* and *snack* meals after having a *meat* or a *fish* meal and with a lower likelihood of changing to a *meat* meal independently of the meal category.

Furthermore, after a *meat* meal, individuals with increasing household income were more likely to have a *fish* meal, whereas individuals with lower education level presented an opposite trend. Changing towards an *ovolactovegetarian* meal after meat seems to be more likely among unmarried individuals. The likelihood of consuming a lighter meal (*snack*) after a *meat* meal is higher among individuals with chronic diseases, as well as in people with less education.

After a *fish* meal, increasing household income is associated with higher hazard of changing to the *meat* category in the next meal and with lower hazard of changing to the *snack* category. Having a chronic disease, in its turn, was associated with a higher hazard of changing from a *fish* to *snack* (HR: 1.25, 95%CI: 1.02–1.54) and from *ovolactovegetarian* to fish (HR: 2.07, 95%CI: 1.51–2.84) in a next meal. The transition from *fish* to *ovolactovegetarian* seems to be also more likely among individuals with chronic disease (HR: 1.26, 95%CI: 0.98–1.63), but this association was only marginally significant.

Tables S1 and S2 (Supplementary Material) present the results from the sensitivity analysis conducted, showing some small differences in the frequencies of transition, particularly regarding the *ovolactovegetarian* and *snack* categories.

Discussion

This study evaluated the associations between the consumption of *meat, fish, ovolactovegetarian* and *snack* meals and socioeconomic, health-related and lifestyle characteristics, as well as the transitions between meal categories across lunch and dinner.

Our results show that, independent of the meal category consumed, the most frequent meal category consumed in the next consecutive meal is meat and that the consumption of different meal categories is influenced by several socioeconomic factors. Targeted strategies to specific population groups are needed to promote replacing meat with other protein sources to improve human health and environmental sustainability, as stated by previous evidence (Springmann et al. 2018; Willett et al. 2019).

Compared to men, women tend to consume more *ovolactovegetarian* and *snack* meals, and it is also more likely for a woman to change from *meat* or *fish* categories to *snack* in the next meal. These findings seem to be aligned with previous evidence, reporting that compared to males, females tend to present dietary patterns characterised by a lower frequency of meat consumption and a higher frequency of consumption of fruits and vegetables (Daniel et al. 2011; Knudsen et al. 2014; Ax et al. 2016; Bertin et al. 2016; Gregório et al. 2017; Beck et al. 2018; Marques-Vidal et al. 2018). Women tend to be more health-conscious and more keen on nutritional topics (Ruby 2012; Spronk et al. 2014), more concerned with body image (El Ansari et al. 2014; Hagmann et al. 2019) and more sensitive to animal welfare than men (Ruby 2012), which may help explain these results.

Regarding age, our results show that increasing age leads to higher odds of consumption of all meal categories alternative to meat, and it also increases the likelihood of changing from a *meat* meal to an *ovolactovegetarian* or *snack* meal and decreases the

Table 3. Hazard ratios for the explanatory variables included in the transitions' multi-state final model, and respective 95%CI, IAN-AF 2015–2016 survey.

