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The association of sodium intake with successful aging, in 3,349 middle-aged and older adults: Results from the ATTICA and MEDIS cross-sectional epidemiological studies

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Abstract.
BACKGROUND: The association between sodium intake and successful aging is not elucidated to date.
OBJECTIVE: To evaluate the association between sodium intake and successful aging, in people aged >50 years, living in Greece.
METHODS: A cross-sectional study was conducted in middle aged and older adult participants of the ATTICA ($n = 1,128$) and MEDIS ($n = 2,221$) epidemiological studies. Anthropometric, clinical, socio-demographic and lifestyle characteristics derived through standard procedures and questionnaires. Sodium intake was measured based on the USDA Food Composition database; table salt or salt from processed foods were not evaluated. Successful aging was assessed using the Successful Aging Index (SAI, range 0–10, higher values indicating higher successful aging) comprising of health-related, social, lifestyle and clinical characteristics.
RESULTS: Participants with ≥1500 mg/day sodium intake had 20.2% on average lower SAI score compared to those with <1500 mg/day sodium intake; stratification by sex and age revealed that in both females and males high sodium intake (≥1900 mg/day) was also inversely associated with SAI compared to low sodium intake (<1300 mg/day); this association was more evident among older males (high vs. low: >70-males/>70-females, –90% vs. 82.5%, $p < 0.001$) and overweight/obese participants (high vs. low: overweight/obese/normal weight, –59% vs. –35%, $p's < 0.05$).

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CONCLUSIONS: Daily sodium intake of <1500 mg seems to be a key factor for achieving successful aging. Public health nutrition policies should enforce their actions on reducing sodium intake by people of all ages.

Keywords: Sodium, salt, successful aging, middle-aged adults, older adults, Mediterranean

1. Introduction

Numerous studies have been carried out to identify the effects of salt or sodium intake on human health. High sodium intake has been associated with elevated risk for hypertension [1], stroke [2], cardiovascular events [3], cancer progression [4] and mortality from all-causes and cardiovascular disease (CVD) [5]. Due to the adverse impact of high sodium intake (defined as >2 grams/day, equivalent to 5 g of salt/day) on human health, it has been supported that sodium reduction has been identified as one of the most cost-effective measures countries can take to improve population health outcomes [6]. According to the American Heart Association, a sodium intake reduction of 1,000 mg a day can improve blood pressure and heart health [7].

Successful aging is a complex phenomenon and its definition remains difficult. A common definition proposed and developed, in the 1990s, by Row and Kahn included absence of disease and disability, maintenance of cognitive function and physical activity and engagement in social activities [8]. Nowadays, though, gerontologists have gone way past this model, suggesting that success means finding ways to cope with potential illnesses and other challenges with medication, lifestyle and nutrition modifications. For example, adherence to a healthy dietary pattern and physical activity could lead to lower functional and physical disabilities– both components of successful aging- in older ages [9].

Yet, there are very few studies investigating the association between lower and higher sodium intake on successful aging. This association could be supported by centenarian studies, which have found that nutritional restriction, including reduction in sodium intake could possibly indicate that this dietary behavior might also be responsible for their extended longevity [10]. Salt (sodium chloride) has deep roots in Greek culture since it was the only way to preserve and add flavor to the foods in the past years. Many other nutritional factors commonly seen in the Mediterranean region (i.e., exclusive culinary use of olive oil or increased intake of whole grain products) are already associated with successful aging [11, 12]. Thus, the aim of the present work was to evaluate the association of at least 1500 mg and <1500 mg daily sodium intake, based on the content of sodium present in the food groups and foods consumed more among Greeks, without taking into account table salt or salt from processed foods, with successful aging, among middle aged and older (i.e., >50 years old) individuals participating in the MEDIS (MEDiterranean Islands Study) and ATTICA epidemiological studies, conducted in the Mediterranean region.

2. Materials and methods

2.1. Design

Two cross-sectional, population-based, large-scale epidemiologic studies, i.e., the ATTICA [13] and the MEDIS [14] conducted in Greece, were combined for the purposes of the present work and selected variables were harmonized following standard procedures.

