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Geography and Environment

Assessing the needs of older people in urban settings: integration of emotive, physiological and built environment data

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Design of the built environment for navigability and walkability is an increasingly important aspect of urban planning. This focus derives in part from increasing interest in lifestyles and behaviours, including level of physical activity and health outcomes. Geographical information systems and virtual realities are playing a significant role in advancing this agenda: examples exist of integrating qualitative data (words about or visual images of places) and quantitative data (numerical descriptions of places). However, there remain opportunities for exploring alternative ways of linking different types of data (physiological measurements, emotional response, street walkability and urban design quality) to address issues of urban planning and renewal. Using a case study approach this paper explores the application of geographic information science and systems to participatory approaches in built environment planning with the aim of exploring older people's response to an unfamiliar urban environment. It examines different ways of combining temporally and spatial referenced qualitative and quantitative data. The participants in the study were a group of 44 older people (60+) from Swansea, Wales, who viewed a filmed walking route around Colchester, England. While viewing the film they gave an oral commentary and physiological readings were made, which have been integrated with primary data collected on the built environment along the walking route. Proximity and inverse distance weighting approaches for combining these datasets produce complementary results in respect of older people's physiological and emotive response to variation in the walkability and design quality of a walking route through an unfamiliar town centre. The results reveal participants experienced an elevated average heart rate close to Colchester Town railway station and expressed a comparatively negative emotional response to this location. Conversely participants experienced lower average heart rate, indicating reduced stress, in Brook Street where the overall Urban Design Quality score was relatively low.

Key words built environment; older people; oral narratives; spatial analysis; walkability

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Revised manuscript received 3 April 2017

***Geo: Geography and Environment*, 2017, 4 (1), e00037**

Introduction

Design of the built environment for both navigability and walkability is becoming an increasingly important part of urban planning (Birch and Silver 2009; Rohe 2009; Sallis *et al*. 2007), especially in localities where renewal schemes are a cornerstone of the policy agenda (Blackman 2006). Much of this impetus stems from the increasing interest in the role of lifestyles and behaviours, including physical activity levels, in influencing health outcomes (Leslie *et al*. 2007; Miles *et al*. 2008; Nielsen and Hansen 2007; Pearce *et al*. 2009; Sugiyama *et al*. 2008). An OECD report claimed that within its constituent countries, 43% of older people

The information, practices and views in this article are those of the author(s) and do not necessarily reflect the opinion of the Royal Geographical Society (with IBG). ISSN 2054-4049 doi: 10.1002/geo2.37

were living in cities and anticipated this proportion would increase (OECD 2015). In this context, developing and regenerating built environments to suit the needs of an ageing population is crucial. There is a growing need to plan cities in such a way that environmental improvement can lead to older people staying healthy and active, thus offering the potential for greater economic participation and social engagement and for reducing health and social care costs Given the importance of the immediate locality for older people and the time they spend there, the outdoor physical environment will have significant impact (Phillipson 2007).

The accessibility and usability of the built environment is also a major factor in the health, wellbeing and quality of life of older people (Wahl and Oswald 2010). The increasing emphasis in policy and practice on 'Active and healthy ageing' (European Union 2007) and 'Age-friendly cities' (WHO 2007) has spearheaded the adoption of the WHO principles across the major global cities and regions. These principles focus on tangible aspects of the physical fabric of the urban environment (outdoor natural spaces and the built environment) as well as community support and health services, civic participation and employment, communication and information, respect and social inclusion (WHO 2007), and provide a guide to assess age friendliness of different places. Framing this issue is the emphasis in policy on 'ageing in place', enabling people to continue living independently in their familiar environment for as long as possible, which has become synonymous with autonomy and wellbeing. The concept has endured despite being increasingly challenged as cities and communities change and the needs of older people require a change in place. There is increasing evidence that older people prefer to move rather than always 'age in place' (Hillcoat-Nallétamby and Ogg 2014), although this is not necessarily associated with living in a disadvantaged community (Scharf *et al*. 2003).

The importance and meaning of 'place' to older people has been much debated and is a constant issue in environmental gerontology. With its roots in psychology, the emphasis has traditionally been on quantifiable objective measures of the interaction between the person and the environment (Lawton and Nahemow 1973). However, this field has broadened to incorporate the voices of older people and their meaning of place and space (Rowles 1978) and how this changes over time. Understanding the relationship between place and ageing has also emerged within the field of geographical gerontology, which initially focused on where people live (Golant 1972) and their daily spatial lives (Rowles 1978) (both quoted in Andrews *et al*. 2007), and more recently addressed older people's identity in their environment (Peace *et al*. 2006). Walkability, a central concept of this paper, provides a fruitful area for convergence of environmental and geographical gerontology, both conceptually and methodologically.

Geographic information systems (GIS) are playing a significant role in advancing this agenda. For example, Stevens (2005), Schlossberg (2006) and Schlossberg *et al*. (2007) summarise the use of mobile GIS tools for integrating qualitative and quantitative data on the built environment, though with the general populace in mind rather than older people specifically. Their work in Portland, Oregon focused on the use of TIGER street datasets (www.census.gov/geo/www/tiger/index.html) for suggesting improvements to the walking infrastructure by focusing on network analysis around bus and/or tram stops. In the Stevens (2005) and Schlossberg (2006) studies, purely quantitative data were assessed using desktop ArcGIS Network Analyst: walkability ratings for parts of the city were developed using the density of walkable streets (taken as the minor-to-major road ratio), walking access to key locations and intersection density (i.e. street connectivity). The work was then taken further as described in Schlossberg *et al*. (2007) with the development of mobile GIS street audit tools for use on personal digital assistants (PDAs), facilitated by field collection of fine-scale intra-street quality data using the Systematic Pedestrian and Environmental Scan (SPACES) method. SPACES (Pikora *et al*. 2003 2006) was developed in Australia for the purpose of identifying the determinants of cycling and walking behaviour, and as a method included measures of variables such as sense of safety, building aesthetics and pavement quality. However, whilst SPACES is a useful general measure of street quality, it was not designed specifically with older people in mind. Nevertheless, it inspired the creation of the Senior Walking Environmental Assessment Tool (SWEAT) and its later revised version SWEAT-R (Cunningham *et al*. 2005; Michael and McGregor 2005). The SWEAT-R method was developed collaboratively by both professionals and senior citizens again in Portland, Oregon to identify those aspects of the built environment most relevant to older people. Further work with the tool using paired auditors carrying out separate audits in neighbourhoods in Portland, Oregon and Vancouver, British Columbia reveal 'a majority of SWEAT-R items had high inter-rater reliability' (Chaudhury *et al*. 2011, 449). Independent validation of the method, by (1) senior citizens not actively involved in its conception, (2) other sources of data and (3) members of the public unfamiliar with the study area in question, has not been attempted.

The Urban Design Quality (UDQ) index (Ewing *et al*. 2005 2006) captures information about the quality of urban spaces, including such items as the range of building uses, the presence of amenity areas and planting. Together these provided a quasi-objective assessment of the condition and ambience of the urban

ISSN 2054-4049 doi: 10.1002/geo2.37

environment with reference to five design protocols: imageability, enclosure, human scale, transparency and complexity. Arguably the assessment of walkability or the quality of urban design by means of SWEAT-R and UDQ (or similar measures), alone or in combination, do not provide a holistic perspective of the urban environment for older people. In this paper we take into account other potentially relevant factors by supplementing these auditing tools and integrating field-collected data for a walking route around Colchester, England with oral commentary and physiological readings from a group of 44 participants from Swansea, south Wales obtained while they viewed a film of the walking journey. The research formed a pivotal role in the Older People's Use of Unfamiliar Space (OPUS) project, itself part of the New Dynamics of Ageing Programme (2016).

