General and Specified Vulnerability to Extreme Temperatures among Older Adults

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ABSTRACT

Extreme temperatures pose significant risks to human health and well-being. Older adults are particularly at risk and their susceptibility is a function of vulnerability to general daily life circumstances and to specified events or threats. For the first time, this paper develops a combined general and specified approach to understand the determinants of vulnerability. The findings show that most participants exhibit high levels of heat-related vulnerability, followed by cold-related vulnerability and lastly, general vulnerability. General vulnerability was shown to be primarily shaped by financial, physical and social assets. Whilst, specified vulnerability was found to be mainly shaped by human, physical and placed based assets. Such findings present opportunities to focus on the types of assets that contribute to reducing vulnerability. These findings also suggest that the role assets play in shaping vulnerability must be attended to if we are to fully understand and effectively implement strategies to reduce vulnerability.

Keywords

Vulnerability; Specified vulnerability; Vulnerability assessments; Extreme temperatures; Older people; Assets

1. Introduction

Climate change, extreme events and more frequent and intense extreme temperatures pose risks and cause impacts to human health and well-being, and undermine sustainable development (WHO 2012; IPCC 2014; Nunes et al. 2016). Furthermore, certain individuals and groups are at higher risk of being affected by both heat waves and cold spells, these include children, pregnant women, chronically ill individuals, those living with low income and older people (Balbus and Malina 2009; Hajat 2017; Arbuthnott and Hajat 2017; Mayrhuber et al. 2018).

Older people are particularly affected by extreme temperatures both in terms of mortality and morbidity (Hajat et al. 2007; Balbus and Malina 2009; Astrom et al. 2011; Mazick et al. 2012; CCC 2014; Hajat 2017; Arbuthnott and Hajat 2017; Mayrhuber et al. 2018). Nevertheless, these risks and impacts are preventable and avoidable through vulnerability reduction programmes and measures (Conlon et al. 2011). As a result, there has been increasing interest in understanding and measuring vulnerability (Astrom et al. 2011).

This paper focuses on the vulnerability of older people and recognizes that they are not a homogenous group. Individual, social, and environmental factors, among others play a crucial role in shaping vulnerability to extreme temperatures. Some of these factors include, health status (chronic disease), sex (menopause), marital status, living arrangements (nursing homes, care home, independent living) and social networks (Kovats and Ebi 2006; Hajat et al. 2007; Belmin et al. 2007; Bouchama et al. 2007; Hajat 2017; Arbuthnott and Hajat 2017; Mayrhuber et al. 2018). As such, older adults are at greater risk of being vulnerable to extreme temperatures as a consequence of their asset portfolio (e.g. health status, housing, income), defined as access, availability and accumulation of a diverse range of assets to manage daily living (Moser 1998; Bebbington 1999; Alwang et al. 2001; Nunes 2016; Hajat 2017; Arbuthnott and Hajat 2017; Mayrhuber et al. 2018; Nunes 2018).

This paper explores the characteristics of older people and their surrounding environments that influence general (i.e. daily life) and specified (i.e. extreme temperatures) vulnerability. The study used an asset-based approach to identify different types of assets contributing to both general and specified vulnerability. This will help understand the relationship between assets and vulnerability and how older people can be assisted in reducing their general and specified vulnerability. Assets and assets portfolio include human, financial, physical, place-based and social factors or characteristics directly or indirectly available to individuals.

This research was developed in the context of Lisbon, Portugal, an ideal case study for its mild Mediterranean climate characterized by dry and warm summers, and wet and cool winters but faced with changes in the frequency and intensity of temperature extremes (e.g. 1981, 1991, 2003, 2006, 2009 and 2010 heat waves; 2003, 2006, 2010, 2012 cold spells) with severe impacts on human health (Lucio et al. 2010; Mazick et al. 2012; Carvalho et al. 2014).

2. Background

2.1. Definitions and interpretations of Vulnerability

The concept of vulnerability is understood and used differently across a wide range of disciplines (Alwang et al. 2001; Adger 2006; Gaillard 2010). As a result, it has become a much contested concept as no agreed definition exists with implications for interpretation and assessment. Supplemental Material 1 presents definitions of vulnerability according to disciplinary fields, showcasing complexity within definitions. Despite this, common structures and elements can be found in all definitions presented, regarding levels of specificity, focus and factors of interest. Additionally, it has been argued that existing definitions of vulnerability have mainly derived from two disciplinary traditions. These include either an entitlements

failure framing approach (i.e. assets or resources) identifying the importance of assets in shaping vulnerability or a hazard/disaster framing approach.

As seen in Supplemental Material 1, most definitions of vulnerability concern a general threat or event despite calls for more emphasis on vulnerability to specified ones (Brooks 2003). In this paper, vulnerability represents the degree of susceptibility to harm determined by the availability of assets. General vulnerability represents the vulnerability of individuals to all daily life circumstances, and specified vulnerability, the vulnerability of individuals to a particular type threat, stress or event (e.g. extreme temperatures). As a result, heat-related vulnerability represents the vulnerability of individuals to extreme heat, and cold-related vulnerability the vulnerability of individuals to extreme cold.