2.2. Setting

In brief, the ATTICA study is a population-based, observational survey conducted in Athens greater area, Greece. Baseline evaluation was performed during 2001–2002 and, the follow-up during 2012. Eligible participants (overall sample $n = 3{,}042$) where over the age of 18, free of CVD and cancer, as assessed through a detailed clinical evaluation by the study's physicians. In addition, the MEDIS study is also a population-based, longitudinal, observational survey that enrolled older people, i.e., 65+ years (overall sample $n = 3{,}138$) from 26 Mediterranean islands of 5 countries, during 2005-2017; individuals who resided in assisted-living centers, had a clinical history of CVD or cancer or had left the island for a considerable period of time during their life (i.e., >5 years) were excluded from the sampling. Further details of the studies may find elsewhere [13, 14].

2.3. Sample

From the original sample of the ATTICA study, a sub-group of $n = 1{,}128$ participants, aged >50 years old, were studied for the purposes of the present work. In addition, a sub-group of $n = 2{,}221$ participants from the MEDIS study, living in the 20 Greek islands, were also studied here. We studied only participants from Greek islands in order to avoid potential confounding effect of cross-cultural influences. For both studies, a group of trained health scientists (cardiologists, general practitioners, dietitians, and nurses) collected all information using standard, validated questionnaires and clinical procedures [13, 14].

2.4. *Ethical standards disclosure*

The ATTICA study was approved by the Bioethics Committee of Cardiology Department, University of Athens Medical School and was carried out in accordance with the Declaration of Helsinki (1989) of the World Medical Association. The MEDIS study was approved by the Institutional Ethics Board of Harokopio University (16/19-12-2006) and followed the ethical recommendations of the World Medical Association (52nd WMA General Assembly, Edinburgh, Scotland, October 2000). In both studies, participants were informed of the study's aims and procedures and provided written informed consent for their participation prior to enrollment.

2.5. *Measurements*

2.5.1. *Socio-demographic characteristics*

The socio-demographic characteristics studied here were age (years), sex (male/female), place of residence (Athens area or Greek islands) and education level (measured as total years of school). Smoking status was evaluated following standard procedures for observational studies. Particularly, current smokers were defined as those who smoked at least one cigarette or any type of tobacco per day at the time of the interview. Former smokers were defined as those who previously smoked but had quit within the previous year. Current and former smokers were combined as ever smokers. The remaining participants were defined as nonsmokers.

2.5.2. *Physical activity levels*

Physical activity was evaluated in metabolic equivalent (MET) minutes per week, using the shortened, translated and validated in Greek version of the self-reported International Physical Activity Questionnaire (IPAQ) [15]. Those who reported at least 3 MET-minutes per week were classified as physically active. All others were defined as physically inactive.

2.5.3. *Dietary habits assessment*

The evaluation of dietary habits in the ATTICA study was based on a semi-quantitative food-frequency questionnaire (FFQ) that was provided by the Unit of Nutrition of Athens University Medical School [16]. Dietary habits in the MEDIS study were assessed through a similar semi-quantitative, validated and reproducible FFQ [17]. In both studies, participants were requested to report the average intake (per week or per day) of several food items and beverages that they have been consuming (during the last 12 months). Information regarding frequency of all food groups and beverages, as well as fast-food consumption was collected, based on "*daily*", "*weekly*" (i.e., 1–2, 3–5 times per week), "*monthly*" basis (i.e., 2–3 times per month), "*rare*", or "*never*". Sodium intake was measured based on the USDA (United States Department of Agriculture) Food Composition database [18], as the total amount of sodium contained in each food category. The food categories and foods measured in this database were those that Greeks tend to consume more. Data on food consumption as reported in the FFQs are converted into sodium intakes estimated from the standardized food tables. Since the 2018 American Heart Association guidelines suggest that daily sodium intake should not exceed 1500 mg for most adults [19], a first categorization of the study's participants was based on this threshold. However, to better understand the association between sodium intake and successful aging, sodium consumption was further categorized as "*Low*" when total daily sodium intake did not exceed 1300 mg, "*Medium*" when daily sodium intake was between 1300–1900 mg and "*High*" when daily sodium intake was at least 1900 mg. The MedDietScore (range 0–55) evaluated the level of adherence to the Mediterranean diet [20].