There are examples of the integration of qualitative datasets [data best described in words or as sensory (visual, audial, tactile or olfactory) perceptions of places] and quantitative datasets (data best described in numbers) in geographic information science (Cope and Elwood 2009), and in fact one need look no further than Streetview on GoogleMaps for an example. However, although there are some examples in the architectural and landscape literature of research combining different types of data for planning purposes (Coyne 2007; Mavros *et al*. 2012; Ward Thompson *et al*. 2012), there are fewer instances in the geographical literature reporting on methods for incorporating emotive, physiological and built environment datasets with quantitative information with respect to urban planning and renewal. There is also growing interest in the use of mobile interview methods in geographical research, which take people into the environments and situations that are the focus of the research (Büscher and Urry 2009; Fincham *et al*. 2010; Murray 2009). However, there is little exploration of the use of film as a way of incorporating mobile methods in a static situation, for example with people having mobility impairment. Although such individuals were not the focus of this research, it was concerned with using film as a means of introducing older people to an unfamiliar urban environment in a standardised or consistent fashion. The growing public health interest in built environment quality for active living and its suggested links to factors contributing to cardiovascular disease risk (Booth *et al*. 2005; Catlin *et al*. 2003; Rundle *et al*. 2008) is only one facet of the challenge facing urban planners. The hypothesised relationship between emotive perceptions of urban environments and mental health (Burton and Mitchell 2006; Valdemarssen *et al*. 2005) and the policy trend towards joined-up urban planning and public health (Blackman *et al*. 2001; Blackman 2006) are part of a growing research agenda.

Recognition that the application of GIS and science has considerable potential for developing participatory approaches to built environment planning has been appreciated since the 1990s (Obermeyer 1998). Public participation GIS initially tended to focus on community development planning rather than recognising the differential needs of older people (Elwood and Leitner 1998; Elwood and Ghose 2001; Ghose 2003). Where differential needs have been recognised, more attention has been paid to engaging with young people, on the basis that they are 'the future' rather the growing numbers of older people (Moore and Davis 1997). More recently, the potential for incorporating volunteered geographic information has provided further impetus to engaging the public in environmental planning, place making and community building (Elwood *et al*. 2012). Although not reported here, the present research also explored the development of tools for older people to collect geographic data.

Increasingly it is being acknowledged that the voices of older people are crucial in the relationship between the person and the environment. Participatory approaches in developing age-friendly environments have also led to change in both power dynamics (between planners, architects, academics and older people) and as a result improvement in the fabric of the environment (Hockey *et al*. 2013; Buffel 2015). This article contributes to Blair and Minkler's (2009) call for the voices of older people not only to be heard, but also, in their review of 10 studies using participatory approaches, to conduct research *with* older people in line with Israel's principles of 'collaborative, equitable partnership in all phases of research'. The knowledge generated by the study came from such an approach and was able to identify the key issues that concerned older people, the changes that were necessary and the priorities that needed tackling as well as what constituted a good walkable town centre. This study extends the growing body of research within psychology (Laumann *et al*. 2003; van den Berg *et al*. 2003; Hartig *et al*. 2003) using film to explore people's response to mobile environments in a static situation to other disciplines and by focusing on older people in unfamiliar settings.

Methods

The research adopted a mixed methods approach combining the collection of quantitative and qualitative data from over 40 participants and more intensive work with a subset who engaged in focus group, workshop and feedback sessions, as well as undertaking fieldwork during a visit to the unfamiliar locality. Our mixed methods approach fits with the 'concurrent nested design' approach in which 'a predominant method ... guides the project [and another] method (quantitative or qualitative) is nested or embedded' (Cresswell *et al*.

ISSN 2054-4049 doi: 10.1002/geo2.37

2003, 229) within it. Overall there were five main elements to the research:

- Neighbourhood environment walkability and ageing in place.
- Accessing familiar and unfamiliar town centres.
- Physiological response to walking in virtual environments.
- Spatial analysis of unfamiliar town centre.
- Impressions of an unfamiliar town centre.

The researchers faced the challenge of exploring older people's emotional and sensory response to unfamiliar environments without influencing participants' reactions and perceptions during the course of data collection and in a manner that would allow comparisons between participants. Participants in some studies (e.g. Parks 2001; Yen *et al*. 2015) have been encouraged to explore places in a free-ranging fashion allowing them to go where they wished, taking photographs and recording audio narratives. Such unfettered exploration would have been inappropriate in our case because we sought to integrate the quantitative audit data with qualitative oral narratives and physiological data after experiencing a common unfamiliar environment. This consideration precluded allowing participants to explore an unfamiliar environment on their own because of the potential for a high degree of variation in the places visited, which would have limited opportunities for assessing responses to the same environmental stimuli. In recent years human geographers alongside other social science researchers have pioneered the use of mobile methods as either part or the whole of the data collection component of their investigations (Sheller and Urry 2006). Mobile methods have been favoured over more static, in-depth interview approaches in a number of studies exploring people's mobilities in an increasingly mobile world (Büscher and Urry 2009; Fincham *et al*. 2010; Murray 2009). Murray argued that people's

> everyday activities [are] so embedded in space that to carry out research in another space can limit the potential of the data as it removes the immediate relationship between the participant and that emotional and social space. Murray (2009, 472)

The objectives of our research meant that previously used mobile methods, such as accompanied journeys and independent video or photographic recording, would not suffice. We therefore developed methods that brought a standard spatial experience to participants in the controlled milieu of a 'reality cave'.

Some of these mobile methods have come together with qualitative approaches to using GIS and global positioning system (GPS) technologies to explore people's mobilities and use of space (e.g. Jones *et al*. 2011; Yen *et al*. 2015). The combination of these technologies enables mapping of people's movements and the routes followed in combination with other data sources, for example describing the physical environment in a systematic fashion. They benefit from the ability to use space as an organising framework for the data collected that is automatically assigned to the locations where participants take photographs or digitally record. Our method develops this approach by georeferencing participants' psychological experience of and physiological response to a real location in a virtual setting. Analytical tools in GIS then allow integration of these data and exploration of spatial patterns using a range of geostatistical or spatial statistics techniques. This article explores two ways of connecting the different types of experiential, perceptual and physiological georeferenced data from the participants in respect of an unfamiliar 'real' place they were virtually 'visiting'. The following subsections outline the mixture of methods we adopted to address these data collection challenges.

Recruitment and film viewing

Ambulatory participants were recruited from organisations for older adults in Swansea (University of the 3rd Age and 50+ Forum) using an age threshold of 60 years for males and females. They received some remuneration for participation in the research (£10 retail gift vouchers). They completed a questionnaire to gather information on their socio-economic and demographic background, travel behaviours including frequency, modes of transport used and preparatory planning and navigation procedures, the usefulness of signage and situations or areas avoided. The questionnaire was also used to administer the Cognitive Abilities Screening Instrument (CASI), which indicated the absence of any pre-existing diagnosis of cognitive impairment (average CASI scores for males and females were 96.3 and 97.0, respectively). The majority of participants were female (26, 60%) and overall the group was drawn from middle-class organisations requiring a high degree of involvement and most were well educated (32% to degree level, 41% to school level and 27% with other qualifications) [for further details of the sample, see Appendix Table A1; and Phillips *et al*. (2013)].

Participants first viewed 2D photographic images of familiar and unfamiliar urban centres, respectively Swansea and Colchester, in order to calibrate their physical and perceptual responses, and then watched a 31-minute filmed walking route through Colchester town centre in a reality cave accompanied by a member of the research team. Participants were screened at the recruitment stage to ensure they had not previously visited Colchester or knew people who lived there. The film of the route (Figure 1) included pauses where 180 (degree) panoramas were inserted to simulate a visitor looking around at these locations for the first time. Filming took place over two days in June when weather

ISSN 2054-4049 doi: 10.1002/geo2.37

Figure 1 'Virtual' walking route around Colchester town centre showing examples of film images for walking route segments and location of 24 SWEAT-R and UDQ, and 31 physiological and oral narrative data point locations

Source: Images, members of research team; map, Ordnance Survey

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conditions were good, with sun and light clouds in a blue sky. The pedestrian journey around Colchester included the central retail district, residential areas, moderate slopes and public spaces: it incorporated the central restricted traffic area and main roads connecting the town centre with outer residential localities.

ISSN 2054-4049 doi: 10.1002/geo2.37

The circular route started and ended at Colchester Town railway station to simulate a first-time visitor's arrival in an unfamiliar town by means of public transport. Three components of the data collected from participants are combined in the analysis presented in this paper: recording of physiological measurements; recording and transcription of oral narratives, and walkability street auditing using adapted SWEAT-R and UDQ tools.

