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Investigating the potential of EDA data from biometric wearables to inform inclusive design of the built environment

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A B S T R A C T

This paper presents a pilot of a method which measures quantitative biometric data to understand the emotional response of people to their physical environment. The aim of the audit method is to address the problem of lack of accessibility of public buildings for those with hidden disabilities. People with invisible disabilities such as Autistic Spectrum Disorders (ASD, Autism) sometimes feeling forced to withdraw from public spaces and communities and unfamiliar or busy environments such as art galleries can be particularly problematic (Amaze, 2018). As part of the Audit, data is collected using a wearable biometric device that is mapped against internal location. In this study the EDA (Electrodermal Activity) Audit was trialed with participants with ASD at a public art gallery in UK. The results reveal that participants with ASD experienced a greater increase in stress level compared to the neurotypical control participants. Areas where noticeable 'peaks' of stress were recorded usually had a restricted view or required human interaction. Comparison of GSR (Galvanic Skin Response) data with questionnaire information gathered before and after visiting the gallery also implies that the participants with ASD were less able to articulate their emotional response to spaces. We discuss the development of an EDA Audit method that could provide knowledge to help designers envision spaces that are more inclusive.

1. Introduction

When designing a building or public space, architects and designers must predict how that space will be used (Baumers and Heylighen, 2010). These predictions are likely to be based on their education and own perception and understanding of the surrounding environment (Smith, 2009). However, this environmental understanding may be vastly different from that of some people who will eventually inhabit the resultant spaces. When this mismatch occurs, the built environment becomes a barrier (Heylighen et al., 2017) and a person's 'ability to connect seamlessly with their community is compromised' (Smith, 2009: 222) Clarkson (2010) term this 'disabled by design' asserting that it is not diverse bodies and minds that constitute 'disability', but environments that do not cater to users' needs. If it is possible to disable by insensitive design, it must also be possible to enable through good design (Barnes et al., 2004). Enabling or Inclusively designed environments are defined by Heylighen as those that are 'useable to the greatest extent possible, by all people throughout their lifespan, without adaptation' (2008: 531). The almost synonymous notions of Universal Design and Design for All (Imrie and Hall, 2001) have similar ambitions. Whilst inclusivity may be an aspiration for designers, the reality is that a significant portion of the population, find it extremely difficult to access the range of spaces available to the typical-bodied and neurotypical (Mostafa, 2008).

This can be particularly true for people with Autistic Spectrum Disorders (ASD, Autism) who have a 'distinct way of perceiving and processing information' (Baumers and Heylighen, 2010: 14). This means that they often feel confused and unsure of how to behave in a given space, thus limiting their ability to integrate with others (Smith, 2009). ASD is thought to be one of the most common developmental disorders exhibited in children (Schilling and Schwartz, 2004) affecting around one percent (approximately 700,000) of the UK's total population (Brugha et al., 2012). ASD affects people throughout their life and is associated with a difficulty in communication, forming relationships and unusual or repetitive behaviours. It has also been asserted that 'there is robust evidence that a building's design or modification can improve access and participation for autistic people' (Amaze, 2018: 5). It is therefore surprising to discover a conspicuous lack of design guidance for ASD and current inclusivity legalisation said to stop 'far short of setting a standard suitable for buildings to be inhabited by those with ASD' (Assirelli, 2016). This may be due to 'limited research on how environments may affect behaviour' of those with ASD (Gaines et al., 2016: 11).

Whilst all people of diverse abilities deserve careful consideration and consultation in relation to building design, Mostafa (2015a) argues that 'no group among these can benefit more from the sensory input that the built environment provides than those with Autism', meaning an understanding of their needs particularly important. Baumers and

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Heylighen (2015: 327) note, it is 'a challenge for designers to anticipate the diverse experiences of future users' and design spaces accordingly. This challenge is profound when designing for people with ASD who frequently struggle to conceptualise and convey their own emotions (Zangwill, 2015). Therefore, an approach to research that does not rely on self-reporting but quantitative data would seem valuable in understanding the spatial experience and needs of this group.