2.5.4. *Anthropometric and clinical characteristics*

Weight and height were measured using standard procedures, and Body Mass Index (BMI) (in kg/m^2) was then calculated. Overweight was defined as BMI between 25 and 29.9 kg/m^2, while obesity was defined as BMI $\geq$ 30 kg/m^2. Type 2 diabetes mellitus (T2DM) was determined by measuring fasting plasma glucose and in accordance with the American Diabetes Association diagnostic criteria (fasting blood glucose >126 mg/dL or use of antidiabetic medication) [21]. Participants who had blood pressure levels >140/90 mmHg or who were administered antihypertensive medications were classified as hypertensive. Fasting blood lipids levels were also recorded. Hypercholesterolemia was defined as total serum cholesterol levels >200 mg/dL or the use of lipid-lowering agents according to the National Cholesterol Education Program Adult Treatment Panel III guidelines [22]. The coefficient of variation for the blood measurements was less than 5%.

2.5.5. *Successful aging index*

A Successful Aging Index (SAI), ranging from 0 to 10 (higher score indicates higher successful aging), which has been previously developed and validated [14], using 10 attributes that reflect and have been found associated with the aging process, was applied for assessing successful ageing. The index encompasses health-related social-, lifestyle- and clinical factors, including: 1) education status, 2) financial status, 3) physical activity status, 4) BMI, 5) depression (symptoms of depression during the past month were assessed using the validated Greek translation of the shortened, self-report Geriatric Depression Scale (GDS) [23]), 6) participation in social activities with friends, 7) participation in social activities with family, 8) number of yearly excursions/outdoor activities, 9) total number of clinical CVD risk factors as a cumulative score of overall cardiometabolic risk (i.e., history of hypertension, diabetes, hypercholesterolemia and obesity) and 10) level of adherence to the Mediterranean diet [14].

2.6. *Statistical analysis*

Continuous variables are presented as mean ± standard de-viation (SD) and categorical variables as frequencies. Associations between categorical variables and participants' sodium intake group (i.e., low or high sodium intake) were evaluated using the chi-squared test, while associations between continuous variables and groups (i.e., <1500 mg or ≥1500 mg daily sodium intake) were performed using the independent samples *t*-test. Spearman rho correlation coefficient was used to evaluate relationships between sodium intake (as a continuous variable) and BMI (kg/m^2), age (years), on SAI score (range 0–10). Linear regression analysis was used to evaluate the association between sodium intake (evaluated as a categorical variable, "*Low*", i.e., <1300 mg, "*Medium*", i.e., 1300–1900 mg, and "*High*", i.e., ≥1900 mg daily sodium intake) (independent variable) and the SAI score (outcome), after adjusting for various participants' characteristics (i.e., age, sex, smoking habits and energy intake). Similar analyses were conducted stratified by sex (female, male), BMI (<25 kg/m^2, ≥25 kg/m^2) and age (<70, 70+ years). The rationale of BMI stratification was the fact that older adults are vulnerable to malnutrition [24] and low level of sodium intake may be associated with inadequate caloric intake. Results are presented as unstandardized beta coefficients ±standard error, 95% confidence interval and *p*-value. Linearity of models' fitting was tested through the scatter plots of standardised residuals against fitted values; normality of regression residuals was evaluated through P-P plots; dependency was tested using the Durbin-Watson test and homoscedacity using the Variance Inflation Index (value <4 suggests lack of heteroscedacity). STATA (M. Psarros & Associates, Sparti, Greece) software version 13 was used for all calculations.

3. Results

Various socio-demographic, lifestyle and clinical characteristics of the MEDIS and ATTICA study participants based on the amount of sodium intake and sex are presented in Table 1. Both male and female participants with ≥1500 mg daily sodium intake had lower SAI levels, as compared to those with <1500 mg daily sodium intake ($p < 0.001$). In particular, individuals who consumed ≥1500 mg/d sodium had 20.2% lower SAI score, as compared to those who consumed <1500 mg/d. More precisely, female and male participants with <1500 mg daily sodium intake had higher level of SAI compared to those females and males with ≥1500 mg daily sodium intake (SAI, females: <1500 mg/day vs. ≥1500 mg/day: 3.6 ± 0.8 vs. 2.3 ± 1.3, $p < 0.001$, SAI, males: <1500 mg/day vs. ≥1500 mg/day: 3.6 ± 0.6 vs. 3.0 ± 1.3, $p < 0.001$). The later was also supported by the significant linear correlation observed between sodium intake and SAI score (Spearman rho = –0.336, $p < 0.001$). Further trend-analysis revealed that the correlation between sodium intake and SAI was not parabolic, exponential or logarithmic (all *p*'*s* > *0.05*). Moreover, participants with ≥1500 mg daily sodium intake were more likely to have hypertension, diabetes, higher BMI, and to