Physiological readings

The stress associated with the experience of potentially disconcerting environmental features can be quantified by assessing their influence on heart rate control. An electrocardiogram (ECG) records morphological and temporal parameters of the heart's rhythm and electrical activity, and is visually represented as lines tracing the wave patterns of the cardiac cycle (see Appendix). Comparison of a specific ECG with what is regarded as a normal waveform helps with diagnosing many cardiac diseases. Two parameters considered of particular importance in relation to their association with clinical or lifestyle-related factors contributing to an abnormal ECG are heart rate variability (HRV) and the time duration of the ventricular QT phase, corresponding to the interval between the contraction and relaxation of the heart's larger chambers (ventricles). These are the change in the heart's beat-to-beat duration and the time between the start of the Q wave and the end of the T wave of the cardiac cycle, respectively. The HRV and QT phase vary in relation to clinical and lifestyle factors, and elevated QT duration is connected with cardiac arrhythmias and increased mortality (Goldenberg *et al*. 2005). There is mounting evidence, including examples involving virtual environments (Jang *et al*. 2002), that quantitative measurement of HRV and QT is effective for assessing the role of lifestyle as well as clinical factors on cardiac autonomic nervous system (ANS) integrity [see discussion in Lewis and Phillips (2012)].

A Holter monitor, which records morphological and temporal ECG parameters of cardiac activity in ambulatory situations, was used to take the physiological measurements from study participants (see example in Figure 2). Participants fitted the equipment themselves in a private room, having been given instructions on how to fit the monitor, including a diagram showing where to place the three electrodes. The researcher started the monitor and checked the signals when they returned to the pre-test interview area and physiological measurements were recorded from that time until the end of the post-assessment interview. The researcher pressed the incident (start) button on the monitor to delimit the different phases of data collection:

- Beginning of pre-assessment session.
- Start of walk to second building.
- Seated in visualisation studio.
- Beginning of still panoramas.
- End of panoramas.
- Beginning of walk around town (unfamiliar route).
- End of walk around town.
- End of post-assessment session.

Figure 2 Example of a three-lead ambulatory ECG Holter monitor fitted privately by participants and worn from start of pre-assessment session to end of post-assessment interview
Source: Applied Cardiac Systems Inc.

Measurements taken during these different phases enabled the physical and perceptual response to viewing an unfamiliar environment in the reality cave to be calibrated with reference to walking 15–20 minutes between the pre-assessment area and the visualisation studio, and viewing familiar and unfamiliar locations.

Nine key ANS indicators, selected using published guidelines (Task Force of the European Society of Cardiology *et al*. 1996), were recorded at one-minute intervals using the Holter monitor to take ECGs. Previous studies reporting on associations between HRV measures and conditions of greater mental and physical stress helped us to limit the present analysis to a subset of four of the nine indicators. The first indicator is the average heart rate (AvHR). The second indicator, which is calculated from the beat-to-beat interval (the NN or RR interval), is the standard deviation of the NN interval (SDNN): this represents total power or total variability. The third is the square root of the mean of the squares of successive differences in NN intervals (RMSSDNN), which is analogous to the high-frequency power contribution to HRV. The fourth is the QT variability index (QTVI), which quantifies change in the

ISSN 2054-4049 doi: 10.1002/geo2.37

QT interval in comparison to HRV (Berger *et al.* 1997). Situations of heightened or reduced physical and mental stress are associated with certain combinations of values of these indicators. For example, low SDNN and QTVI together with low frequency (LFn) in HRV are linked with raised physical and mental stress, whereas low-stress situations would commonly be connected with contrary values on these indicators.

Oral narratives

The researcher sitting with the participants provided initial guidelines by asking them to comment on specific items and to give a detailed account of their reactions to and perceptions of the filmed unfamiliar walking route. The researcher also responded to questions from participants but did not initiate conversations during the virtual journey. Participants were encouraged not only to consider those features that were immediately visible and in sight, but also to ponder signs of what 'might be round the corner'. The participants' commentaries referred to ease of navigation and sense of place during the virtual journey. All of the participants' narratives were recorded and subsequently transcribed, revealing a common focus on architectural descriptions such as building size or colour and the presence/absence of unusual features (e.g. columns). There were also regular references to aspects relating to the wider built environment, such as street obstacles (e.g. 'rubbish' in the context of refuse bins), land uses (e.g. offices) and landmarks (e.g. 'bus stop'). All these are topics collected in the SWEAT-R and UDQ tools (see below). There was a limited occurrence of emotive phrases such as 'attractive flowers' and 'messy coming out of the station', some of which are captured within the SWEAT-R and UDQ measures, such as the presence of small plants (UDQ) and litter/graffiti (SWEAT-R).

The narratives were assessed by tallying (in Microsoft Excel) keywords that related to the aesthetic, communal and safety aspects of the built environment found in the SWEAT-R categories of (1) maintenance of buildings, gardens and pavements, (2) variety of public spaces and (3) pedestrian crossings. Keywords were used rather than full SWEAT-R/UDQ items to reflect the everyday use of language by members of the public and to reflect the emphasis on incorporating the 'voices' of older people into the research process and design. The research method adopted an inductive approach to tallying comments in the narratives relating to the buildings, sounds, transport and visual appearance of each segment of the route (see below) using a five-point scale:

1 Multiple or strong negative mention.
3 Negative mention.
5 Neutral or no mention.
7 Positive mention.
9 Multiple or strong positive mention.

The narratives for each participant's oral commentary were tallied in minute-long segments in order to provide spatial correspondence between these emotive responses to the physical environment and the physiological dataset (see above). Two members of the research team listened to and tallied the oral narratives: over 85% agreement was achieved and in cases of disagreement a third researcher enabled a consensus to be achieved.

SWEAT-R and UDQ data collection

Quantitative measures of the built environment and walkability of the filmed walking route were collected during fieldwork in Colchester using customised ArcPad forms underpinned by VBScript code on a hand-held PDA device. Before developing the mobile GIS forms at the paper stage, some modifications were made to the Oregon version of SWEAT-R to tailor phrasing, spelling and other nuances: for example, the American English 'sidewalks' was changed to British English 'pavements', and 'transit stop' was changed to 'bus or tram stop'. The alpha-build PDA-based forms were then introduced to the subset of 13 participants who pilot tested the forms by street auditing in Swansea. Further interface amendments were made following the Swansea field testing before commencing final data collection for the Colchester study area by a subset of 12 participants and researchers. Tables 1 and 2 respectively detail the SWEAT-R and UDQ variables and the procedure for calculating the audit scores from the raw data. A subset of research participants assisted the researcher team with this walkability and street auditing three months after all participants had completed viewing the filmed walking route in order to assess the design of the PDA data collection tool.

The original paper-based SWEAT-R audit tool was applied at a neighbourhood level in Portland by 'calculating the proportion of segments in each neighbourhood that showed a certain characteristic' (Pikora *et al*. 2006, 710). Separate segments are defined along one side of a road terminated at each end by a side road, crossroads or T-junction. The scores were averaged across each group of road segments and denoted the relative walkability of the set of streets in each neighbourhood. Our research used a modified SWEAT-R audit tool to determine the walkability of the circular route around Colchester town centre. It similarly captured 165 attributes, including a set of 16 items that were recorded for the north-west corner start, mid and south-east corner end points (e.g. presence of traffic signal, pedestrian signal, grooves, pavement colour contrast, etc.) of each segment and others relating to the whole of the 24 street segments that made up the filmed walking route. While it is feasible to count the number of items and calculate the proportions of segments with each of the different

ISSN 2054-4049 doi: 10.1002/geo2.37

Table 1 Street features audited in adapted Senior Walking Environmental Assessment Tool – Revised with count and percentage of items aggregated over 24 segments of Colchester walking route