2.2. Vulnerability assessments

The diverse definitions of vulnerability discussed above have allowed the development of a series of methods to measure vulnerability (Alwang et al. 2001; Adger 2006; Hahn et al. 2009; Gaillard 2010). As an example, some authors have identified three main types of vulnerability assessments: end point (i.e. vulnerability is measured as an outcome); focal point (i.e. vulnerability is used as an overarching concept for the assessment); and starting point (i.e. vulnerability is used for identifying the sensitivity of the system) (Kelly and Adger 2000). Assessments of vulnerability are varied, with some being actor-centred (Nelson et al. 2007), others context and purpose dependent (Fussel 2007; Romero-Lankao et al. 2012), and others methodologically quantitative or with a quantitative output to enable the findings to be translated into indices and GIS maps for example (Kelly and Adger 2000; Cutter et al. 2003; Emrich and Cutter 2011). The development of indices uses in most cases a composite index approach. Moreover, there has been a growing interest in the development of quantitative measures of vulnerability in different disciplines (Alwang et al. 2001). One of such

interdisciplinary approaches includes the Social Vulnerability Index by Susan Cutter (Cutter et al. 2003) in the disaster literature and widely used in the context of climate change (Fussel 2007). Additionally, some vulnerability assessments measure the availability of assets aiming at minimizing the impact of threats (Birkmann et al. 2010) using the sustainable livelihoods and asset-based approaches (Alwang et al. 2001).

Furthermore, several studies have acknowledged the entitlements approach developed by Sen (1981) as a useful tool for vulnerability assessments (Ribot 1996; Kelly and Adger 2000) as he identifies inequitable access to health, food, education and services as sources of vulnerability. By doing this, vulnerability assessments incorporate access to assets as main features, an approach used by other authors (e.g. Hahn et al. 2009) and implemented in this paper. Such measurements tend to use quantitative indicators based on secondary data and integrate this with the sustainable livelihoods approach (SLA) to explore the different types of assets available to individuals or communities (Hahn et al. 2009; Shah et al. 2013). Most composite indices have used secondary data at regional and national levels using, for example, Census data as an alternative to primary data collected at household or individual levels (Hahn et al. 2009). Using secondary data is considered a limitation as it may create problems regarding missing data and data collection procedures (Hahn et al. 2009).

Qualitative data has also been used to assess vulnerability. Such qualitative assessments mainly focus on understanding the root causes of vulnerability and the impacts of climate events. Limitations include only being applied to small areas (e.g. neighbourhood, city and regional levels) and requiring large resources (Dessai and Hulme 2004; Benzie 2014).

This paper aims to measure general vulnerability through the development of a composite index and assess specified vulnerability to extreme temperatures, using primary quantitative and qualitative data at the individual level. General (i.e. daily life) and specified vulnerability (i.e. heat- and cold-related) consider different types of assets (human, financial,

physical and place-based and social). It explores if and how different assets affect general and specified vulnerability. It answers the following questions: (1) to what extent do levels of vulnerability differ between older people?; (2) how is vulnerability expressed?; (3) what types of assets are available to older people and how diverse are they?; and (4) how do assets contribute to and shape vulnerability?.

3. Methods

3.1. Research design and methods

This study was conducted in three phases using an inter-seasonal approach where primary data was collected when it was more likely for extreme heat and cold temperatures to occur. For convenience the first (general vulnerability) and second phases (heat vulnerability) were conducted in June, July and August, and the third phase (cold vulnerability) in December, January and February – with older adults living independently in their homes in the city of Lisbon, Portugal (see Section 3.2 for the type of data collected in each phase).

Prospective participants were approached at local authorities and public or charitable institutions (i.e. local authority health service, university of the third age, day care centres, cultural and activity centres, ward's contact lists).

Recruitment was done face-to-face, the aims and objectives of the study were explained using an 'Information for Participants' flyer and contact details obtained for later contact to arrange an interview. Selection of participants took into account the following inclusion criteria: being 65 years of age or over; living independently in their homes; living in the city of Lisbon, Portugal. The recruitment strategy also comprised the inclusion of participants with diverse characteristics such as age, sex, marital status, living arrangements, education level, financial status, health status, among others. To achieve this a combination of non-probability sampling techniques (e.g. purposeful, convenience, quota and snowball) were used. In addition,

participants' levels of competence and autonomy to understand the study and their involvement were also considered prior to inclusion. This strategy discouraged individuals with dementia or cognitive impairment from participating as it was based on a free and voluntary willingness to participate.

Face-to-face interviews were arranged at a convenient time to participants in a familiar location, a private and neutral environment in the Lisbon ward from where they were recruited (e.g. office, meeting room). Interviews were conducted by the author, who is trained in quantitative, qualitative and mixed methods research.