	Meal category transition – final model[a] HR (95%CI)											
	Reference: meat → meat			Reference: fish → fish			Reference: vegetarian → vegetarian			Reference: snack → snack		
Variable	Meat-fish	Meat-vegetarian	Meat-snack	Fish-meat	Fish-vegetarian	Fish-snack	Vegetarian-meat	Vegetarian-fish	Vegetarian-snack	Snack-meat	Snack -fish	Snack-vegetarian
Sex												
Female	Ref.	Ref.	Ref.	Ref.	Ref.	Ref.	Ref.	Ref.	Ref.	Ref.	Ref.	Ref.
Male	**1.21 (1.07–1.37)**	0.96 (0.80–1.15)	**0.45 (0.39–0.52)**	**1.22 (1.09–1.38)**	0.94 (0.74.1.18)	**0.48 (0.39–0.58)**	1.19 (0.97–1.48)	**1.45 (1.08–1.95)**	**0.39 (0.27–0.55)**	**1.31 (1.09–1.56)**	**1.33 (1.04–1.70)**	1.24 (0.85–1.80)
Age												
Per 10 y increase	1.03 (0.98–1.08)	**1.19 (1.11–1.27)**	**1.11 (1.05–1.17)**	**0.89 (0.85–0.93)**	**1.26 (1.15–1.38)**	**1.17 (1.09–1.26)**	**0.90 (0.84–0.98)**	1.03 (0.92–1.15)	1.08 (0.96–1.26)	**0.89 (0.83–0.95)**	**1.12 (1.03–1.22)**	1.04 (0.91–1.19)
Marital status												
Married	Ref.	Ref.	Ref.	Ref.	Ref.	Ref.	Ref.	Ref.	Ref.	Ref.	Ref.	Ref.
Unmarried	0.94 (0.82–1.08)	**1.26 (1.04–1.53)**	1.15 (0.99–1.34)	**0.86 (0.75–0.99)**	1.04 (0.80–1.36)	**1.30 (1.06–1.60)**	1.00 (0.79–1.26)	**0.86 (0.75–0.99)**	0.94 (0.67–1.32)	0.93 (0.77–1.11)	0.86 (0.67–1.11)	1.16 (0.81–1.66)
Educational level												
≤6 years	**0.81 (0.66–0.99)**	1.14 (0.84–1.54)	**1.34 (1.05–1.70)**	1.10 (0.91–1.35)	0.96 (0.64–1.43)	0.99 (0.71–1.39)	1.38 (0.97–1.96)	0.78 (0.49–1.26)	1.06 (0.63–1.79)	0.99 (0.75–1.31)	0.77 (0.52–1.13)	0.67 (0.38–1.19)
7–12 years	0.89 (0.76–1.03)	1.07 (0.84–1.54)	1.15 (0.95–1.39)	0.98 (0.85–1.14)	1.04 (0.75–1.44)	1.14 (0.86–1.49)	1.13 (0.85–1.49)	0.96 (0.66–1.39)	1.05 (0.69–1.60)	0.98 (0.79–1.22)	1.01 (0.74–1.39)	0.75 (0.48–1.19)
>12 years	Ref.	Ref.	Ref.	Ref.	Ref.	Ref.	Ref.	Ref.	Ref.	Ref.	Ref.	Ref.
Household income												
Per 1 MW increase	**1.09 (1.01–1.17)**	1.06 (0.96–1.18)	1.00 (0.92–1.08)	**1.08 (1.01–1.16)**	1.04 (0.90–1.19)	**0.90 (0.80–1.00)**	1.01 (0.90–1.14)	1.17 (0.99–1.38)	0.94 (0.80–1.12)	1.02 (0.92–1.12)	1.04 (0.91–1.18)	0.87 (0.72–1.06)
Having a chronic disease												
No	Ref.	Ref.	Ref.	Ref.	Ref.	Ref.	Ref.	Ref.	Ref.	Ref.	Ref.	Ref.
Yes	0.96 (0.84–1.10)	1.06 (0.87–1.29)	**1.25 (1.07–1.45)**	0.90 (0.79–1.03)	1.26 (0.98–1.63)	**1.25 (1.02–1.54)**	0.85 (0.68–1.07)	**2.07 (1.51–2.84)**	0.93 (0.67–1.29)	0.96 (0.80–1.16)	1.04 (0.81–1.34)	0.76 (0.52–1.11)

MW: minimum wage; Ref.: reference category.
[a]Adjusted for all the variables included; bold values are statistically significant with a confidence level of 95%.