Table 1

Socio-demographic, lifestyle and clinical characteristics of the ATTICA ($n = 1{,}128$) and MEDIS ($n = 2{,}221$) study's participants based on the daily sodium intake (i.e., <1500 mg, ≥1500 mg) and sex (i.e., female, male)

	All participants	Sodium intake <1500 mg/day		Sodium intake ≥1500 mg/day		*p*	*p*[1]	*p*[2]
		Female	Male	Female	Male			
N	3349	623	613	975	1138			
Age (yrs)	69 ± 10	61 ± 9.0	61 ± 9.0	73 ± 7.0	74 ± 7.0	*<0.001*	*<0.001*	*<0.001*
Ever smoking n (%yes)	1358 (43)	217 (35)	390 (64)	86 (9)	665 (65)	*<0.001*	*<0.001*	*0.96*
Current smoking n (%yes)	788 (24)	180 (29)	235 (38)	57 (6)	316 (28)	*<0.001*	*<0.001*	*<0.001*
Physically active n (%yes)	1372 (41)	237 (38)	278 (45)	350 (36)	507 (45)	*0.34*	*0.45*	*0.88*
Years of education (yrs)	8.0 ± 4.2	9.6 ± 4.1	6.0 ± 3.5	10 ± 4.0	7.1 ± 4.0	*0.001*	*0.001*	*0.001*
Financial status (good or very good, n %)	804 (24)	237 (38)	312 (51)	117 (12)	216 (19)	*<0.001*	*<0.001*	*<0.001*
Participation in family activities (per week)	1.7 ± 1.1	1.5 ± 1.0	2.0 ± 1.3	1.7 ± 1.0	1.8 ± 1.1	*0.91*	*0.35*	*0.12*
Participation in social activities (per week)	2.4 ± 1.5	1.7 ± 1.4	1.9 ± 1.3	1.8 ± 1.3	2.8 ± 1.6	*0.29*	*0.27*	*<0.001*
Participation in excursions, outdoor activities (per year)	1.5 ± 1.0	1.0 ± 0.8	1.4 ± 0.8	1.4 ± 1.0	1.6 ± 1.2	*0.016*	*0.22*	*0.01*
Energy intake (kcal/day)	1766 ± 738	2075 ± 1055	2256 ± 1021	1625 ± 517	1618 ± 537	*<0.001*	*<0.001*	*<0.001*
MedDietScore (0–55)	29 ± 7.0	24 ± 5.9	23 ± 6.5	33 ± 5.1	33 ± 4.9	*<0.001*	*<0.001*	*<0.001*
Geriatric Depression Scale (0–15)	3.0 ± 2.5	1.6 ± 3.3	1.8 ± 2.9	3.6 ± 4.0	2.4 ± 3.1	*0.14*	*0.76*	*<0.001*
Cumulative CVD risk factors (0–4)	1.6 ± 1.1	1.4 ± 1.0	1.3 ± 1.0	1.9 ± 1.0	1.6 ± 1.0	*<0.001*	*<0.001*	*<0.001*
Hypertension n (%yes)	1881 (56)	282 (45)	233 (38)	669 (69)	697 (61)	*<0.001*	*<0.001*	*0.001*
Diabetes n (%yes)	696 (21)	102 (16)	103 (17)	210 (22)	281 (25)	*<0.001*	*0.012*	*<0.001*
Hypercholesterolemia n (%yes)	1747 (52)	358 (58)	319 (52)	564 (58)	506 (45)	*0.03*	*0.92*	*0.005*
Obesity n (%yes)	962 (29)	152 (24)	151 (25)	372 (38)	287 (25)	*<0.001*	*<0.001*	*0.82*
Body Mass Index (kg/m2)	27.7 ± 4.0	26.3 ± 4.8	27.5 ± 3.7	29.2 ± 5.0	28.5 ± 3.9	*<0.001*	*<0.001*	*0.34*
Successful Aging Index (0–10)	3.1 ± 1.2	3.6 ± 0.8	3.6 ± 0.6	2.3 ± 1.3	3.0 ± 1.3	*<0.001*	*<0.001*	*<0.001*

Values are presented as frequencies (percent) or mean value ± standard deviation. *p*-values derived from Students' *t*-test for continuous variables or the chi-square test for the categorical variables. *P*-value: for <1500 mg vs ≥1500 mg daily sodium intake, p^1: for females of <1500 mg vs ≥1500 mg daily sodium intake, p^2: for males of <1500 mg vs ≥1500 mg daily sodium intake, BMI = body mass index; SAI = successful aging index; CVD: cardiovascular disease.