Domains and subdomains	*Street feature*	*Total items*	*Mean % of items/segment*
Functionality			
Buildings and land uses (39 items)	Continuous items: none Categorical items: predominant building height, presence/absence of 40 building types (e.g. detached, apartments/flats, terraced, semi-detached) and land uses (e.g. institutions, retail, commercial, public and religious)	177	18.9%
Pavements (14 items)	Continuous items: minimum width and count of benches Categorical items: presence/absence of pavement and pavement continuity on one or both sides, surface materials, slope, obstructions, covering, repairs and undamaged benches	151	44.9%
Street life (8 items)	Continuous items: count of street lights Categorical items: presence/absence of 21 retail or leisure services/facilities (e.g. library, restaurant, outdoor market, public garden, older people's housing/activities and fitness centre)	55	28.6%
Aesthetics (9 items)	Continuous items: proportion of buildings with bars on windows, well maintained gardens and buildings in good condition; count of trees Categorical items: residences with front porches, abandoned buildings or plots, litter, graffiti, broken glass, etc. and quality of public spaces	104	48.2%
Safety			
Personal safety (50 items)	Continuous items: maximum height of kerb cut and signal crossing time at start, mid and end points of segment Categorical items: presence/absence of kerb cuts, crossing area, crossing area markings, signs (stop, give way and pedestrian crossing), signal (pedestrian activated, not pedestrian activated and traffic), pedestrian overpass, underpass or bridge, kerb cut grooves/bumps, colour contrast and material contrast), broad apron kerb cuts at start, mid and end points of segment	318	26.57%
Traffic safety (18 items)	Continuous items: number of traffic lanes Categorical items: presence/absence of different surface types, traffic-calming devices, bike lanes, pavement extensions, school speed zone and cul-de-sac; one- or two-way street	165	38.2%
Destination (27 items)	Continuous items: none Categorical items: kerbside parking, car parks, bus stops, cul-de-sac	106	16.4%

types (see Table 1), these should not be interpreted as corresponding to the overall walkability of Colchester town centre because only a linear subset of streets was audited rather than the whole area. However, the data for the 24 segments provide a means of assessing variation in walkability along the route. The complete set of audited features is divided into four broad domains, two of which are further subdivided: functionality (subdomains: buildings, pavements and street life), safety (subdomains: personal and traffic), aesthetics and destination. Each domain and subdomain could include two types of feature: first, those that were continuous along the segment (e.g. pavement width and numbers of different types of building), these were respectively measured and counted; and second, categorical features generally recorded as their presence or absence at any point along the segment (e.g. kerb side parking). The original SWEAT-R tool separated the domains and subdomains into two groups representing different walking frameworks or purposes, namely walking for recreation and walking for transport, and calculated walkability indicators for each by summing the individual scores. We adopted a similar approach to determine two environmental scores, the route overall and for each segment. The overall walkability scores were calculated by adding the feature scores together. For example, the overall score for walking for recreation was the sum of the functional, safety, aesthetic and destination feature scores.

The UDQ index audits a smaller number of features (22) than SWEAT-R, some of which are used twice in calculating separate subscale values for the five urban design qualities. For example, Q07 Proportion of windows at street level is used in both the Human and Transparency subscale calculations. Each audited feature has a weight associated with it, which is applied to the data collected together with a constant to obtain the subscale values: the overall UDQ score is obtained by summation of the subscale values. Table 2 shows the weights for each feature (e.g. +0.42 for Q03 Presence of outdoor dining) and includes the Transparency subscale formula as an example calculation. The 22 UDQ features were collected for each of the 24 street segments at the same time as the SWEAT-R auditing.

ISSN 2054-4049 doi: 10.1002/geo2.37

Table 2 Street features audited in Urban Design Quality (UDQ) tool with overall and subscales values aggregated over 24 segments of Colchester walking route

UDQ subscales	*Street feature*	*Weight*	*UDQ value*
Enclosure	Constant	–2.57	4.80
	Proportion street wall – your side	+0.72	
	Proportion street wall – opposite side	+0.94	
	Q19 Number of long sight lines	–0.31	
	Proportion sky – ahead	–1.42	
	Proportion sky – across	–2.19	
Human	Constant	–2.61	–0.44
	Q01 Number of small planters	+0.05	
	Q02 Number of pieces of street furniture and other items	+0.04	
	Q06 Average building heights	–0.003	
	Q07 Proportion windows at street level	+1.10	
	Q19 – Number of long sight lines	–0.74	
Complexity	Constant	–2.61	2.70
	Q11 Number of pieces of public art	+0.29	
	Q15 Number of buildings	+0.05	
	Q16 Number of basic building colours	+0.23	
	Q17 Number of accent colours	+0.12	
	Q03 Presence of outdoor dining	+0.42	
	Q04 Number of people	+0.03	
Imageability	Constant	–2.44	2.23
	Q03 Presence of outdoor dining	+0.64	
	Q04 Number of people	+0.02	
	Q10 Number of courtyards, squares and parks	+0.41	
	Q12 Number of buildings with identifiers	+0.11	
	Q13 Number of buildings with non-rectangular shapes	+0.08	
	Q14 Proportion historic building frontage	+0.97	
	Q18 Number of major landscape features	+0.72	
	Q22 Noise level (1 – very quiet; 2 – quiet; 3 – normal; 4 – loud; 5 – very loud)	–0.18	
Transparency	Constant	–1.71	–0.10
	Q05 Proportion active uses	+0.53	
	Q07 Proportion windows at street level	+1.22	
	Q08 Proportion street wall	+0.67	
Transparency =	–1.71 + (+0.53 × Q05) + (+1.22 × Q07) + (+0.67 × Q08)		
UDQ score for walking route			1.84

This generated data that could be used to calculate subscales and UDQ scores for the entire route. The index values obtained provide an assessment of the quality of the urban design along the entire walking route and the individual segments in a similar way to the SWEAT-R assessment of their walkability. The average subscale values and overall UDQ score for the circular walking route are included in Table 2, but again these should not be regarded as applying to the whole of Colchester town centre.

Data integration

The focus of this section is on how the different types of data (physiological measurements, oral narrative tallies, SWEATR-R walkability and UDQ audit scores) were integrated. The film of the walking route lasted 31 minutes and its overall length was 3.148 km, given a slight time delay in capturing the physiological readings, 31 rather than 32 points were plotted at 100 m intervals (see Figure 1). The participants' oral narratives were recorded while they watched the filmed walking route, and although asking participants to vocalise their emotions could bring on a physiological response that might not have occurred otherwise, the measures taken to validate the Holter monitor recordings outlined above were intended to compensate for this possibility. The recording points around the route are numbered sequentially from the start to the end of the route at Colchester Town railway station. Therefore, the spatial-temporal matching between the coded oral narratives and physiological measures presented no practical difficulties since the fixed 31-minute duration of the film for each participant meant these could be date-time 'stamped' by reference to the automated physiological recording device. However, matching these two datasets with the built environment (SWEATR and UDQ) datasets was less straightforward. The SWEAT-R audit tool uses street segments delineated by crossings and/or turnings as the basic spatial units, which were also used for the UDQ recording. There were 24 such segments along the walking route, as shown in Figure 3. Segment length

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varied over the whole route, with an average of 131.2 m (SD = 83.9 m). Furthermore, the separate features recorded by the customised SWEAT-R and UDQ audit tools relate either to specific points along a segment (e.g. presence/absence of drop kerbs at start, mid and end crossing points) or to a whole segment (e.g. average pavement width, proportion of historic frontage and the presence/absence of permitted parking) as detailed in Table 2. Therefore some of the SWEAT-R and UDQ items relate to entire linear segments of different lengths and others to specific locations on these segments. Both types of data needed to be combined and located on the segment: this was achieved by attaching the data to an end-of-segment point feature. However, as is evident from Figure 3, differences in segment length mean that these points were spaced irregularly and not sequenced to the timing of the film. Two spatial assignment strategies were devised to approximate correspondence between the SWEAT-R and UDQ street audit data at 24 end-of-segment points and the narrative/physiological data at 31 regularly spaced time sequenced recording points.

The first approach to combining these datasets spatially was based on proximity between the segment end points to which the SWEAT-R/UDQ attributes were attached and the regular time-controlled points of the physiological/oral narratives data. Some segments included only one physiological/oral narrative data point, whereas seven segments (circled on Figure 3) had two or three of these points. Joining by means of proximity was attempted in two ways: just to the nearest preceding time-slice point, or alternatively for segments where there were two or three points, to the average of their physiological/oral narrative data on the segment. While in some cases it may seem that these points are not sufficiently close to their corresponding film viewing-related locations (Figure 3), it should be borne in mind that the physiological/oral narrative data always referred to pavements already traversed in the virtual journey. In summary, there were 17 segments with a single time-slice point assigned to the nearest SWEAT-R/UDQ point ahead of them, and seven occasions when the data values for two or three were averaged with a forthcoming SWEAT-R/UDQ point. Thus for each end-of-segment SWEAT-R/UDQ point attribute data fields were added for physiological and oral narrative scores.

The second approach to spatial assignment applied inverse distance weighting (IDW) (Watson and Philip 1985) to create raster datasets using the 31 physiological and oral narrative time-slice data points and the 24 end-of-segment SWEAT-R/UDQ points. This approach therefore retained all of the original data and sought to reveal spatial connections between the different sets of variables. The IDW technique calculates a value for each raster cell, which is constrained to lie within the range of original values used in the interpolation process because it is weighted by the distance between sample points. Data values at sample points exert more influence when calculating the average value for the raster cells when the centre of a target cell is a short distance compared with those further away. These raster datasets were clipped to a 30 m buffer zone around the route. This was applied because two or more storey buildings lined the majority of the pavement segments on the route and the roads were an average 16.1 m wide. People's view from the route was constrained by the buildings and the width of

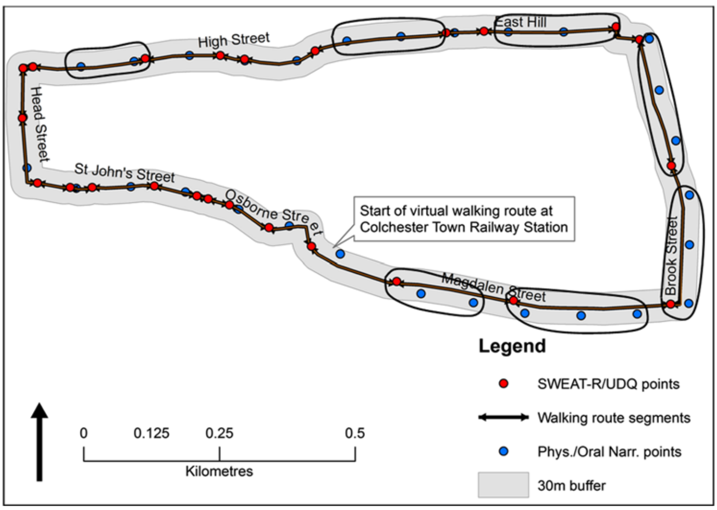

Figure 3 Joining walking route segments and physiological and oral narrative data point locations
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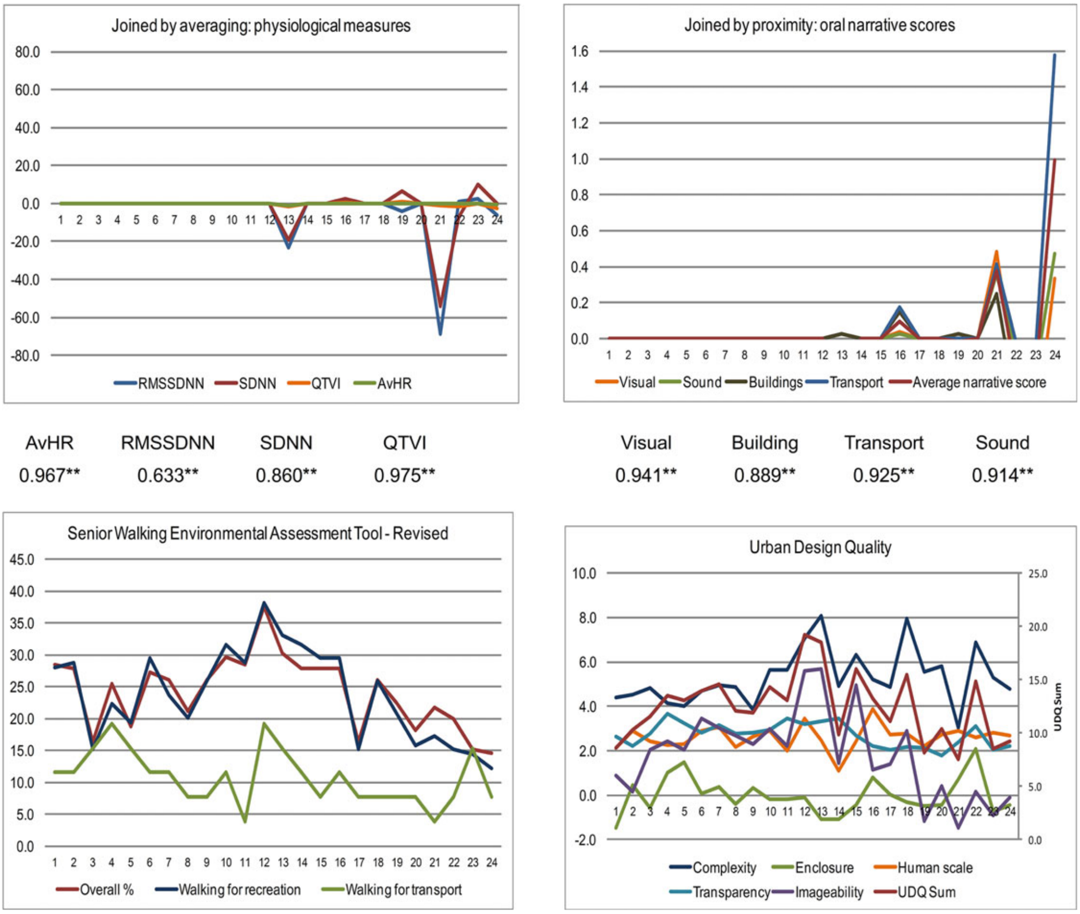

Figure 4 Variations in physiological, oral narrative and street audit data along walking route, and correlation coefficients comparing nearest and average joining methods

Source: Survey Data

Note: Correlation coefficients between the two joining methods are all significant at 0.01

the road, meaning that their data responses were to this buffer corridor rather than to the overall, broader townscape. The buffer zone had an area of 188,194.1 m^2, giving densities of 6070.8 m^2 and 7841.4 m^2, respectively, for the physiological/oral narrative and SWEAT-R/UDQ points. The following parameters were set in the IDW: raster cell size 2.12 m^2, the power decay function 2, the search radius variable and number of search points 3. The raster datasets created by IDW allowed the segment data from the physiological/oral narrative scores and the SWEAT-R/UDQ measures to be visualised coincidently.

Results

This section focuses on the results obtained by analysis of the combined street audit and physiological/oral narratives data rather than considering them separately. Once the coded oral narrative tallies and physiological measures had been joined by means of proximity using the nearest and averaging methods to the SWEAT-R and UDQ scores for the 24 end-of-segment points (see above), non-spatial Pearson's product-moment correlation and analysis of variance were applied using SPSS statistical software (version 22). The results obtained by the nearest and averaging methods for the 24 points produced were highly positively correlated and statistically significant at p = 0.01 (see Figure 4). For example, nearest and averaged AvHR values and the visual oral narrative comments respectively yielded R = 0.967 and 0.941, with both significant at p = 0.01. The absence of a statistically significant difference between the two methods of proximally joining the physiological and

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oral narratives data to the end-of-segment points was confirmed by analysis of variance, which resulted in no significant difference. These results indicate that it is immaterial whether only the nearest or average preceding physiological and oral narrative data are combined with the SWEAT-R and UDQ scores at the end-of-segment points. The line charts in Figure 4 show the difference between the four physiological and five oral narratives variables: in each case along much of the route there was no difference between nearest and average values, but for points 13, 16, 21, 22, 23 and 24, some important disparity was recorded. The location of these points on the route can be seen in Figure 1. The two lower line charts in Figure 4 trace the UDQ and SWEAT-R scores along the route. There is a general increase in the walkability of the route from the start point at Colchester Town railway station, which builds along Head Street to a peak in the High Street where there are wider pavements and one-way traffic flows in a single lane. The UDQ domain scores show considerable and in some cases contrary variation along the route. Nevertheless the overall UDQ lines show a rise towards points 11, 12 and 13 followed by a fluctuating decline down East Hill, up Brook Street and along Magdalen Street back towards Colchester Town Station.

Pearson's product-moment correlation has been used to examine the relative merit of joining the average of the oral narrative tallies and the four physiological measures with the overall SWEAT-R walkability and UDQ scores by means of the nearest and average point methods (see above). The results in Table 3 show limited differences in the strength or significance of the correlation coefficients for the two methods of joining the data for the 31 oral narrative/physiological points to the 24 UDQ/SWEAT-R end-of-segment points. Only one of the correlation coefficients was significant at p = 0.01: this was between SWEAT-R walkability and SSDN when the latter values were joined by the averaging method. This suggests that higher walkability scores were associated with lower levels of stress. Additionally, there were some statistically significant correlation coefficients between subdomains of UDQ and SWEAT-R, and the oral narrative tallies and the four physiological measures not shown in Table 3: the –0.45 correlation coefficient between average heart rate and the UDQ enclosure score was significant at 0.05 (data joined using both the proximity and averaging methods); the –0.41 coefficient between the visual oral narrative tally and the UDQ imageability score (joined by averaging) was similarly significant; and the most significant linear relationship (0.01) was for the +0.63 coefficient between RMSSDNN and UDQ complexity (joined by proximity).

Mapping of the IDW interpolated raster surfaces provides a way of exploring the spatial patterns produced by the different datasets by visual comparison (see Figure 5). The geospatial and attribute data were analysed using ArcGIS (version 10.2.2). The maps in Figure 5a relate to the four physiological measures and those in Figure 5b to the walking for recreation and for transport frameworks of SWEAT-R, overall SWEAT-R, the overall UDQ index score and the overall average of the oral narrative tallies. The average heart rate, QT variability index and average oral narrative tallies show a similar pattern, with relatively high values interpolated along the western side of the High Street and to some extent around Colchester Town railway station near the start of the route. The standard deviation and square root of the mean of the differences in the beat-to-beat interval display a contrasting pattern, with a relatively low range of values around most of the route and only very local high points, in the first case in a similar location to the previous one on the High Street and at the top of East Hill, and in the latter case on Brook Street on the eastern side of the route. The first three maps on the right show the interpolated percentages of the SWEAT-R audit tool items present along the segments of the route and the fourth map of the UDQ overall index score. There is considerable similarity in these spatial patterns, with higher values in the High Street, although the SWEAT-R items for the walking for transport framework are elevated along the St John's Street, Osborne Street and Magdalen Street sections of the route.

The spatial patterns displayed by these sets of indicators were also tested to detect any evidence of statistically significant clusters and outliers using the Local Moran's I statistic (Anselin 1995). Clusters of closely proximate high values and low values are respectively referred to as hot and cold spots (H-H

Table 3 Correlation of street audit data with physiological and coded oral narrative data for 24 data points for segments along Colchester walking route

	AvHR	*SDNN*	*RMSSDNN*	*QTVI*	*Average oral tally*
Joined by averaging					
UDQ sum	0.007	–0.152	0.028	–0.210	–0.151
SWEAT-R	0.234	–0.413*	–0.126	0.153	0.030
Joined nearest proximity					
UDQ sum	0.047	0.077	0.380	–0.125	–0.186
SWEAT-R	0.153	0.185	0.034	–0.207	0.085

*Significant at 0.05.
AvHR – average heart rate; RMSSDNN – square root of the mean of the squares of successive beat to beat intervals; SDNN – standard deviation of the beat to beat interval; QTVI – variability index of the time between the start of the Q wave and the end of the T wave of the cardiac cycle.

ISSN 2054-4049 doi: 10.1002/geo2.37

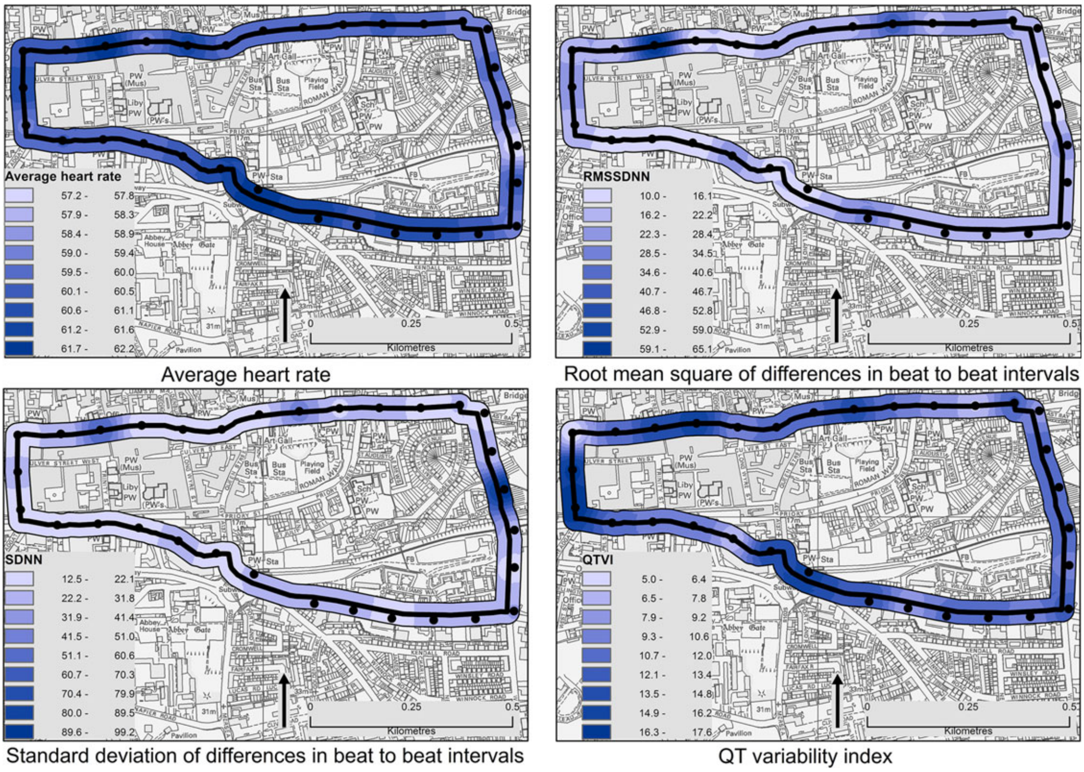

Figure 5a Inverse distance weighted interpolated surfaces for street audit, physiological and coded oral narrative data along Colchester walking route. Each IDW interpolated raster surface has been classified into 9 equal interval classes

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and L-L) and signify positive and negative spatial autocorrelation, whereas outliers occur when high and low values are located close together (H-L or L-H). Figure 6 shows the significant clusters for the physiological, oral narrative, walkability and urban design quality measures (SSDNN has been omitted because there were no statistically significant clusters). There are hot spots in different places on the route for AvHR and QTVI as well as a cold spot for AvHR. There are also two hot spots on the route near Colchester Town railway station for average oral narratives, which coincide with the AvHR hot spot. This suggests an emotional response to the environmental increase in heart rate. The hot spots for the walkability and urban design quality scores do not seem to be associated with either hot or cold spots for the physiological or oral narrative data. The cold spot along Magdalen Street for both SWEAT-R and UDQ suggests this part of the route was less suitable for walking by older people and has a lower design quality. The presence of H-L and L-H outliers for the oral narratives analysis along this stretch of the route indicates some variability in emotive responses among the study participants.

Discussion

The main purpose of this study was to test whether older people's experience of an unfamiliar town centre circular walking route in a virtual environment produced physiological and emotive responses that were spatially correlated with changes in the walkability and urban design along this route. It also sought to explore different ways of combining qualitative and quantitative data that were temporally and spatially referenced to points and linear segments along the route. Participants in the study were recruited in Swansea, south Wales on the basis that they had not previously visited or knew people living in Colchester, Essex, which was used as the unfamiliar environment.

First, we found that joining the more numerous coded oral narrative tallies and physiological measurement points to the fewer end-of-segment locations by using the nearest point or the average of points along a segment produced a non-significant difference. There were three discrete sets of points along the route where a non-zero difference occurred between the two methods of spatially joining the data. The most