In this study, we test an approach we term an 'EDA Audit'. The method uses EDA Electrodermal activity) (Dawson et al., 2007) data that has been gathered using a wearable device that measures Galvanic Skin Response (GSR)(Shovel et al., 2018). GSR is said to 'indicate effective correlation to [emotional] arousal' (Kim et al., 2010) which can be correlated to stress levels. GSR is useful measure as it is able to 'detect a very sensitive amount of arousal' (Kim et al., 2010) and has been used by researchers to assess participants' emotional response to images (Rosco et al., 2018) and larger urban areas (Shovel et al., 2018; Nold, 2009; Fathullah and Willis, 2018; Osborne and Jones, 2017; Pánek, 2020; Zeile et al., 2016; Resch et al., 2015a). This paper presents a methodology for auditing the emotional responses to public buildings using GSR data in relation to internal location to provide a historically lacking insight into how people with ASD perceive and respond to the built environment. Results and information gathered from this study contribute to the development of a standardized tool; an EDA Audit; which evaluates the spatial qualities that can be barriers to full participation of people with hidden disabilities such as ASD. The audit method may help managers and designers better understand and identify spatial stressors for people with ASD, linking them to specific areas that may exist within their facilities; a step towards inclusivity.

2. Literature review

2.1. Inclusive design

Many private and public institutions have commonly failed to achieve design inclusivity for people with ASD (Assirelli, 2016). Social isolation rates are high among those with ASD (Schiltz et al., 2021; Mazurek, 2014) as well as associated depression and underachievement (STAR Institute, 2018). This is exacerbated by a lack of accessible public spaces. Some parents of children with ASD feel that 'planning days out to public spaces like the museum and theatre can seem impossible' (Davis-Hofbauer, 2018) and designers have a responsibility to educate themselves about their building's users and apply their expertise to help people with ASD achieve their potential through access to appropriate built facilities (Sánchez et al., 2011). Hypersensitivity and hyposensitivity to stimuli are also common in people with ASD who can be particularly sensitive to changes in light contrast and air quality, that would usually be ignored by the neurotypical (Shell, 2017). Linguistic analysis of autobiographies written by people with ASD has revealed that 'interpretation of the world is mostly based on immediate perceptions of space' (Baumers and Heylighen, 2010: 15) meaning that some with ASD find it difficult to imagine what may lay beyond a particular door or street corner even if they have been there before. Perception of the body as well as external environment is also different for people with ASD. Whitehurst notes that children with ASD commonly have 'difficulties being aware of their own bodies in relation to the context in which they find themselves' (Whitehurst, 2007: 4). This can lead to poor coordination and orientation when trying to navigate a building, often particularly problematic in large or confined spaces.

These common discrepancies in environmental and bodily perception and comprehension of space between designer and user lead to challenges for people with ASD trying to navigate and function within the built environment.

2.2. Studying ASD and the built environment

The inadequacies of the built environment for people with ASD may stem from a historic lack of understanding and knowledge relating to the design of spaces for neurodivergent people (Heylighen, 2008). Mostafa (2015b) found 'absolutely nothing' on how to design for people with ASD when approached by a group of parents with autistic children in 2002. Mostafa went on to create the ASPECTSS Design Index, defined as the 'first ever set of evidence-based design guidelines to address built environments for people with ASD' (Mostafa, 2015b). The anachronym focusses on seven design areas (Acoustics, Spatial sequencing, Escape space, Compartmentalisation, Transitions, Sensory zoning and Safety) salient for users with ASD (Mostafa, 2015a). Whilst this study seems the most methodical, a plethora of others have independently affirmed Mostafa's findings based on experience in designing for and working with people with ASD ((Beaver, 2011).