Table 2
Results from linear regression models that evaluated the association of sodium intake categories on successful aging (outcome), among ATTICA ($n = 1{,}128$) and MEDIS ($n = 2{,}221$) study participants, based on sex (female, male)

	b	SE	95% CI	R^2	*p*
All participants					
Sodium intake					
*Medium vs. Low**	–0.921	0.123	–1.162, –0.679	0.195	*<0.001*
*High vs. Low**	–1.880	0.112	–2.101, –1.659	0.502	*<0.001*
Interaction sodium intake by sex	0.447	0.51	0.348, 0.546	0.133	*<0.001*
Interaction sodium intake by age	0.028	0.003	0.022, 0.034	0.147	*<0.001*
Females, age <70 yrs					
Sodium intake					
*Medium vs. Low***	–1.141	0.144	–1.426, –0.856	0.286	*<0.001*
*High vs. Low***	–2.151	0.121	–2.389, –1.912	0.639	*<0.001*
Females, age >70 yrs					
Sodium intake					
*Medium vs. Low***	–1.286	0.467	–2.211, –0.362	0.085	*0.007*
*High vs. Low***	–2.560	0.460	–3.466, –1.653	0.173	*<0.001*
Males, age <70 years					
Sodium intake					
*Medium vs. Low***	–0.767	0.097	–0.958, –0.575	0.203	*<0.001*
*High vs. Low***	–1.406	0.117	–1.635, –1.176	0.421	*<0.001*
Males, age > 70 years					
Sodium intake					
*Medium vs. Low***	–1.322	0.517	–2.341, –0.303	0.042	*0.01*
*High vs. Low***	–2.790	0.542	–4.173, –2.037	0.137	*<0.001*

Low: <1300 mg daily sodium intake, Medium: 1300–1900 mg daily sodium intake, High: ≥1900 mg daily sodium intake. *Models are adjusted for age, sex, smoking and energy intake. **Models are adjusted for smoking and energy intake. Results are presented as b and SE: Unstandardized b coefficients, Standard Error, their 95% CI: Confidence Interval, R-square and *p-value*.

adhere to the Mediterranean diet, but were less likely to be or had been smokers, as compared to participants with <1500 mg daily sodium intake (all p's < 0.001). Further information about participants' characteristics by sodium intake group is presented in Table 1.

To further evaluate the research hypothesis, multiple linear regression analysis was applied. Moreover, since the interaction between sodium intake and sex, as well as age, was highly significant (p's for interaction <0.001), analyses were also stratified by sex and age. As shown in Table 2, after adjusting for age, sex, smoking habits and energy intake, it was revealed that compared to low sodium consumers (<1300 mg/d), participants who had medium daily sodium intake (1300–1900 mg/d) had 30% on average lower SAI score and those with high daily sodium intake (≥1900 mg/d) had 60.5% on average lower SAI score. Similar results were observed when the analysis was stratified by age and sex, with the association between high sodium intake and SAI be more evident among older females and males (females, >70 years/females, <70 years old, 82.5% vs 69% on average lower SAI score, p's < 0.001) compared to females with low daily sodium intake, while older males over 70 years with high daily sodium intake had 90% on average lower SAI score ($p < 0.001$), compared to males with low daily sodium intake. No significant difference was observed on SAI levels between the participants of the two studies [mean SAI score: 2.8 ± 0.9 vs. 2.6 ± 0.8 for ATTICA and MEDIS study respectively, $p = 0.78$]. Moreover, the aforementioned significant, inverse effect of sodium intake on SAI was observed in both the ATTICA and the MEDIS study samples, separately (p's < 0.001).

A significant interaction was also observed between sodium intake and BMI on SAI (*p for interaction <0.001*). Therefore, data analysis was further stratified by BMI level (i.e., <25 kg/m^2 and ≥25 kg/m^2) (Table 3). However, since BMI level was part of SAI, the analyses were performed excluding BMI from the calculation of SAI. It was revealed that compared to low sodium consumers, normal weight and overweight/obese participants with medium daily sodium intake had 23% ($p = 0.003$) and 28% ($p < 0.001$) on average lower modified SAI score respectively. Accordingly, normal weight and overweight/obese participants with high daily sodium intake had 35% ($p < 0.001$) and 59% ($p = 0.008$) on average, respectively, lower modified SAI score

Table 3

Results from linear regression models that evaluated the association between sodium intake categories and successful aging index (outcome)* based on BMI status (<25 kg/m^2, ≥25 kg/m^2) and sex, among ATTICA (n = 1,1128) and MEDIS (n = 2,221) study participants

		b	SE	95% CI	R^2	p
<25 kg/m^2	*Overall* † *(n = 750)*					
	Medium vs. Low	–0.729	0.243	–1.209, –0.250	0.076	*0.003*
	High vs. Low	–1.117	0.188	–0.269, 0.195	0.441	*<0.001*
	Females ‡ *(n = 388)*					
	Medium vs. Low	–0.317	0.328	–0.971, 0.336	0.253	*0.336*
	High vs. Low	–1.005	0.237	–1.476, –0.534	0.575	*<0.001*
	Males‡ *(n = 362)*					
	Medium vs. Low	–0.909	0.350	–1.602, –0.216	0.076	*0.01*
	High vs. Low	–1.134	0.305	–1.739, –0.529	0.339	*<0.001*
≥25 kg/m^2	*Overall* † *(n = 2,536)*					
	Medium vs. Low	–0.898	0.134	–1.162, –0.633	0.246	*<0.001*
	High vs. Low	–1.861	0.124	–2.104, –1.617	0.539	*0.008*
	Females‡ *(n = 1,178)*					
	Medium vs. Low	–0.904	0.220	–1.339, –0.469	0.279	*<0.001*
	High vs. Low	–2.233	0.159	–2.546, –1.920	0.579	*<0.001*
	Males‡ *(n = 1,358)*					
	Medium vs. Low	–0.877	0.172	–1.215, –0.538	0.201	*<0.001*
	High vs. Low	–1.500	0.193	–0.051, 0.400	0.422	*<0.001*

Low: <1300 mg daily sodium intake, Medium: 1300–1900 mg daily sodium intake, High: ≥1900 mg daily sodium intake. Results are presented as b and SE: Unstandardized b coefficients, Standard Error, their 95% CI: Confidence Interval and p-value. *BMI was excluded from the SAI index. †Adjusted for age, sex and smoking habits. ‡Adjusted for age and smoking habits.

compared to normal weight and overweight/obese participants with low daily sodium intake. Moreover, high sodium intake was also inversely associated with modified SAI in females and males irrespective of their body weight status. The above-mentioned association was more evident among overweight/obese females with high daily sodium intake who had 70% on average lower modified SAI score *(p < 0.001)* compared with overweight/obese females with low daily sodium intake.

4. Discussion

The present study aimed to investigate the association between sodium consumption and successful aging among middle-aged and older adults living in the Mediterranean region. Based on the observed results, ≥1500 mg daily sodium intake was associated with lower level of successful aging, i.e., –20.2% on average SAI levels, independently of participants age, sex, smoking habits and energy intake compared <1500 mg daily sodium intake. The association seemed to be more evident among older males with ≥1900 mg daily sodium intake compared to females, as well as among overweight/obese females with ≥1900 mg daily sodium intake. In addition, participants with ≥1500 mg daily sodium intake were more likely to have and other cardiometabolic disorders, i.e., hypertension, diabetes and higher BMI, as compared to participants with <1500 mg/day sodium intake. According to World Health Organization (WHO) fact sheets, most people consume too much salt, on average 9–12 g per day, or around twice the recommended maximum level of intake [25]. Taking into account that projections shows that by 2050 nearly 1 out of 6 people in the world will be over 65, and near to half a billion will be older than 80 [26], the presented results should be taken into account from a public health point of view.