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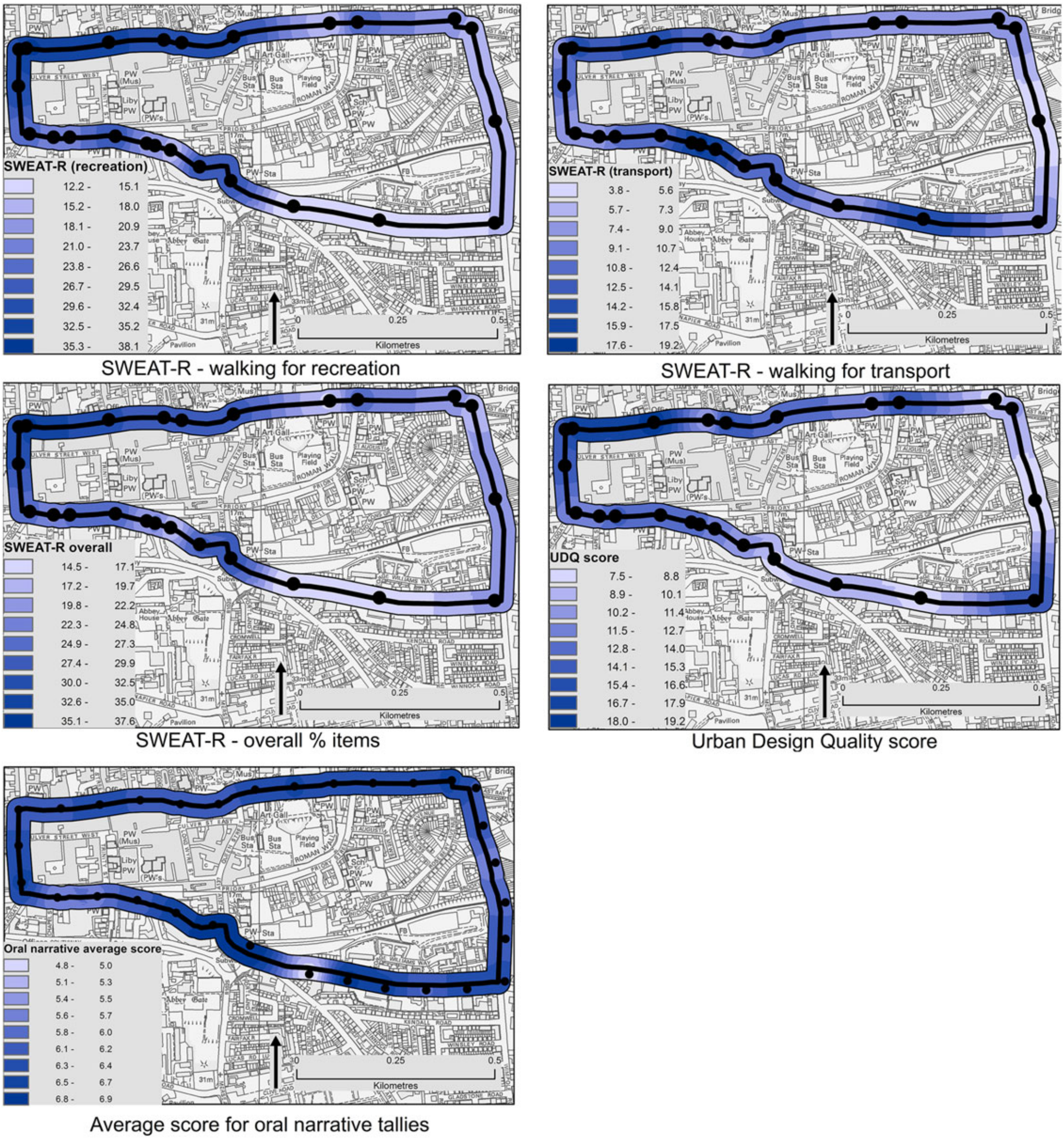

Figure 5b Inverse distance weighted interpolated surfaces for street audit, physiological and coded oral narrative data along Colchester walking route. Each IDW interpolated raster surface has been classified into 9 equal interval classes
Source: Ordnance Survey

significant of these was around the start and end of the walking route near Colchester Town railway station at St Botolph's roundabout. The walking route passed along the northern side of this busy road junction, which has traffic flow converging from five directions. Second, correlation analysis of the walkability and urban design quality scores with the physiological and emotive response data produced coefficients that were largely non-statistically significant. The one exception indicated that higher walkability scores were associated with lower levels of mental and physical stress.

Finally, we examined the spatial connections between the different types of data using IDW. The results revealed the changing walkability, design quality, physiological and emotive response of participants along the route as well as points around which high and low values were spatially clustered. To some extent, the hot and cold spots for these data occur at separate

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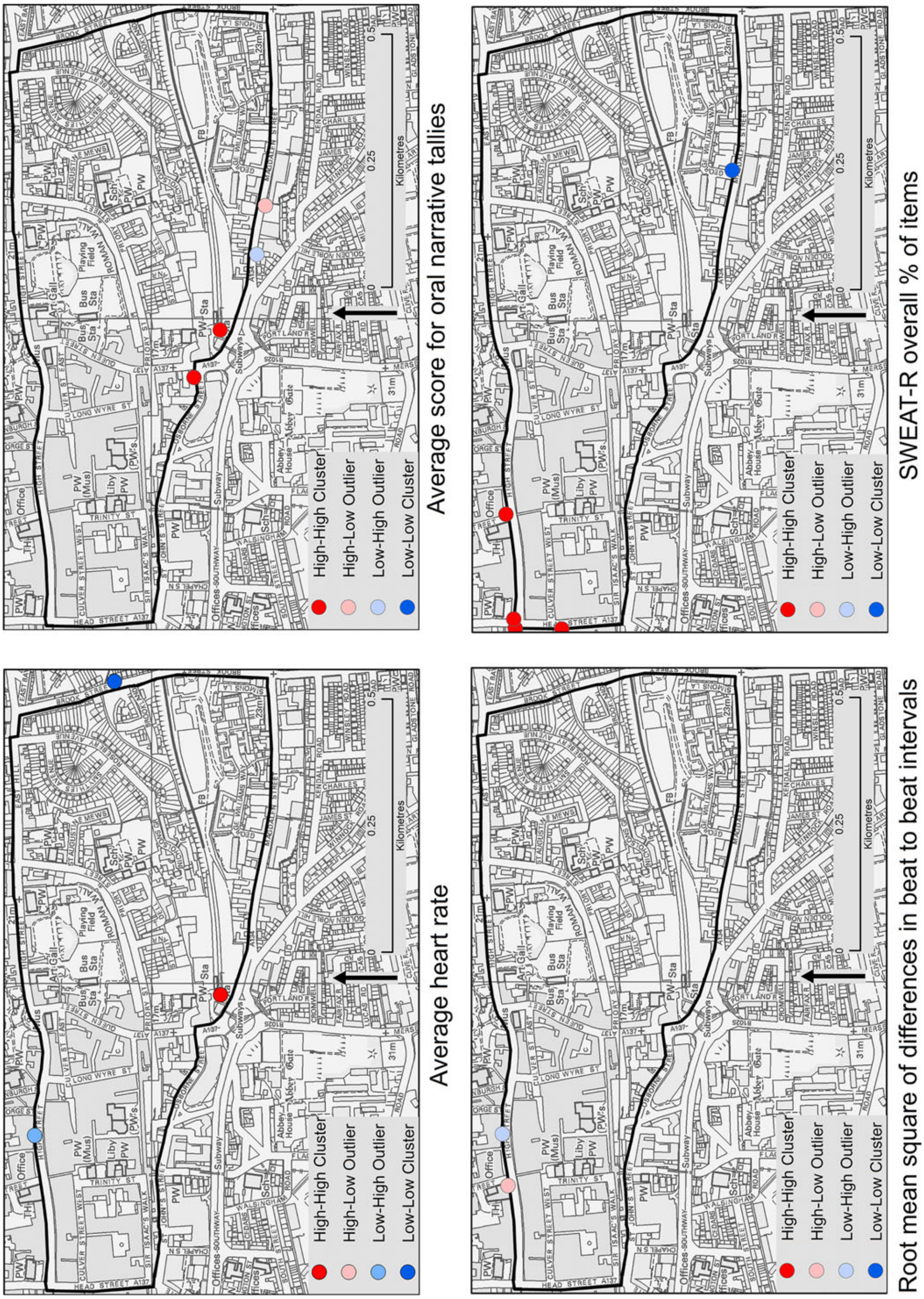

Figure 6 Local Moran's I analysis of spatial autocorrelation for street audit, physiological and coded oral narrative data along Colchester walking route
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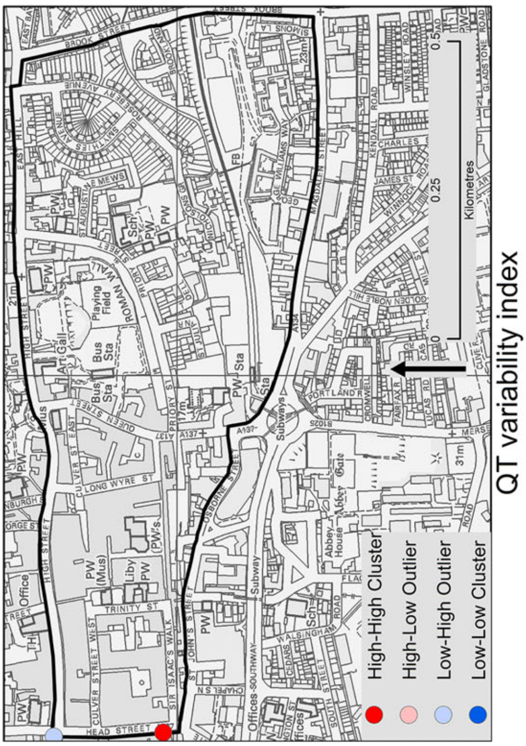