All phases of the research involved structured (phase 1) and semi-structured (phases 2 and 3) interviews. Phase 1 interviews consisted of questions on general vulnerability (elicited during the summer months), whilst Phases 2 and 3 interviews consisted of questions to explore specified vulnerability (heat- and cold-related, taking place in the summer and winter months, respectively).

All participants gave written informed consent for inclusion before participation in the study. The study was conducted in accordance with the Declaration of Helsinki and ethical approval was obtained from the University of East Anglia, Faculty of Medicine and Health Sciences Research Ethics Committee (Reference 2011/2012 – 30) and from the Universidade de Lisboa, Instituto de Ciências Sociais Ethical Committee.

3.2. Data collection

All three phases of the study combined the collection of quantitative and qualitative data. Phase 1: General Vulnerability structured interviews were designed to explore the general vulnerability of participants and was used to develop the General Vulnerability Index (GVI), at both sample and individual participant levels. Phase 2: Heat-related and Phase 3: Cold-

related semi-structured interviews were designed to explore the specified vulnerability of participants (Supplemental Material 2).

This paper reports on a total of 52 general vulnerability structured interviews, 52 heat-related semi-structured interviews (Phases 1 and 2, respectively) and 46 semi-structured cold-related interviews with the same participants (Phase 3). From the 52 participants who took part in Phases 1 and 2 only 6 participants withdrew from participating in Phase 3 (4 females and 2 males) due to unwillingness to participate, ill health, being uncontactable or unable to travel. Furthermore, the sample size obtained was one that ensured theoretical saturation (Bryman 2012).

Phase 1 and Phase 2 interviews combined ranged from 22 minutes to 1 hour and 47 minutes, with a mean of 55 minutes, and a total of 48 hours of interviews. Phase 3 interviews ranged from 17 minutes to 2 hours, with a mean duration of 37 minutes and a total of 29 hours of interviews. Research participants' characteristics are presented in Table 1.

Table 1. Participants' characteristics

Characteristics	Participants	Census data (source INE, 2011)
Age (mean), y	75.1	-
Min., y	65	-
Max., y	95	-
Sex, M/F, %	67 / 33	62 / 38
Living alone, %	58	27
Marital status		
Widowed, %	48	32
Married, %	29	52
Divorced, %	8	7
Single, %	15	9

3.3. Data management and analysis

All interviews (Phase 1 to 3) were audio recorded, Phase 1 structured interviews were also recorded (handwritten) using individual participants' interview sheets which were then

transferred to Microsoft Excel to provide descriptive frequencies. Phase 2 and 3 semi-structured interview transcripts were transferred to NVivo for qualitative data analysis using thematic analysis (King and Horrocks 2010). Initial themes and codes were obtained and included until final codes were reached using a systematic approach to coding and categorisation of data.

Each set of data (Phases 1, 2 and 3) were analysed separately. The first part of the analysis consisted of descriptive statistics such as frequencies and the development of the General Vulnerability Index (GVI) from Phase 1. The second part consisted of the analysis of Phase 2 transcripts, and subsequent analysis of Phase 3 transcripts. As a result, this study used a convergent parallel mixed methods design (Creswell 2014) where each set of data was analysed separately and brought together at a later stage to compare all sets of data.

3.3.1. Calculating the General Vulnerability Index (GVI): composite index approach

The data analysis of Phase 1 interviews included the implementation of a composite index approach for the development and calculation of the GVI, building on work from Sullivan (2002), UNDP (2007) and Hahn et al. (2009). The GVI combines earlier methods drawing upon the sustainable livelihoods approach (SLA) which uses five different types of assets (human, financial, physical, place-based and social assets). It differs from previous work that used secondary data and climate models, as it uses primary data collected at the individual level during Phase 1. The use of primary data in the development of such types of indices is uncommon as most rely on secondary data and face problems of missing data and errors due to time and space scales (Hahn et al. 2009). Furthermore, community and household level data is most commonly used (Hahn et al. 2009; Antwi-Agyei et al. 2013; Shah et al. 2013) and up to this point there has been no other vulnerability index which use individual primary level data, which makes this a novel study. The GVI was specially developed for this study and

comprises fifty eight sub-indicators aggregated in five indicators, selected based on an extensive literature review on the factors shaping vulnerability. The five indicators include human, financial, physical, place-based and social assets. Supplemental Material 3 presents each indicator and sub-indicator and how they are quantified.

The GVI uses a balanced weighted approach where each of the sub-indicators provides an equal contribution to the overall vulnerability (Sullivan 2002; Vincent 2004; UNDP 2007; Vincent 2007), even though each indicator is composed by a different set of sub-indicators. This aims to simplify the development of the GVI allowing it to be applied by different end-users in different settings. The robustness of the weighting was tested through a sensitivity analysis. It tested both whole sample and individual participants' GVI values and showed that overall the results are not affected by changes, revealing high levels of certainty, which also shows robustness.

A number of steps were undertaken to calculate the GVI and the formulae used are presented below. In order to assess their comparability, all indicators were standardized using the UNDP (2007) procedure using equation (1) which also guarantees that all indicators are normalised to relative positions between 0 (lowest vulnerability) and 1 (highest vulnerability) (Vincent 2004; Hahn et al. 2009).

$$index_{s_i} = \frac{s_i - s_{min}}{s_{max} - s_{min}} \quad (1)$$

In this equation, s_i represents the original sub-indicator value and s_{min} and s_{max} represent the minimum and maximum possible value for the sub-indicator, respectively.

After the standardisation of each sub-indicator these are averaged using equation 2 (Hahn et al. 2009), obtaining a final value for each indicator (i.e. assets).

$$M_i = \frac{\sum_{i=1}^{n} index_{s_i i}}{n} \quad (2)$$

In the equation, M_i represents one of the five indicators [Human Assets (HA), Financial Assets (FA), Physical Assets (PA), Place-based Assets (PBA), or Social Assets (SA)], $index_{s_{ii}}$ represents the sub-indicators, indexed by i, that are part of each indicator, and n is the number of sub-indicators for each indicator.

Following the calculation of values of each of the five indicators, they are averaged using equation 3 (also expressed as equation 4) (Hahn et al. 2009) to create the GVI score. The weights of each indicator depend on the number of sub-indicators that are part of each indicator, allowing all indicators to contribute in an equal way to the overall GVI (Sullivan et al. 2002).

$$GVI_i = \frac{\sum_{i=1}^{5} w_{M_i} M_i}{\sum_{i=1}^{5} w_{M_i}} \quad (3)$$

also expressed as

$$GVI_i = \frac{w_{HA} HA_i + w_{FA} FA_i + w_{PA} PA_i + w_{PBA} PBA + w_{SA} SA_i}{w_{HA} + w_{FA} + w_{PA} + w_{PBA} + w_{SA}} \quad (4)$$

In equations 3 and 4, GVI_i represents the General Vulnerability Index value, resulting from the weighted mean of the five indicators. The w_{M_i}, represents the weights of each indicator and is derived from the number of sub-indicators that are part of each indicator. The inclusion of the w_{M_i} ensures that all sub-indicators have an equal contribution to the overall GVI. In this research the GVI varies between 0 (lowest vulnerability) and 1 (highest vulnerability) with a 0.500 cut-off point.

The contribution of each of the five indicators to the GVI was also calculated by dividing the GVI indicators index for each indicator by the sum of all GVI indicators index values.

3.3.2. Assessing Heat- (HRV) and Cold-related Vulnerability (CRV)

The data analysis of Phases 2 and 3 was performed using thematic analysis (King and Horrocks 2010). Codes and themes were identified highlighting participants' vulnerability to

extreme temperatures. A high and low classification of participants was developed using themes associated with the five types of assets (human, financial, physical, place-based and social assets) also used to develop the GVI (as above) to understand the different levels of specified vulnerability (see Supplemental Material 2). Heat- and cold-related vulnerability were assessed for each participant using their individual assets portfolio. As a result, a set of five high asset-based vulnerability was defined as:

- *High human assets vulnerability* - having health problems during very hot/cold weather and/or physical health limitations during very hot/cold weather;
- *High financial assets vulnerability* - facing difficulties paying energy bills for cooling/heating and/or did not want to spend energy/money to keep cool/warm;
- *High physical assets vulnerability* - having problems with temperature in the home and/or inability to keep the home cool/warm and/or not able to keep themselves cool/warm in the home during very hot/cold weather and/or no use of cooling/heating devices;
- *High place-based assets vulnerability* - did not have/or went to green spaces and/or facilities close by to keep cool/warm and were not aware of the Heat wave/Cold Weather Plan and/or had no interest on it, and;
- *High social assets vulnerability* - having low social contacts and/or not receiving or providing information or advice on what to do and/or low social activities during very hot/cold weather.

Heat- and cold-related vulnerability were determined using the following procedure: participants with at least three 'high' assets vulnerability (i.e. human, place-based and social) are considered to have high heat-/cold-related vulnerability, and; participants with two or less 'high' assets vulnerability are considered to have low heat-/cold-related vulnerability.

4. Results

4.1. General Vulnerability

Quantitative data obtained from Phase 1 was used to develop the General Vulnerability Index (GVI) using a composite approach. Table 2 presents a full list of the GVI results for the fifty eight sub-indicators and five indicators. The GVI for this study is 0.413 with possible values ranging from 0 (least vulnerable) to 1 (most vulnerable). This value

denotes a moderate general vulnerability of the study's sample. Greatest vulnerability was found on financial assets (FA = 0.449), followed by physical assets (PA = 0.448), social assets (SA = 0.421), human assets (HA = 0.407) and place-based assets (PBA = 0.358). The results of the five indicators values are presented in Figure 1 as a radar chart.

Figure 1.

Table 2. General Vulnerability Index sub-indicators values, minimum and maximum sub-indicators values (overall sample)

Indicators	Sub- indicators	Sub-indicator value	Sub-indicators index value	Indicators index value
Human assets	Percentage of individuals living alone	57.7	0.577	0.407
	Percentage of individuals that have no formal education	17.3	0.173	
	Percentage of individuals in lower supervisory and technical occupations, semi-routine and routine occupations, or never worked	71.1	0.711	
	Percentage of individuals with poor health	19.2	0.192	
	Percentage of individuals with current health worse than a year ago	30.8	0.308	
	Percentage of individuals hampered in their daily activities	48.1	0.481	
Financial assets	Percentage of individuals that have financial difficulties	42.4	0.424	0.449
	Percentage of individuals with monthly income ≤500 euros	46.1	0.461	
	Percentage of individuals that have pensions as source of income	94.2	0.942	
	Percentage of individuals that have difficulties paying the housing expenses	28.8	0.288	
	Percentage of individuals that have difficulties paying for food	26.9	0.269	
	Percentage of individuals that have difficulties paying for healthcare or medication	30.8	0.308	
Physical assets	Percentage of individuals that live in apartment buildings	76.9	0.769	0.448
	Percentage of individuals that live on the first floor or above	53.8	0.538	
	Percentage of individuals that do not have lift in the building	82.7	0.827	
	Percentage of individuals that live in houses with 50 years or older	69.3	0.693	
	Percentage of individuals that are not satisfied with their house	11.5	0.115	
	Percentage of individuals that live in rented homes or social housing	61.5	0.615	
	Percentage of individuals that are not happy with their living conditions	59.6	0.596	
	Percentage of individuals that do not own a landline phone	13.5	0.135	
	Percentage of individuals that do not own a mobile phone	15.4	0.154	
	Percentage of individuals that do not own a TV	0.0	0.000	
	Percentage of individuals that do not own a radio	3.8	0.038	
	Percentage of individuals that do not own a computer	65.4	0.654	

	Percentage of individuals that do not own a car	69.2	0.692	
Place-based assets	Percentage of individuals that do not have a food store or supermarket within walking distance	11.5	0.115	0.358
	Percentage of individuals that do not have a post office within walking distance	50	0.500	
	Percentage of individuals that do not have banking facilities within walking distance	32.7	0.327	
	Percentage of individuals that do not have a cinema, theatre or cultural centre within walking distance	60.8	0.608	
	Percentage of individuals that do not have public transport facilities within walking distance	0.0	0.000	
	Percentage of individuals that do not have access to private and public spaces close to their house, where they can sit and relax, have a coffee, or talk peacefully to neighbours, acquaintances and friends	13.5	0.135	
	Percentage of individuals that do not have access to public facilities close to their house where they can practice physical activity (such as playgrounds, parks, sport centres, swimming pools, etc.)	42.3	0.423	
	Percentage of individuals that rate their neighbourhood as bad or very bad	15.4	0.154	
	Percentage of individuals that rate health services as bad or very bad	26.9	0.269	
	Percentage of individuals that rate public transport as bad or very bad	35.3	0.353	
	Percentage of individuals that rate care services for the elderly as bad or very bad	26.4	0.264	
	Percentage of individuals that rate state pension system as bad or very bad	64.7	0.647	
	Percentage of individuals that do not go to private and public spaces	50.0	0.500	
	Percentage of individuals that do not go to public facilities for physical activities	71.2	0.712	
Social assets	Percentage of individuals that do not have people available who can help them when they need	25.5	0.255	0.421
	Percentage of individuals that do not have people that care for them	2.0	0.020	
	Percentage of individuals that have direct social contact with any of their children once or twice a month or less	36.5	0.365	
	Percentage of individuals that have direct social contact with any brother, sister or other relative once or twice a month or less	88.5	0.885	
	Percentage of individuals that have direct social contact with any friends or neighbours once or twice a month or less	11.5	0.115	
	Percentage of individuals that have indirect social contact with any of their children once or twice a month or less	5.7	0.057	

Percentage of individuals that have indirect social contact with any brother. sister or other relative once or twice a month or less	48.1	0.481
Percentage of individuals that have indirect social contact with any friends or neighbours once or twice a month or less	54.9	0.549
Percentage of individuals that take part in social activities less or much less than most people their age	36.5	0.365
Percentage of individuals that take part in caring for and educating children less often than once a week	82.7	0.827
Percentage of individuals that take part in cooking and housework less often than once a week	11.6	0.116
Percentage of individuals that take part in caring for elderly/disabled relatives at least once a week	5.8	0.058
Percentage of individuals that take part in voluntary and charitable activities less often than once a week	92.3	0.923
Percentage of individuals that take part in activities organized in their local area less often than once a week	23.1	0.231
Percentage of individuals that spend too little time in contact with family members	60	0.600
Percentage of individuals that spend too little time in other social contact (not family)	44.2	0.442
Percentage of individuals that spend too little time in their own hobbies/interests	32.7	0.327
Percentage of individuals that spend too little time taking part in voluntary work or political activities	78.8	0.788
Percentage of individuals that would find it difficult or very difficult to borrow money. if in serious financial difficulties	60	0.600

Note: All Sub-indicators units are percentages (%); Maximum sub-indicator values for all Sub-indicators is 100; Minimum sub-indicator values for all Sub-indicators is 0

Individual participants' general vulnerability was also calculated using the same methodology used for calculating the overall sample general vulnerability (GVI) (as above). Results show that the majority of participants in this study fall into the high vulnerability group regarding financial assets (59.6% of participants), followed by human assets (53.8% of participants) and social assets (53.8% of participants). Some participants also revealed high place-based assets vulnerability (32.7% of participants), followed by high physical assets vulnerability (17.3% of participants). In relation to general vulnerability, the majority of participants (59.6% of participants) displayed low levels of general vulnerability (see Figure 2).

Figure 2.

4.2. Heat- (HRV) and Cold-related Vulnerability (CRV)

Themes emerging from Phases 2 and 3 data were organised according to different types of assets (i.e. human, financial, physical, place-based and social assets) and are summarised in Supplemental Material 4. Most of the themes are found to be mainly associated to assets but life experience and faith in God were also found to shape participants' vulnerability to both extreme temperatures. The most commonly mentioned assets and themes comprised: financial assets (income constraints, costs of energy) and physical assets (lack of insulation, lack of cooling and heating devices); and the least mentioned assets and themes included: social assets (self-reliance, social isolation, lack of trust in others); human assets (illiteracy, awareness of risks to health), and; place-based assets (lack of safety and cleanliness, used to keep cool and warm).

Many commonalities were found but also some differences between heat- and cold-related vulnerability. These were mainly rooted in the characteristics of participants and their

environments, their general vulnerability and finally the characteristics of extreme temperatures.

Heat- and cold-related interview data were analysed individually for each participant. Assets vulnerability and, overall heat- and cold-related vulnerability were coded as 'high' or 'low' according to the relative availability of human, financial, physical, place-based and social assets.

Regarding extreme heat temperatures, most participants displayed high physical assets vulnerability (84.6% of participants), followed by high human assets vulnerability (75.0% of participants), high financial assets vulnerability (67.3% of participants), high place-based assets vulnerability (65.4% of participants), and social assets vulnerability (53.8% of participants). Overall, the vast majority of participants revealed high vulnerability to heat (HRV) (75.0% of participants). These findings illustrate the factors in which participants' vulnerability to heat is rooted (see Figure 3).

Figure 3.

As for extreme cold temperatures, the vast majority of participants revealed high levels of human assets vulnerability (82.6% of participants) and place-based assets vulnerability (82.6% of participants), followed by physical assets vulnerability (71.7% of participants), financial assets vulnerability (69.6% of participants) and social assets vulnerability (56.5% of participants). Overall the majority of participants revealed high cold-related vulnerability (CRV) (73.9% of participants). See Figure 4.

Figure 4.

4.3. General and Specified vulnerability

In summary**,** high heat-related vulnerability is more frequent (75.0% of participants) than high general vulnerability (59.6% of participants). High cold–related vulnerability is also more frequent (73.9% of participants) than high general vulnerability (59.6% of participants). Finally, heat-related vulnerability is slightly more frequent (75.0% of participants) than cold-related vulnerability (73.9% of participants).

As each participant represents a unique profile of vulnerability that can be underrepresented when looking at overall sample data, one of the aims of presenting the findings was to bring to life participants' individual vulnerability characteristics. Individual profiles were thus developed from participant's interview transcripts and one is presented below (Figure 5) illustrating the participant asset context and diversity as well as their real individual general, heat- and cold-related vulnerability. Participants' profiles as the one presented reproduce the type and depth of individual participants' data (i.e. quantitative and qualitative) that is only possible by both individual participants' and sample level data analysis and interpretation.

Figure 5.

5. Discussion

This study's interdisciplinarity allowed the development and implementation of a novel multimethodological approach for assessing general and specified vulnerability. This paper offers a novel approach in terms of the methods used to assess general vulnerability through the development of an index. It has explored general and specified vulnerability, and has outlined differences between general, heat- and cold-, and slight differences between heat- and cold-related vulnerability. These findings are relevant to understand the root causes of specified

vulnerability in order to tackle the sources of vulnerability, as well as to plan and implement strategies to reduce vulnerability through different types of assets.

This study's results point out the importance of a general vulnerability index (GVI) and specified vulnerability assessments (HRV and CRV) both collectively and individually as crucial to understand the challenges extreme temperatures pose to the vulnerability of older adults.