The nature of ASD means that 'it is not obvious how to gain access to the range of thought of people with ASD' (Baumers and Heylighen, 2010). Interview questions or reflective techniques usually used to understand building users' needs can be of limited value as 85% of people with ASD are thought to experience Alexithymia, a condition characterised by difficulties in identifying and processing feelings (Heaton et al., 2012; Hill et al., 2004). This leads to a 'shortfall in the ability to name their own emotions' (Zangwill, 2015). Baumers and Heylighen (2015: 329) emphasise that 'emotions play a valuable role in sense-making and influence how people interpret, appraise and explore their environment'. This suggests that a quantitative approach to measuring emotional response that does not rely on an individual communicating them verbally would be particularly beneficial when working with those with ASD. Features that reportedly cause stress to

Table 1
Categorisation of environmental stressors for people with ASD.

Feature	Research
Lighting	People with ASD can be sensitive to bright, flickering or fluorescent lights. Some also find that areas with highly contrasting lighting such as strong shadows can be disturbing. (Assirelli, 2016; Davis-Hofbauer, 2018)
Colour/texture:	Bright or contrasting colours and textures can be a distraction to people with ASD, sometimes causing obsessive behaviours. Some may also find patterned flooring confusing and anxiety-inducing. (Mostafa, 2008)
Acoustics:	Cited by Beaver (2011) as the most important aspect of design for people with ASD, spaces that are loud or allow sounds from outside or other parts of the building to be heard can be extremely difficult as people with ASD often find background noise distracting.
Spatial configuration and scale:	People with ASD generally feel more comfortable in well-ordered spaces which have a clear purpose. Spaces that are very large or small, such as corridors can also cause anxiety if no 'escape' is visible in times of overstimulation. (Matusiek; Baumers and Heylighen, 2010; Mostafa, 2015a)
Social circumstances:	As detailed above, people with ASD frequently struggle to comprehend social situations. Other distractions or sensory stimuli can cause missed social cues, heightening anxiety caused by interpersonal interactions and busy places. (Ghazali et al., 2019)
Presence of 'blind corners' and closed doors:	It is thought that some people with ASD have impaired ability to imagine what lays beyond what they cannot see. Therefore, pictures on doors and provision of maps in large public buildings can help people prepare for what they will encounter, reducing anxiety. (McAllister and Maguire, 2012; Mostafa, 2008)
Abrupt sensory transitions:	Sudden changes in sensory stimuli can cause processing difficulties. It can be necessary for people with ASD to 'recalibrate' their senses on going from one level or type of stimulus to another. 'Sensory rooms' can provide a safe place to do this. (Ghazali et al., 2019)

Table 2
List of participants.

Date of participation	Participant number	Age	Gender	Information about participant
	P7	29	M	Independent – recruited through support group newsletter
10.1.19	P8	27	F	Spectrum (autism provider organisation)
	P9	29	M	Spectrum
	P10	32	F	Neurotypical participant
	P11	23	F	Neurotypical participant
2.3.19	P1	12	M	Dreadnought Aspires
	P2	14	M	Dreadnought Aspires
	P3	14	M	Dreadnought Aspires
	P4	15	M	Dreadnought Aspires
	P5	32	F	Independent - (Came with Carer -recruited through support group newsletter)
	P6	54	F	Independent - Came alone

people with ASD have been collated and summarised below with current guidance on how to mitigate the stress they may cause (Table 1).

2.3. The potential of biometric wearables for inclusive design

GSR has been used to assess emotional response to various stimuli including to gain an overview of response to external urban environments (Nold, 2018; Pykett et al., 2020; Zeile et al., 2015; Birenboim et al., 2019; Fathullah and Willis, 2018; Resch et al., 2015a). Empirical studies by Resch and Zeile take an approach that seeks to use GSR devices for 'extracting contextual emotional information from human and technical sensors' in what they refer to as a 'people as sensors' model. They argue that data from "human sensors' can supplement or sometimes replace expensive and specialized sensor technology and sensor networks' (Resch et al., 2015b) and potentially inform urban planning decision making. A more contextual and people centred method is described by Osborne and Jones (2017) who argue that biosensing can offer a potentially powerful tool for understanding individuals' responses to physical environments, but only when used in combination with other datasets in a mixed methods approach (Osborne and Jones, 2017: 168). This approach is demonstrated by the work of Nold (2009) who, over a decade, has used GSR data gathered from participants to facilitate local groups and city planners to inform an approach to participatory decision making. For example, a project in South east London involved local residents linked up to a GSR device as they walked through an urban area which was used to generate a Greenwich Emotion Map. The map shows that an emotional response was elicited from a 'variety of visual, auditory, taste and smell stimuli' including noticeable reactions to stressful urban features and social interactions (Nold, 2009). A study that focused specifically on urban design features that can cause stress was carried out by the authors (2018). GSR data mapped to GPS location showed that in general, participants experienced lower emotional arousal in green, open areas than urban ones with Stress 'peaks' noted in correlation to crossings and junctions (Fathullah and Willis, 2018).

Whist GSR data has been used to effectively measure response to stimuli on a very small (i.e. a single image) and very large (i.e. whole urban area) scale, there appears to be a lack of precedent for using GSR data on an intermediate, i.e. individual rooms and buildings scale. Concurrent with trends towards technology-assisted inclusivity (Clarkson, 2010), GSR devices could have the potential to help people understand and deal with their emotional response to the built environment and its stressors.

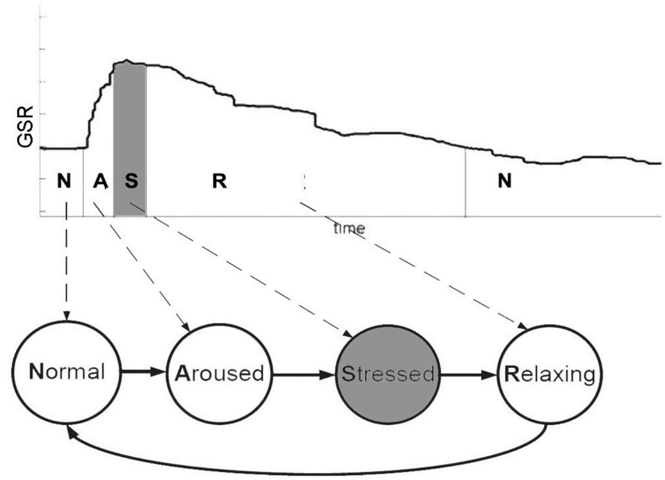


Fig. 1. (Found in, adapted from Bakker et al. (2011)):— 'An example of acute stress pattern observed from GSR data and how it can be mapped to the symbolic (time-stamped) representation of person's stress'.

3. Method

3.1. Methodological approach

The method we introduce we have termed an 'EDA Audit'; that is an audit of the Electrodermal response of a person to an internal building environment. We propose that an EDA audit is a method for measuring emotional response that can indicate stress levels correlated to location and specific environmental features such as room lighting and acoustic levels, as well as spatial features (as described in Table 2). The method indicates that it is possible to correlate GSR emotional response data to internal location and relate it to specific spatial features.

Galvanic Skin Response (GSR) is a form of electrodermal activity (Dawson et al., 2007) and is considered 'one of the most sensitive and valid markers of emotional arousal' (Kyriakou KR et al., 2019). GSR devices measure tiny changes in sweat secretion (Boucsien et al., 2012) that occur when a person is exposed to an emotionally arousing situation (also referred to as 'emotional sweating'). GSR is modulated by the autonomic sympathetic nervous system meaning that it cannot be controlled consciously. A GSR device measures emotional response by tracking marginal changes in sweat secretion from eccrine sweat glands and GSR can therefore be said to offer a measure of stress (Kyriakou KR et al., 2019). Fig. 1 shows how 'peaks' in GSR readings can be identified as stressful stimuli and corelated to time (Fathullah and Willis, 2018).

3.2. Participants

The study took place in two phases; the first with five participants; three participants who identified as autistic and two participants who identified as neurotypical. The second phase was with six autistic participants who were recruited via autism provider groups and support groups. The participants were selected on being a similar age and having never visited the Tate St Ives gallery before. Due to the sometimes stressful and unpredictable nature of ASD, the participants from Spectrum had their key workers accompanying them.

Nine participants who identified as autistic and two participants who identified as neurotypical took part in this research which was carried out on two separate occasions in January and March 2019 (see Table 2). Five out of nine had never visited the Tate St Ives gallery before. Participants were recruited through tow autism provider support groups

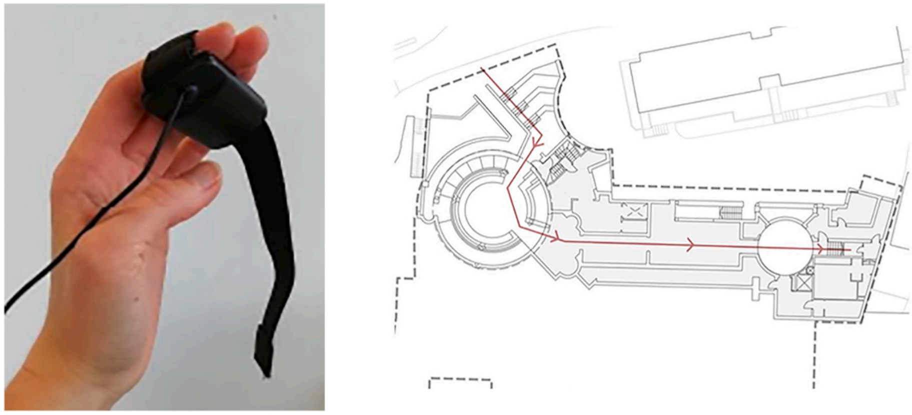


Fig. 2. (**a**) GSR device (**b**) route of study walk.

and networks in Cornwall, UK. Spectrum is a Cornwall based group that provides residential care and to support for adults and children with ASD.[1] The organisation was contacted in an initial step to accessing potential participants and identified two individuals in care of Spectrum who would be suitable to participate in the research: both participants have typical autism (P8 and P9). Four participants were young people who attend the Dreadnought Aspires activity group (P1, P2, P3 and P4).[2] The participants from both Spectrum and Dreadnought Aspires had their Key Workers accompanying them during the study. Three further participants were adults who were contacted via autism support groups; two were adults (P5 and P6) and one, P7 who has atypical Asperger's (a condition that is part of the Autism spectrum, associated with an average or above intelligence and fewer problems with speech than typical Autism). The two neurotypical participants were, both post-graduate students from the University of Plymouth (P10 and P11). It should be noted that a visit took typically two to three months to arrange, as those with ASD require any new activity to be planned long in advance. All participants completed an Ethics Informed Consent; either themselves or through a guardian, and participant names are anonymised.

3.3. Setting

Public spaces can be challenging and often exclusionary environments for people with ASD. This is particularly true of art galleries (Amaze, 2018) which, by necessity often feature bright lights, narrow corridors which open into vast galleries and acoustic-reflecting surfaces. They can also become crowded and have unpredictable spatial configurations. As described above, these features can be stressors for people with ASD. For this study we worked with a national museum; The Tate St Ives, which is ranked in 115 amongst the most visited attractions in UK, and in 2018/2019 had over 300,000 visitors. In 2018 the Tate art gallery initiated the 'Welcome Project' aimed at increasing visitor numbers amongst previously excluded groups including the visually impaired, deaf and those with ASD. The gallery has existing provision for visitors who are wheelchair users, visually impaired or dyslexic. As part of the Welcome project The Tate identified the need to improve accessibility for people with ASD, and as a result the study was undertaken in collaboration with Zara Deveraux; