Seasonal and Meteorological Associations with Depressive Symptoms in Older Adults: A Geo-Epidemiological Study

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Abstract

Background: Given increased social and physiological vulnerabilities, older adults may be particularly susceptible to environmental influences on mood. Whereas the impact of season on mood is well described for adults, studies rarely extend to elders or include objective weather data. We investigated the impact of seasonality and meteorological factors on risk of current depressive symptoms in older adults.

Methods: We used data on 8,027 participants from the first wave of The Irish Longitudinal Study of Ageing, a population-representative cohort of adults aged 50+. Depressive symptoms were recorded using the Center for Epidemiological Studies Depression Scale. Season was defined according to the World Meteorological Organisation. Data on climate over the preceding thirty years, and temperature and rain over the preceding month, were provided by the Irish Meteorological Service and linked using Geographic Information Systems techniques to participant's geo-coded locations at a resolution of one kilometre.

Results: The highest levels of depressive symptoms were reported in Winter and the lowest in Spring (mean 6.56 [CI95% 6.09, 7.04] vs. 5.81 [CI95%: 5.40, 6.22]). In fully adjusted linear regression models, participants living in areas with higher levels of rainfall in the preceding and/or current calendar month had greater depressive symptoms (0.04 *SE* 0.02; p=0.039 per 10mm additional rainfall per month) while those living in areas with sunnier climates had fewer depressive symptoms (-2.67 *SE* 0.88; p=0.003 for every additional hour of average annual daily sunshine).

Limitations: This was a cross-sectional analysis thus causality cannot be inferred; monthly rain and temperature averages were available only on a calendar month basis while monthly local levels of sunshine data were not available.

Conclusions: Environmental cues may influence mood in older adults and thus have relevance for the recognition and treatment of depression in this age group.

Introduction

Rosenthal's seminal description of Seasonal Affective Disorder confirmed a place in modern psychiatric thinking for hypotheses linking affective state and light [1]. In the intervening decades, accumulating evidence ranging in scope from the basic neurosciences [2] to population-based observational studies [3], has continued to point to the meteorological determinants of mood.

Depressive symptoms are common, under-recognised and often inappropriately treated in older adults [4]. Older adults' mood may be particularly vulnerable to the effects of changing environmental stimuli owing to pragmatic considerations (e.g. reduced physical activity in winter months [5]) but also due to changing neurophysiology which accompanies ageing (e.g. altered circadian rhythms [6]). Much of the work investigating seasonality in the epidemiological literature however has not extended to include older age groups [7] or has focused on particular age extremes [8]. In addition, clinical research on Bright Light Treatment in older adults has largely been based in institutionalized or tertiary care settings, hence limiting the generalisability of results to the wider older population [9].

In tandem with the ageing demographic, climate change is one of the most pressing public health concerns of our time [10]. Despite this, investigation of the impact of long-term climate (i.e. the long-term or thirty year prevailing weather conditions) on mood has received little attention. Rather, prior research has often relied on self-reported seasonality of mood or season alone, eschewing the use of objective weather variables [11,12]. Interestingly, a recent study from Spain using local objective climate data found that those living in areas with the highest temperatures, least rain and longest duration of sunshine were most likely to be become depressed [13] while a prospective study noted little relationship between objective weather data and mood [14]. The relationship between weather and mood is thus complex and competing psychosocial explanations must be explored. Furthermore, regional level weather data may not accurately reflect the weather to which the individual is exposed, as even within a small country such as Ireland there may be significant variations in local weather conditions [15,16]. The availability of objective weather data combined with the power of modern analytical geographical mapping tools, now allows linkage of individual level weather conditions to an individual's mental health.

Based on the island of Ireland, located in a temperate region at 53 N bound by the Irish Sea to the East and the Atlantic Ocean to the West and South, we sought to investigate the impact of seasonality on risk of current depressive symptoms in a large cohort of older adults, while controlling for a wide array of important confounders. We additionally wished to explore the impact of accurately mapped (at a resolution of 1km) objective state-compiled records of climate and proximal (within one month of interview) meteorological data.

Methods

Sample

We used data from first wave of The Irish Longitudinal Study on Ageing (TILDA) which was collected from late 2009 to early 2011. TILDA contains a nationally representative sample of 8,175 people aged fifty and above who are resident in Ireland. The study covers the Republic of Ireland only and not Northern Ireland. As part of the sampling procedure the addresses of all participants included in the study were geo-coded. A detailed description of the survey methodology and the weighting scheme for TILDA has been published [17]. Researchers at TILDA used the 'RANSAM' system [18] to construct the sample. Under the RANSAM system, all residential addresses in Ireland are grouped into 3155 geographic clusters which range in size from 500 to 1180 addresses. 640 of these clusters were selected, stratified by socioeconomic group and geography so as to maintain a nationally representative sample based on the most recent census taken before TILDA data collection. Given a target sample size of 8000 and a target response rate of 60%, within each of the chosen clusters, 40 addresses were visited by field workers so as to ascertain whether anyone aged over 50 was living in the household and, if so, to invite the person(s) for interview. The overall response rate among randomly chosen eligible households was 62%. To eliminate potential bias due to differential participation by certain groups of people in TILDA, weights were constructed by comparing the number of sample members in each gender, age group (age 50-64, 65-74 and 75+) and educational attainment group (primary, secondary and tertiary) with the corresponding cell in the Quarterly National Household Survey from the Irish Central Statistics Office.

For our analysis, we used a sample of 8,027 participants who had complete information for the variables that we included in our models. 148 from the total of 8175 observations (or 2% of the sample) are omitted from the final working sample as they did not complete the CES-D questionnaire in the survey. However as discussed, we use the sampling weights calculated using the Quarterly National Household Survey so as to ensure our results are nationally representative relative to the joint distribution of educational attainment and age group in the overall population.

The 148 participants who did not answer the CES-D were older and had lower levels of education. To ensure that we used as many observations as possible, dummy variables indicating missing values were used in relation to use of medications (78 observations), exercise levels (75 observations), delayed recall tests (154 observations) and wealth (459 observations). Information was missing in relation to these variables due to the respondent's refusal to answer the relevant question or not knowing the answer. Our results do not change qualitatively when using complete cases only.

Ethical Standards

Trinity College Dublin Health Research Ethics Committee granted ethical approval for the study. Each participant provided written informed consent prior to enrolment in the study.

Data Collection

Interviewers carried out face–to-face interviews with respondents in their homes. The location of each TILDA respondent was geo-coded using Global Positioning System technology (Figure 1). Data was collected at a constant rate throughout late 2009 to early 2011. TILDA collected detailed information on many aspects of the respondents' lives such as economic circumstances, health (e.g. physical health, cognitive function, mental health, health service needs and usage) and other socio-demographic information.

Assessment of Depression

Levels of depressive symptoms over the previous week were recorded using The Center for Epidemiological Studies Depressions Scale (CES-D). Each question offers a four-point response scale with options ranging from, "Rarely or none of the time (less than 1 day)" to "All of the time (5-7 days)". This is a 20-item questionnaire, which produces a total score ranging from 0-60 and is validated for use in epidemiological populations [19]. Higher scores indicate greater levels of depressive symptoms. A cut-off score of sixteen on the CES-D has been shown to have high levels of sensitivity and specificity for clinical depression [20].

Season

When controlling for season at date of interview, we used the World Meteorological Organisation's (WMO) definition of season (i.e. summer starting on the 1st of June).

Weather Data

We used the Irish Meteorological Service's gridded data which consists of meteorological data for a national grid of points 1km apart. The gridded data are derived using data from weather stations extrapolated to the grid points using meteorological models. Monthly averages are available for 2009-2011 in relation to rainfall and temperature. Given that monthly data was available at the *calendar* month level only, in analysis relating to participants interviewed before 15th day of each calendar month, we averaged the weather data of the calendar month preceding the date of interview and the calendar month of interview itself. For those participants interviewed after the 15th, weather parameters from the calendar month of interview itself were used. Climate data (i.e. thirty year weather averages as defined by the World Meteorological Organization) were available in relation to sunshine, rainfall and temperature.

Co-Variates

Participants were asked to report their age, sex, level of education achieved (primary/none, secondary and tertiary), marital status and with whom, if anyone, they were currently living. Self-reported doctor-diagnosed chronic conditions (including diabetes, lung disease, asthma, arthritis, osteoporosis, cancer, peptic ulcer, hip fracture) were summed to give an indication of age-related chronic physical co-morbidities. Smoking was coded as 'current', 'past' or 'never'. Self-reported levels of physical activity were measured using the International Physical Activity Questionnaire - Short Form [21]. Validated cut-points were used to classify the population into three levels of physical activity: 'Low', 'Moderate' and 'High'.

Medications were coded using the World Health Organization's Anatomical Therapeutic Chemical (ATC) codes [22]. Anti-depressant use was identified where the first four digits of the ATC code were "N06A". Antidepressant treatment (yes/no) was coded and participants taking five or more regular medications were defined as subject to polypharmacy (yes/no).

Given the age profile of our cohort a measure of cognition was included in this analysis - Delayed Word Recall (DWR) score. In this test ten common words are presented orally which the participant is then asked to remember [23]. The number of words recalled after a short delay is recorded with higher scores indicating better recall.

In our analysis we also included a categorical variable indicating self-assessed wealth, based on housing wealth which is the major component of individual wealth in Ireland [24]. Furthermore we used a series of dummy variables in our models to account for residency in one of the 34 administrative regions of the Republic of Ireland.

Geographic Information System Analysis

The analysis utilised a gridded data set of over 84,000 Irish Meteorological Service data points distributed throughout Ireland. The points are generated from data obtained from a network of weather station locations. Through geostatistical methods, the data generated from these stations is processed to produce the gridded dataset for Ireland at 1km^2 resolution.

The Irish Meteorological Service data were inputted into a Geographic Information System (ArcGIS version 10.1) and subsequently matched through a point distance calculation with the network of TILDA respondent geo-coded addresses. The resulting output matches Irish Meteorological Service data points that are less than 1km in distance from the address of each TILDA respondent.

Statistical Analysis

To eliminate potential bias due to differential participation by certain groups of people in TILDA, weights derived from the Irish Central Statistics Office's Quarterly National Household Survey were used so as to maintain a nationally representative sample in relation to gender, age and educational attainment. All statistical analysis was weighted and estimated using STATA version 12.1. We estimated linear regression models using ordinary least squares to determine the effect of season, weather and climate on the CES-D scale. We controlled for a number of possibly confounding factors: use of anti-depressant medication, smoking history, age, gender, degree of urbanisation of local area, highest educational level attained, living arrangements, marital status, cognitive function, level of physical activity, co-morbidities, employment status and housing wealth (to proxy for overall wealth). To account for potential regional differences in depression scores between the administrative areas we also controlled for regional fixed effects by using dummy variables to control for the 34 different administrative areas within Ireland. Thus our weather variables are not merely picking up regional fixed effects on depressive symptoms.

Results

Of 8,027 participants, the average age was 63.91(*SD*9.76) and 51.94% were female. The average CES-D score was 6.01 (*SD*7.2), 10% of the sample scored above the screening cut-off for Major Depressive Disorder (i.e. >=16). 6.87% of the sample were taking anti-depressants (5.14% among those with CES-D <16 and 20.93% among those with CES-D >=16). As displayed in Table 1, just under half of the sample lived in a rural area, about one third of people were classified as being non-active physically and 22.64% of the sample had no history of chronic disease. There were no significant differences in depressive symptoms between rural and urban areas.

Table 2 shows that the average CES-D score varied by season without controlling for other factors. For those interviewed in winter months, CES-D scores were higher compared to those interviewed at other times of the year.

Although Ireland is a small country of just 84,421km^2, Table 3 shows that there was considerable variation in weather and climate conditions by location in Ireland. For example, those living in western counties experience about one third more rainfall than those living in eastern counties. The differences in sunshine and temperature are less stark for different areas of the country but are nonetheless significant. Furthermore, there is seasonal variation in monthly temperature and rainfall in Ireland with an average of 123.58mm of rain in winter, reducing to 66.66 mm in Spring; and an average temperature of 5.53 °C in winter rising to an average of 13.56 °C in Autumn.

Table 4 shows the estimates of our different models for the independent variables of interest (full co-efficient displayed in Supplementary Tables 1a-c). Model A shows the association between season and CES-D with winter being the reference category. Those interviewed in spring or summer scored between 0.5 and 0.7 units lower on the CES-D than those interviewed in Winter. Those interviewed in Autumn scored even lower, around 0.83

lower on the CES-D than someone interviewed in Winter. These associations are statistically significant at the 10%, 5% and 1% levels in relation to Summer, Spring and Autumn interviews respectively.

Model B shows that average temperature in month of interview had no statistically significant effect on CES-D. However there was a statistically significant positive association at the 5% level between CES-D score and average rainfall levels in the respondent's locality in the month of their interview; if average monthly rainfall were 10mm greater in a local area, then CES-D scores rise by about 0.04 of a unit.

Model C shows the relationship between climate and CES-D. Long term average annual temperature and rainfall do not have a statistically significant effect on CES-D. Average annual daily hours of sunshine has a negative and statistically significant effect on CES-D. An increase in annual average daily sunshine by one hour would reduce CES-D by 2.7 units.

A sensitivity analysis (data not shown) was conducted to assess the potential differential effect of age on the impact of meteorological determinants of mood by repeating the analysis including an interaction term with age in each of the models; there was no evidence of an age gradient in the effects reported. A further sensitivity analysis investigating differential effects according to gender did not show any significant interactions (data not shown).

Discussion

In this large population-representative cohort of older adults, greater levels of current depressive symptoms are related to season and to local climate as mapped to a resolution of 1km of the respondent's home address. Specifically, older adults report the highest levels of depressive symptoms in winter, while those participants living in areas with longer-term higher levels of sunshine have fewer current depressive symptoms. We found a strong effect of annual sunshine on mood - an increase in annual average daily sunshine by one hour was associated with a decrease in current depressive symptoms as measured by the CES-D of 2.7 units. To put this magnitude into perspective one should consider that the difference in average daily sunshine between East coast and West coast counties in Ireland is about 0.4 hours per day; indicating that exposure to the climate on opposite coasts of Ireland may have a significant impact on mood in older adults over and above a wide array of potential confounders for which we also controlled - including socioeconomic factors.

Prevailing monthly weather conditions may also play a role in determining mood. A higher level of rain fall within the prior and/or current calendar month was associated with a greater number of depressive symptoms at the time of interview in this cohort: if average monthly rainfall were 10mm greater in a local area, then CES-D scores rose on average by 0.04 points. To put this effect into perspective one should consider that 10mm is around the same magnitude as the average difference in monthly rainfall between landlocked and eastern coastal counties in Ireland. Thus the size of the association between mood and rainfall is relatively small. However, despite these limitations given the seasonal pattern and relationships with climate averaged observed, we suggest that it is likely that at least some of the effect of monthly rainfall during the survey is inversely related to the effect of monthly sunshine which we could not observe.

Taken as a whole our findings are in keeping with much empirical research reporting a link between season and mood (Magnusson, 2000) including a study, now almost two decades old, which reported a small but positive association between mood and season in older adults in a community-based sample in the United Kingdom [25]. Our study adds to the epidemiological literature in this field, in particular given its focus on those aged over 50 - notably including a representative sample of the population aged 60+. Furthermore, to the best of our knowledge we are the first study to look at the effect of climate specifically in this age group. Our results however conflict with some prior studies in older adults [8,26]. The Leiden Study previously reported a null finding in relation to the relationship between mood and local weather in the over 85's and had the advantage of a longitudinal design [8]. However, the Leiden study focused solely on a select group of the oldest old (all of whom were born in the same year and lived in a single city in Holland), had a smaller sample size and did not assess the impact of long-term climate. A small non-representative, cross-sectional study investigating seasonality of psychiatric referrals in older adults to a catchment area in the UK, also reported that there were no significant relationships [26]. Such discrepancies in findings may be accounted for by differences in sample size, our use of a population representative sample or alternatively by our use of objective weather data mapped to the individual's location.

Given increased social and physiological vulnerabilities accompanying ageing, older adult's mood may be particularly susceptible to environmental influences, yet little evidence exists in relation to older age groups, particularly in epidemiological settings. Prior research has emphasised seasonality in younger cohorts [27] yet we did not find an attenuation in the observed effects across older age categories. Despite smaller numbers in the older age groups, we found a consistent pattern of associations suggesting that the importance of these environmental influences persists into old age and is not the preserve of the young. These results are in keeping with data showing treatment response beyond placebo in the use of

Bright Light Treatment in older adults with depression [28]. Indeed older adults may be the cohort which has most to gain from interventions such as Bright Light Therapy. Older patients may in particular benefit from these treatment options given the changes in pharmacokinetics that occur with ageing and the risks associated with polypharmacy and drug-drug interactions [29]. Despite this, under-utilisation of such treatments in depression persists [30]. Chronotherapeutic strategies are efficacious in treating even non-seasonal depression [31] including in older adults [28] and have been recommended by a Cochrane review in the use of sleep disorders in the aged – a common symptom of late-life depression [32].

Poorer photo-transduction may contribute to the disruption of circadian rhythm seen in many disorders associated with ageing, including dementia and affective disorders [33]. Ageing of the suprachiasmatic nucleus (SCN), or the ‘biological pacemaker’, may have a detrimental impact on mood in later life, while ageing of the anatomy of the eye may reduce the amount of light that reaches the retina e.g. due to cataracts (Ciarleglio et al., 2011). The combination of lower sensitivity and lower exposure to light in older adults may result in decreased downstream availability of neurotransmitters implicated in the monoamine hypothesis of depression, notably including those targeted by effective antidepressants e.g. serotonin and noradrenaline [2].

Reduced exposure to ultraviolet light may also lower production of Vitamin D. A light dependent vitamin, Vitamin D has seasonal peaks and troughs in its bioavailability and has previously been implicated in the pathogenesis and seasonality of depressive disorders [34] particularly in older adults. Additionally, a recent epigenetic-analysis - including comparison of samples taken from an Irish-based cohort - demonstrated inverted patterns of seasonal gene expression at Northern Latitudes and Southern latitudes and thus was in keeping with much of the epidemiological literature describing patterns of seasonal depressive symptoms [35]. Further, Dopico et al demonstrated that the inflammatory marker C-Reactive Protein (CRP) also has seasonal peaks and troughs [35]. Inflammation, reflected in higher levels of circulating CRP – as may occur in winter in Northern Latitudes – has been repeatedly implicated in the pathogenesis of depression in older adults [36].

Among the explanations for the associations we have found, behavioural theories are perhaps the more prosaic. Winter is associated with a higher level of cardio-respiratory disorders in older adults and increased hospital admissions [37,38]. During winter older adults may restrict their exposure to natural light secondary to risks (e.g. falls) associated with adverse weather conditions [39] - depression may result simply from being less active as higher levels of exercise are also known to be associated with improved mood [40]. We did however control for levels of co-morbidity and self-reported physical activity using a validated measure. While there was evidence of a seasonal effect in self-reported activity levels, this did not mediate the associations described here. Indeed, when compared to objective wrist worn accelerometer data, activity levels are usually over-estimated by this demographic [41] leading if anything, to an underestimation of the associations we have found.

One limitation to the current study is the cross-sectional nature of the design. We note however the use of three different parameters to reflect environmental influences, each of which point to consistent patterns of associations and thus add to the robustness of our conclusions. Additionally, in common with the majority of epidemiological studies on ageing, we did not use a diagnostic interview schedule for depression but rather a self-report questionnaire. Given that rates of depression meeting diagnostic criteria in older adults reduce with age but levels of depressive symptoms tend to increase, this measure may be a better reflection of the morbidity associated with sub-threshold depressive disorders in this cohort [42]. Rather than a specific focus on criteria for Seasonal Affective Disorder - classically associated with atypical depressive symptoms (hypersomnia, weight gain, carbohydrate craving) - the study of the seasonality of typical depressive symptoms may have more relevance in this demographic, in whom even depressive symptoms not meeting strict diagnostic cut-offs may be associated with detrimental outcomes. This approach is in line with current DSM-V thinking which retains seasonality as a 'specifier' rather than a separate diagnostic category [43]. Nonetheless, measurement of self-reported seasonality and atypical depressive symptoms may have improved sensitivity to seasonal variation in this older cohort. Particularly in light of a recent study from the Netherlands Study of Depression and Anxiety investigating self-reported seasonality of depressive symptoms, which showed a clear seasonal pattern in adults aged under 65 where objective parameters had not [44].

While the effect of being interviewed in the summer relative to the definition of winter in the current study is negative (i.e. 0.5 fewer symptoms) it has a p-value of 0.06, however the effect sizes relative to winter were similar across seasons despite varying statistical significance (i.e. 0.7 fewer symptoms in Spring and 0.8 in Autumn). Given that we were investigating objective weather parameters, notably climate averages, we used the WMO definition of season. The WMO definition is standard in climate research and is recommended for use in the Northern Hemisphere [45]. Moving from the WMO reckoning to the Astronomical definition (spring: March 21–June 20; summer: June 21–September 20; autumn: September 21–December 20; winter: December 21–March 20) in particular changes the status of December from being in Winter to being in Autumn and March from Spring to Winter. Repeating our analyses using the Astronomical season we found that those interviewed in Autumn had the greatest levels of depressive symptoms (Beta 0.6 *SE*(0.3) greater than winter (Supplementary Table 2)). Thus irrespective of the definition there is evidence of seasonal variation in CES-D scores suggesting that those interviewed in the colder, darker months had greater levels of depressive symptoms. However, in common with the earlier report from the Netherlands Study of Depression and Anxiety group investigating seasonality in objective depressive symptoms [46], although we saw statistical trends towards seasonal variation using either definition the absolute effect on depressive symptoms is small (<1 on the CES-D). In addition, we note that our collection period covers two winters and one of each of the other seasons – however similar numbers of participants were interviewed in winter months and summer months. Thus again while our results point to small seasonal effects on mood on older adults we cannot definitively rule out secular time trends.

Unfortunately gridded data on monthly levels of sunshine during the time period of the survey were not made available by the Irish Meteorological Service and the monthly data on rain and temperature are aggregated at the calendar month level - thus we were unable to investigate potential daily effects. Given this restriction we had to introduce an arbitrary cut-off (15^{th} day of each calendar month) with regard to the period of monthly weather linked to each interview. However repeating the analysis using a weighted approach to better account for this averaging did not substantively alter the results (Supplementary Table 3).

The main strength of the study lies in the precision with which we were able to link an individual's location to both short-term and long-term local weather data using advanced geomapping capabilities at a resolution of 1km. Given that the CES-D was delivered in participants' own homes and this address was subsequently mapped in a GIS using latitude and longitude co-ordinates, we can be confident that the weather data used accurately reflects that to which the participants are regularly exposed. We note however that we were unable to control for an individual's recent relocations e.g. holidays abroad or an individual's lifetime migration patterns. As a further sensitivity analysis however, we re-estimated our models, restricting our sample to include only those participants who reported that they had always lived in Ireland, in the same administrative region, yielding similar results (data not-shown). Further, although there were differences in depression scores between the administrative areas with, in general, the areas outside of Dublin city (the metropolitan area as opposed to the suburbs) having less depressive symptoms, we were able to control for these 34 administrative areas and the degree of urbanization, so we can be confident that we are picking up the effect of variation in weather/climate/season within these regions. In addition, the nature of the TILDA cohort, which samples approximately 1 in 140 of all the Irish population over the age of 50 in Ireland, allows us to control for a wide range of competing explanations for the associations observed. For example, we controlled for marital status and income and in further sensitivity analyses included the number of nights spent in hospital and recent bereavement (death of a parent) in models – again none of these affected the main relationships described (Supplementary Table 4).

Given the public health importance of depressive symptoms in older adults and the associations with numerous poor outcomes [47,48], we consider our findings to have importance for both the recognition and treatment of depression in older adults. With efficacious interventions, including non-pharmacological approaches with minimal side effects, already available to treat seasonal depressive symptoms in older adults, screening for seasonal patterns of mood disorder should be considered by healthcare providers. Future work in older adults should include repeated measures of depression incorporating daily weather data if possible, and measures of atypical depressive symptoms and self-report seasonality. Moreover, future investigations should consider possible mediators for the associations we report, perhaps including objective assessments of physical activity and light exposure using wrist-worn accelerometers and/or light-sensors [49] or by incorporating serum levels of Vitamin D or CRP. The associations demonstrated here are strongest between local climate and mood in older adults and warrant further investigation, as these findings are particularly prescient given the public mental health implications of climate change and the ageing demographic. Even within a small geographic area on an island with a temperate climate, these results underline the potential importance of season and meteorological determinants of mood in older adults.

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Figure 1: Spatial distribution of TILDA data points geo-coded using Global Positioning System technology.

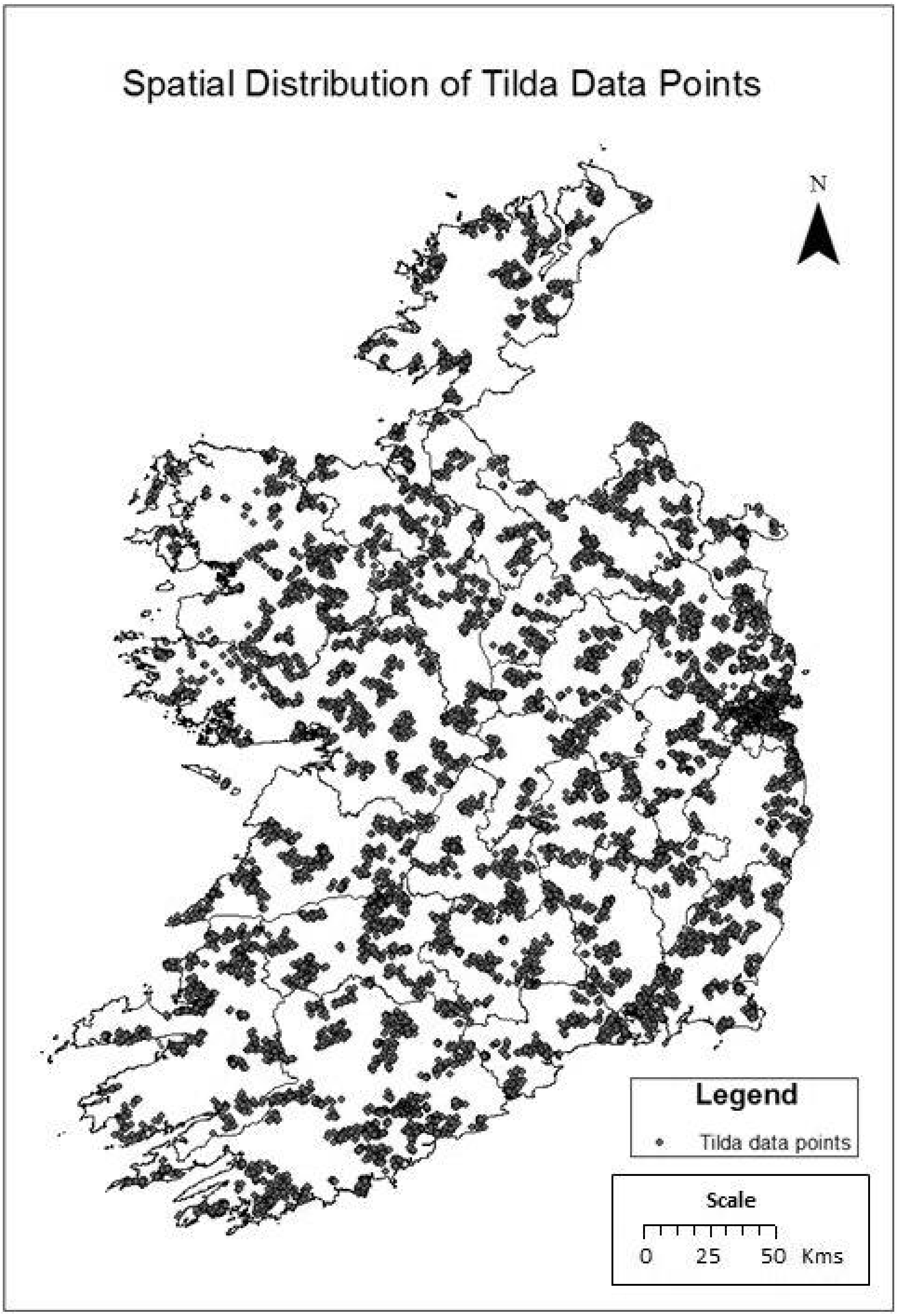

Table 1: Characteristics of Sample (*n = 8027)*

Characteristic	Mean / Proportion
Demographics	
Age *years*	63.91 *(SD9.76)*
Female *n*	4174 *(51.94%)*
Living alone *n*	1846 *(22.57%)*
Primary Education Only *n*	3050 *(37.93%)*
Employment	
Working *n*	2890 *(35.80%)*
Not working and not retired *n*	2328 *(29.00%)*
Urbanicity	
Dublin *n*	1766 *(22.41%)*
Other Urban *n*	2248 *(28.21%)*
Mental Health& Cognition	
CES-D Score	6.01 *(SD7.20)*
Using Anti-Depressants *n*	562 *(6.870%)*
Delayed Word Recall	5.58 *(SD2.46)*
Behavioural Health	
Minimally Active *n*	2649 *(33.27%)*
Physically Active *n*	2649 *(33.19%)*
Co-morbidity	
No chronic diseases *n*	1846 *(22.64%)*
1 chronic disease *n*	2248 *(27.82%)*

2 chronic diseases *n*	1846 *(22.93%)*
Polypharmacy *n*	1686 *(20.90%)*

CES-D= Center for Epidemiological Studies Depressions Scale

Table 2: Mean CES-D score by Season of Interview

Season of Interview	Mean CES-D	CI 95%
Winter	6.56	6.09 - 7.04
Spring	5.81*	5.40 – 6.22
Summer	6.00	5.48 – 6.52
Autumn	5.82*	5.36 – 6.26

*significantly different from Winter score at 5% level
CES-D= Center for Epidemiological Studies Depression Scale
CI 95% = 95% Confidence Interval

Table 3: Weather and Climate Averages Across Ireland

	Landlocked County	Western Coastal County	Eastern Coastal County
Weather in 2009-2011			
Average monthly temperature(°C)	9.33	9.78**	9.79**
Average monthly rainfall (mm)	85.02	104.89**	76.55
Climate 1981-2010			
Average monthly rainfall (mm)	81.73	103.74**	76.13
Average annual temperature (°C)	9.52	9.97**	10.00*
Average daily hours of sunshine	3.41	3.38	3.78**

Test of significant difference with landlocked counties.

** significant at 1% level, *significant at 5% level.

Table 4: Effect of Season and Meteorological Determinants on CES-D score

	Model A		*Model B*		*Model C*	
	Beta (SE)	*p-value*	Beta (SE)	*p-value*	Beta (SE)	*p-value*
Season						
Winter (ref. category)	*Ref.*	-				
Spring	-0.678(0.262)	0.010				
Summer	-0.540(0.289)	0.063				
Autumn	-0.834(0.291)	0.004				
Weather during month of Interview						
Average Rain Fall (10 mm)			0.04(0.02)	0.039		
Average temperature (°C)			-0.006(0.022)	0.791		
Climate						
Average Annual Sunshine (Hours)					-2.665(0.880)	0.003
Average Annual Temperature (°C)					0.345(0.363)	0.336
Average Monthly Rainfall (10 mm)					-0.04(0.09)	0.680

Data are linear regression coefficients *(Beta)* with Standard Errors *(SE)* in parentheses. Models additionally control for age, gender, education, employment status, degree urbanisation, marital status, living arrangements, anti-depressant medication, smoking, cognitive function, level of physical activity, co-morbidities, wealth and county fixed effects using dummy variables to control for the 34 different administrative areas within Ireland. CES-D= Center for Epidemiological Studies Depressions Scale; mm=millimetres; °C=degrees centigrade.