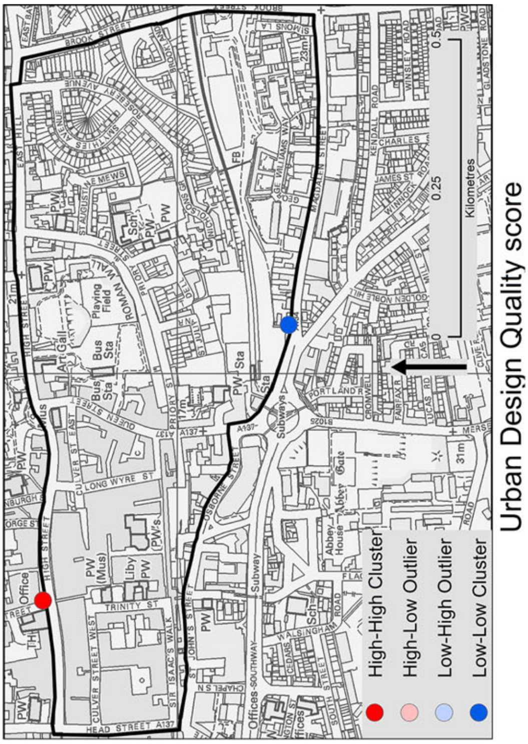

Figure 6 Continued

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locations along the route, although increased average heart rate and higher emotional response coincided near to Colchester Town railway station. Referring back to Figure 1, the illustrative images of the walking route, which were selected on completion of the spatial analysis, help us to visualise the physical environments associated with relatively elevated and depressed data values. The hot spot cluster associated with a raised AvHR for the participants occurred near the start of the walking route at St Botolph's roundabout and Colchester Town railway station, where the coded oral narratives also resulted in a hot spot of higher scores. The cold spot cluster for AvHR on Brook Street occurred close to where the UDQ index was low. These statistically significant clusters reflect this thoroughfare's role as a residential link road connecting the northern and southern sides of the town centre.

Conclusions

Our study offers new insights into the influence of the physical environment on older people by focusing on the walkability and design quality of an unfamiliar place in a virtual setting. Although presentation of the unfamiliar environment to the participants by means of a reality cave does raise the issue of the extent to which embodied ambulation can be disregarded, we feel that the more intensive work with a subset of participants reported elsewhere, including an accompanied visit to Colchester and a meeting with town planners, helped to ensure that overall a holistic perspective on the older people's engagement with unfamiliar environments was achieved. The study builds on previous analysis (Ward Thompson *et al.* 2012) by exploring ways of combining different types of data using spatial proximity and interpolation techniques. Our results suggest that the start and end of walking routes produce elevated emotive and physiological responses, although the presence of hot and cold spots at other points along the route around Colchester town centre indicates that such responses are not just connected to starting and ending a virtual journey. Viewing unfamiliar environments in a virtual setting offers the opportunity to complement mobile data collection methods and the ability to allow participants the opportunity to have a 'standardised' experience. This facility might enable urban designers to assess the impact of regeneration and renewal more holistically than previously and to capture the 'urban experience' through the eyes of a visitor. The methods and results identify the need for older people to have a range of information in an urban environment.

The paper contributes to the growing body of research confirming that qualitative data can make an important addition to the quantitative analyses traditionally associated with using a GIS framework (Schuurman 2009). The combination of qualitative and quantitative data relating to oral experiential narratives, walkability, urban design and physiological measures and their geostatistical analysis arguably has provided a holistic assessment of an unfamiliar urban environment that may be regarded as superior to one or more individual indicators. Viewing a virtual route allowed the older people in the study, whose cognitive scores were checked for consistency in advance, to have a standardised experience, which would not have been feasible if they had been permitted to wander at will. The use of a regular one-minute interval for recording the physiological measures enabled the participants' coded oral narratives to be linked directly to these 'time slices'. This paper has explored spatial proximity, averaging and IDW raster surface methods for connecting these data with the street audit information. There was little difference in the results obtained from proximity and averaging linkage methods, while the raster surfaces and spatial autocorrelation analysis make the visual connections more apparent.

The analyses and findings reported in the paper have contributed to three underpinning disciplines: environmental and geographical gerontology and urban sociology in respect of expanding the concept of person–environment fit (Lawton and Nahemow 1973) with a focus on a specific route as opposed to a fixed location such as the home or a particular street. Using GIS and images georeferenced by means of GPS in combination with the other datasets enhances our understanding of how older people view space and place, and their relationship with urban change. The research also adds to our understanding of the 'everyday life' of older people in urban settings and how they cope with unfamiliarity. In particular, it develops our knowledge of how older people age in urban places, the environmental and social factors that can contribute to facilitate walkability, security and safety. Older people have been viewed as invisible in the planning and regeneration process (Riseborough and Sribjlanin 2000) and where they have been visible this has focused on where to site retirement facilities or general design criteria of inclusivity (Hockey and Spaul 2011). Given the emphasis on sustainability and inclusivity, the voices of older people will become more central to the planning process (Hockey *et al*. 2013). The study illustrates the importance of participation of older people in the planning process through focus groups, interviews with planners and dissemination workshops as well as their own narratives on navigating around the town, empowering them to argue for change.

Acknowledgements

The OPUS study was funded by the Research Councils New Dynamics of Ageing Research Programme (NDA)

ISSN 2054-4049 doi: 10.1002/geo2.37

grant number RES-352-25-0003. We also acknowledge other members of the research team – Prof. Nigel Foreman, Dr Mike Lewis, Edgar Samarasundera, Mark Del Aguila, Anastacia Makati and all the older people who took part in the study. Colchester Borough Council kindly participated as a stakeholder in the research. We would also like to acknowledge the contribution of three anonymous referees who commented on an earlier version of the article.

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Appendix A

Table A1 Characteristics of participants

	Females	*Males*	*Total*
Cognitive Abilities Screening Instrument (CASI)	96.3	97.0	96.7
Mean age	71.1	70.3	70.8
Gender	40.0 (18)	60.0 (26)	100.0 (44)
Living arrangements			
Lived alone	22.2 (4)	38.5 (10)	31.8 (14)
Lived with others	77.8 14)	61.5 (16)	68.2 (30)
Education			
Degree	27.8 (5)	34.6 (9)	31.8 (14)
School or college	38.6 (7)	41.3 (11)	40.9 (18)
Other (vocation, professional, etc.)	33.3 (6)	23.0 (6)	27.3 (12)
Years of residence in Swansea	36.7	36.8	36.8
Place of birth			
Wales	50.0 (9)	50.0 (13)	50.0 (22)
England	44.4 (8)	36.6 (9)	38.6 (17)
Elsewhere	5.6 (1)	15.4 (4)	11.4 (5)

Note: Counts shown in brackets.

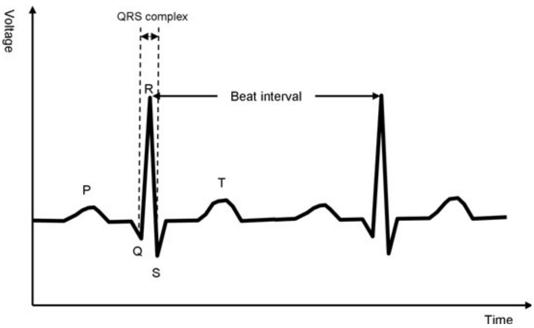

Figure A1 Simplified representation of electrocardiogram (ECG) trace showing Q wave, R wave and S wave (QRS Complex)]
Source: Authors

Changes in the electrical potential in the heart's muscle cells result in cardiac contraction and movement of blood between the four chambers of the heart. Attaching electrodes to the skin at different locations records this electrical signal as it passes through the body and produces a trace of the cardiac cycle. The ECG trace has a distinctive shape in a healthy person (see Figure A1) with rising and falling waves corresponding to different stages in the cardiac cycle as contraction and relaxation of the heart pumps blood between the four chambers. These waves are labelled P, Q, R, S and T, and the time intervals between these waves denote the duration of the different stages; for example, the interval between P and Q is a delay that allows the ventricles to fill. Deviations from the 'standard' waveform indicate the possibility of heart problems or the influence of external (environmental) stimuli.

ISSN 2054-4049 doi: 10.1002/geo2.37