hazard of transition to the *meat* category on the next meal. Accordingly, previous studies showed lower levels of meat, increased fish consumption and the adoption of healthier dietary patterns with increasing age (Daniel et al. 2011; Knudsen et al. 2014; Ax et al. 2016; Bertin et al. 2016; Gregório et al. 2017; Beck et al. 2018; Marques-Vidal et al. 2018). On the one hand, lower *meat* intake at older ages and its substitution with *fish* or *ovolactovegetarian* may be due to a cohort effect because older adults in Portugal tend to have a dietary pattern closer to the Mediterranean diet as expressed by the higher percentage of adherence to this pattern in the elderly compared to younger adults (Lopes et al. 2017). On the other hand, the increasing odds of having *ovolactovegetarian* and *snack* main meals instead of *meat* in older adults may also be related to the specific characteristics of this population or health issues, such as chewing difficulties or even physical constraints impairing the preparation of meals (Koehler and Leonhaeuser 2008; Schütz and Franzese 2018). Moreover, it can also suggest a higher financial vulnerability in the elderly population. In Portugal, food insecurity has been associated with older ages in previous studies (Fernandes et al. 2018; Alarcão et al. 2020).

The findings concerning household income and food insecurity reinforce the hypothesis of financial vulnerability as a justification for the increased intake of *ovolactovegetarian* and *snack* meals and the lower intake of *fish* meals as a surrogate of meat. A previous study reported that low income and high food prices are probably motives to follow a vegetarian/vegan diet (Allès et al. 2017). Furthermore, other studies evaluating factors associated with fish and seafood consumption also found a positive association between household income and fish consumption. In such studies, high-income individuals presented a higher frequency of fish intake (Can et al. 2015; Cantillo et al. 2021), which supports our results.

Commonly, higher educational levels are associated with healthier dietary patterns and higher fish consumption (Daniel et al. 2011; Knudsen et al. 2014; Ax et al. 2016; Bertin et al. 2016; Gregório et al. 2017; Beck et al. 2018; Marques-Vidal et al. 2018). Aligned with this, we found that higher educated individuals present higher odds of having a *fish* meal instead of *meat* and a higher hazard of changing to *fish* after a *meat* meal. Furthermore, there seems to be a trend for the higher educated individuals to change less to *meat* after having a *fish* meal, but this result should be further studied to be confirmed.

In this study, we found that unmarried individuals were more likely to have *ovolactovegetarian and snack* meals instead of *meat* and more likely to change to the *ovolactovegetarian* category in the next meal. This finding agrees with previous evidence that showed being single and having smaller household sizes were linked with a lower frequency of meat consumption (Schmid et al. 2017). Furthermore, in the Netherlands Cohort Study (Gilsing et al. 2013), researchers found that individuals reporting not eating meat were less likely to be married.

Our study has several strengths and limitations that should be addressed. First, thoroughly detailed dietary data on food ingredients consumed were recorded during face-to-face interviews by trained professionals with a background in nutrition sciences, following standardised procedures, reducing the likelihood of misclassifying the meal occasions. However, we cannot rule out the possibility that it has occurred. Moreover, the categorisation of meals followed an empirical method, primarily based on the main protein source except for the snack meals that were defined based on the energetic content, which can also be seen as a limitation of this study. Nonetheless, these represent only around 15% of the total meals observed in the current study and have clear differences in terms of food and nutrient composition to be included in the other three categories and were reported as main meals by the participants, thus should not be excluded. Additionally, the ovolactovegetarian categories include both vegan meals and meals including dairy or eggs. It would be interesting to further separate the ovolactovegetarian category, which was not possible due to the low number of observed meals in the IAN-AF 2015–2016 sample.

To the best of our knowledge, this is the first study that evaluates the transitions between meal categories across the main meal occasions using empirical data from a representative sample of the general population, applying a multi-state model. Such models have been used in public health research to study transitions between disease stages and across BMI categories (Andersen et al. 1993; Putter et al. 2007; Meira-Machado et al. 2009; Moreira et al. 2019). Concerning the meal transitions, this was an exploratory study, and a first attempt to apply such methods, which have the advantage of considering time-dependent variables (meals), to study dietary intake and variety. With the use of multi-state models, it is possible to assess the specific adjusted effects of different variables on the transitions between meals.