Older people in this study revealed a moderate general vulnerability. Financial assets vulnerability was greatest, followed by physical assets, social assets, human assets and lastly place-based assets vulnerability. Major contributing factors to vulnerability include having a pension as sole source of income for those with low pensions (financial assets), living in old buildings and buildings without lifts (physical assets), low participation levels in social activities (social assets), having had certain occupations (i.e. lower supervisory and technical, semi-routine and routine), never having worked, living alone and having no formal education (human assets), and lack of access to amenities (e.g. cinema, theatre, cultural centre), post office and public transport facilities close to home (place-based assets). Another study has also shown that many older adults in Lisbon also lived in rented and old houses in need of refurbishments and that the majority of older people do not take part in social activities (Villaverde Cabral et al. 2011). Furthermore, some studies found lower percentages of older people living alone in the city of Lisbon, than what was found in this research. For example, the Census 2011 found that 26.9% of older people (65 year or more) lived alone (INE 2011) and Villaverde Cabral and colleagues (2011) report a sample in which 15.9% of older people lived alone. This latter study also found that the majority of older people had no formal education and many never worked (Villaverde Cabral et al. 2011).

Specified vulnerability (heat- and cold-related) was found to be mainly shaped by older people's levels of independence, physical and mental health (human assets). These study's

results confirm those of studies in the US, France and internationally, who found that lack of mobility was a factor increasing vulnerability to extreme heat (Klinenberg 2002, Vandentorren et al. 2006 and Bouchama et al. 2007; Hajat 2017; Arbuthnott and Hajat 2017; Mayrhuber et al. 2018). The fear of falls both indoors and outdoors were recurrently mentioned regarding extreme cold. These findings also confirm that accidents and injuries are contributors to vulnerability, having been linked to inefficient housing and low indoor temperatures in the UK (Marmot 2013; Hajat 2017). Illiteracy and health illiteracy were found to be contributing factors to both general and specified vulnerability. These results are comparable to other studies in Western Europe, internationally and in the UK, where low educational levels were found to increase vulnerability to extreme heat (Huisman et al. 2005; Wilhelmi and Hayden 2010; Benzie et al. 2011).

The analysis also revealed that specified vulnerability was linked to increasing electricity, gas and water costs (financial assets vulnerability). Keeping their homes cool during extreme heat or warm during extreme cold temperatures was not a priority for participants' due to their financial situation. A study in the US also found that older adults only use cooling devices (e.g. air conditioning) if they feel they are able to afford paying such expenses and as such struggled to keep their homes cool during extreme heat temperatures (Sheridan 2007). Furthermore, other international and US studies have shown a relationship between low income and increased risk of impacts from extreme heat (Confalonieri et al. 2007; Balbus and Malina 2009; Wilhelmi and Hayden 2010; Arbuthnott and Hajat 2017). Such findings also support suggestions that financial problems are one of the drivers of cold homes due to inability to afford heating (Marmot 2013; Hajat 2017). Evidence that living with a low income is a factor which significantly increases the vulnerability to cold was found for example in Europe and New Zealand (Healy, 2003; O'Sullivan et al. 2011; Hales et al. 2012; Hajat 2017; Arbuthnott and Hajat 2017). In this study, extreme cold was found to constitute a greater threat to older

people than extreme heat due to increased financial burden in keeping the home warm. In addition, these findings agree with other studies where low incomes (financial assets) were found to hinder older people's access to other types of assets, such as physical assets (cooling and heating devices; home insulation) and place-based assets (social activities, use of services and amenities) (Dominelli 2013) and that poverty alleviation measures could reduce winter mortality and morbidity in Europe (Healy 2003). Most participants in this study found that their financial situation also made it difficult to insulate their homes but despite this, they did not want to ask for help from their social contacts.

In this study, physical assets specified vulnerability was related to poor housing insulation. Additionally, financial assets vulnerability meant that many participants were not able to keep their homes at an adequate temperature. The findings of this study agree with those of Vandentorren et al. (2006), Confalonieri et al. (2007) and Benzie et al. (2011), in France, internationally and in the UK, respectively, where poor housing conditions (i.e. poor insulation) contributed to vulnerability to heat. Despite the lack of research on the impacts of extreme cold in Portugal some studies have highlighted that poor housing conditions contribute to difficulties in keeping warm (Vasconcelos et al. 2011; Vasconcelos et al.,2013). Renting posed additional difficulties in getting landlords to refurbish homes, but owners also faced financial constraints (financial assets) to do so. This supports other evidence showing that being a tenant increases the vulnerability of individuals to extreme heat in Western Europe and the UK (Huisman et al. 2005; Benzie et al. 2011) and to extreme cold in New Zealand (Hales et al. 2012).

Place-based assets specified vulnerability was found to be linked to inability to access local infrastructures and amenities due to mobility problems (human assets), distance and lack of public transport (place-based assets), as well as not having company (social assets). These findings confirm others, both worldwide and in the UK where urban location and neighbourhood characteristics influence access to public facilities (Hajat et al. 2007; O'Neill

et al. 2009; Benzie et al. 2011; Wistow et al. 2013). In the US research has also shown that not having access to transport is a contributing factor to increased vulnerability to heat (Semenza et al. 1996). Private (e.g. own garden) or public green spaces (e.g. parks) were used by older people in this research to keep cool. Despite this, lack of shade, lack of trees and safe places close to their homes were barriers to keep cool outdoors. These findings support those of Vandentorren and colleagues (2006) as well as Benzie and colleagues (2011) in France and the UK, respectively, where lack of green spaces increased the vulnerability of individuals to extreme temperatures. Other studies in Europe, internationally and in the US have also suggested that urban location and characteristics can increase older people's vulnerability to cold (Eurowinter 1997; Barnett et al. 2005; Gerber et al. 2006, respectively). In the UK, weak social networks (social assets) were also found to have a negative impact in accessing built infrastructure (Dominelli 2013).