Increasing production of processed food, rapid urbanization, and changing lifestyles are transforming dietary patterns. An already established factor affecting lifespan is nutrition, that also seems to be of considerable importance in the aging process. Most sodium is consumed in the form of salt (i.e., sodium chloride) [27], and comes from processed foods, while a smaller amount comes from naturally occurring sodium in unprocessed foods and from discretionary sodium added during cooking or eating [28, 29]. High salt consumption has been reported to be more common among males compared to females, in various parts of the world, while males very often exceed more the minimum physiological needs compared to females [30].

It has been observed that the past decades both younger and older adults have altered their dietary habits, adopting less healthy nutritional behaviors, closely to westernized diets [31]. Moreover, as people age the sense of taste starts to decline. It has been observed that of the four taste sensations, i.e., salty, bitter, sweet and sour; these of sweet and salty are often the first that decline and as a consequence older adults often over-sweet and over-salt their food. In addition, older adults losing the ability to taste certain foods, turn to tastier (i.e., salty) foods [32]. This change in taste could also be the result of various medications that usually many older people take [33].

Based on the Elderly Nutrition Program that explored how food preferences varied depending on sex, it was found that older males were significantly more likely to prefer deli meats, meat, legumes, canned fruit and ethnic foods compared to older females [34]. This is in line with our findings, suggesting that more males consume foods that are rich in sodium. As supported by Pedro and Nunes (2007), high salt quantities are used in seafood preservation and even some of the most careful and health promoting seafood preservation tactics include the use of salt [35]. It is worthwhile to note that Mediterranean diet is a dietary pattern characterized, among others, by daily consumption of bread and cereals and a moderate consumption of fish and fish products [36], i.e., foods with high sodium content, potentially explaining the high percentage of people belonging to "high" sodium intake group found in the present work, as well as, among the Mediterranean population. This is in line with the considerations of Estruch and Salas-Salvadó (2013) regarding the potentially negative effects of the Mediterranean diet, which can be attributed to limited factors, mainly to high sodium intake [37]. Dietary Approaches to Stop Hypertension (DASH) diet has been proposed as a dietary way to improve blood pressure levels as well as many cardiovascular disease risk factors [38], since it emphasizes in the reduction of the sodium intake. Although restricting or reducing the consumption of foods high in sodium by nature has been considered difficult, limiting the additional sodium intake is considered and immediate necessity. However, herbs and spices could be used to replace sodium in cooking.

To the best of our knowledge, this is the first study evaluating salt intake as sodium consumption in relation to successful aging in middle-aged and older Mediterranean people. As to this effect, two population-based studies were applied, it is anticipated that the effects of population bias have been minimized and the external validity of findings is consequently augmented. However, the present study has some limitations. The observational nature of the cross-sectional design does not allow for causal associations to be drawn. Moreover, sodium intake was evaluated based on the content of sodium present in the food groups and foods consumed by the participants according to USDA and then based on these foods' frequency consumption. Specific added table salt or processed foods were not accounted for in the present analyses due to the lack of relevant information. Data on urinary/plasma sodium or potassium or renal function were also not available; all of them may confound the outcome measures. Dietary habits were measured once based on food frequency questionnaires and thus recall bias may exist. Finally, successful aging is characterized by low probability of disease and related disabilities, high cognitive and physical functional capacity, and active engagement with life; in the present study, successful aging was not evaluated through cognitive behavior, as well as mobility and functionality of the participants, and this may constitute as another limitation; however the successful aging index, used in this work, has been already validated [14].

5. Conclusions

Several authorities and international organizations have already raised concerns about the increased use of sodium intake, especially among more vulnerable populations [40]. As supported by the results of the present work, $\geq$1500 mg daily sodium intake was independently associated with lower successful aging, i.e., –20.2% on average SAI levels, while this association was more evident among older males as well as overweigh/obese females with $\geq$1900 mg daily sodium intake. The reported results deserve further attention from a public health point of view and in particular, health and nutrition policies should enforce their actions on reducing sodium intake by people of all ages.

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Conflict of interest

None.

Authorship

Conceptualization, D.P. and A.F.; methodology, D.P.; formal analysis, A.F.; writing—original draft preparation, A.F.; writing—review and editing, E.C., N.N., L.S., C.C, L.R., E.P., AL.M., S.T.; supervision, D.P.; project administration, D.P.

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