This study used dietary 24-hour recall data from two non-consecutive interviews, implying some limitations. We recognise that longer reporting periods are better to estimate the intake of less commonly consumed foods with high within-variability. With a two-day assessment, we analysed four main meals (lunch and dinner) and we used three transitions (Lunch (d1) → Dinner (d1) → Lunch (d2) → Dinner (d2)) in the multi-state model. If more reporting days were available, the number of dietary transitions to include in the model would be higher, improving the model and, consequently, the validity of the findings. Also, the days assessed in the survey for each participant were not consecutive as the model considered. In fact, the second transition included in the model: "Dinner (d1) → Lunch (d2)" did not happen in a consecutive manner, which may have impacted the results presented in Table 3. To try to assess the impact of this limitation, we conducted a sensitivity analysis, separating the transitions that were consecutive (Lunch → Dinner) and the ones that were not consecutive (Dinner → Lunch), results of which are presented in Tables S1 and S2 (Supplementary Material), respectively. The observed differences can be a result of the independence between these two meal occasions, but they can also reflect differences in the meal pattern at lunch and dinner. Despite this, the majority (75%) of the transitions considered in the model met the assumption of consecutiveness. Thus, our results may reflect more the transition from lunch to dinner than the reverse.

Multi-state models showed to be suitable to be applied to dietary intake studies. Nonetheless, future studies, with more and consecutive days assessed can be useful to improve the accuracy of these models. The application of multi-state models with different categorisation of meals or even dietary patterns can be used to answer to different research objectives. In fact, the model presented in this article was applied in a recently published modelling study from our research team that evaluated the health impact of alternative scenarios reflecting substitutions of fish and meat meals in the Portuguese population (Carvalho et al. 2021). In that study, the main advantage of applying this model was to implement the substitutions in the alternative scenarios in a probabilistic way, implementing the replacements not random by considering the specific characteristics of the population (sex, age, geographical region, etc.), and making the alternative scenarios more realistic.

Furthermore, we argue that besides observational research, in the field of diet and nutrition, multistate models can be applied in intervention studies. For example, we consider these models can be used to study the changes between dietary patterns (DP) over the course of an intervention study (e.g. states: (a1) "unhealthy DP", (a2) "healthy DP" and (a3) "in transition" or (b1) "omnivore", (b2) "flexitarian", (b3) "vegetarian"), allowing to explore the individual effect of several factors and intervention components in the changes. Moreover, in trials assessing the effect of multiple dietary factors in the progression of diseases or states, applying these methods can have advantages compared to traditional methods by providing deeper insights to the effects of multiple interventions or other factors in trial settings with complex disease process, as suggested by clinical trials from other fields (Le-Rademacher et al. 2018, 2022).

In summary, eating meals alternative to *meat* (i.e. *fish, ovolactovegetarian and snack*) at lunch and dinner, and the respective transitions are associated with sex, age and educational level. Most transitions between meals occurred to *meat*. Thus, efforts are needed to change this trend and replace meat consumption with healthier and more sustainable alternatives. This study was the first attempt to apply a multi-state model to analyse transitions between meals. Studying transitions across meal occasions, using such models, can support the development of feasible, realistic and group-specific strategies to replace meat and promote dietary variety.

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Ethical approval

Ethical approval was obtained from the National Commission for Data Protection and the Ethical Committee of the Institute of Public Health of the University of Porto. All participants were asked to provide their written informed consent according to the Ethical Principles for Medical Research involving human subjects expressed in the Declaration of Helsinki and the national legislation. All documents with identification data were treated separately and stored in a different dataset.

Disclosure statement

There are no relevant financial or non-financial competing interests to report.

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