This study has revealed that participants who were regularly visited and supported by family and close neighbours had lower social assets specified vulnerability. These findings agree with evidence from the UK showing that older people were mostly supported by their family and neighbours during extreme temperatures (Wistow et al. 2013). Nevertheless, they contrast with other findings from the UK on the role social networks play in vulnerability (Wolf et al. 2010). This study also revealed that most participants found it extremely difficult to ask for help to be able to keep cool or warm homes (physical assets) despite having financial difficulties (financial assets) during extreme temperatures. These findings support those in the US that found links between social isolation and heat-related mortality (Semenza et al. 1996; Klinenberg 2002), and in the UK where lack of social capital and networks contributed to increased vulnerability to heat (Benzie et al. 2011).

Furthermore, the development of the general vulnerability index (GVI) and assessments of heat-related vulnerability (HRV) and cold-related vulnerability (CRV) represent a

contrasting approach to the existing literature. The bespoke GVI developed in this study contributes to tackling a gap in assessments to measure and elicit general vulnerability at sample level but especially at the individual level. In this paper they served to achieve a better understanding of what shapes vulnerability bringing together various disciplinary perspectives. The GVI, HRV and CRV assessments developed here are novel and useful to advance both theoretical and empirical knowledge in the vulnerability literature.

This research explored general and specified (i.e. heat- and cold-related) vulnerability, and has outlined that there are differences between the distribution of the different types of assets vulnerability between general, heat and cold, and slight differences between heat- and cold-related vulnerability among participants. Aspects of daily living such as low incomes and lack of savings (financial assets), lack of insulation and lack of cooling and heating devices (physical assets) as well as few opportunities to take advantage of place-based assets (e.g. go to the beach or countryside; go to cool or warm places) were all limited by financial assets. Health problems, lack of literacy and health literacy (human assets), and mainly relying on close family members when available due to lack of other social ties (social assets) were other relevant types of assets that increased vulnerability. Due to the existing levels of general vulnerability the asset portfolio available to participants was threatened by the challenges and burdens of extreme temperatures. Vulnerability to heat and cold were thus increased due to inability to assemble and accumulate the needed assets to face such events. Finally, extreme temperatures were found to increase participants' general vulnerability as they limited and increased pressure in assets diversity and availability. This type of investigation is relevant to understand the root causes of specified vulnerability in order to tackle the sources of vulnerability, as well as to plan and implement strategies to reduce vulnerability through different types of assets.

One of the strengths of this study include the integration of both general and specified vulnerability (extreme heat and cold) as most research on vulnerability focuses only on a general threat or event and not specified ones (Brooks, 2003). Another strength of this study is the use of primary data at the individual level for the development of the vulnerability assessments (general, extreme heat and cold), whilst other vulnerability assessments mainly use secondary data at regional and national levels (Hahn et al. 2009). Additionally, another strength is the use of assets to understand vulnerability (Hahn et al. 2009; Shah et al. 2013).

One possible limitation that should be taken into account regarding the GVI is that this approach may not allow a comparison of results between studies if the variables used are not the same and interpretation of results has to be carefully done (Hahn et al. 2009). Other limitations are those related to the general use of indicators and indices (Sullivan 2002; Vincent 2004; UNDP 2007; Vincent 2007). Despite this, the development of such indices contributes to a better understanding of what shapes individual and whole sample general vulnerability.

6. Conclusions

This paper took an interdisciplinary and holistic approach to vulnerability exploring vulnerability as a composite or umbrella concept encompassing numerous features or components (i.e. assets) (Rayner and Malone 1998). Consequently, individuals can be more or less vulnerable generally in their daily lives (e.g. general vulnerability) or to specific threats, stresses, shocks or events (e.g. specified vulnerability or heat- and cold-related vulnerability) due to social, cultural and environmental changes. It explored the role played by assets as sources of both general and specified vulnerability by investigating all five types of assets (human, financial, physical, place-based and social assets) which is novel in a climate change and developed country context. .

This study has shown what shapes vulnerability, what influences the expressions of vulnerability, and ultimately what makes someone vulnerable to extreme temperatures (i.e. specified vulnerability) and how this relates to general vulnerability.

Ultimately, the approach developed here on general and specified vulnerability provides a more insightful tool on the assets available to older people and provides tailored insights towards possible recommendations for reducing vulnerability, building resilience and improving adaptation for sustainable development.

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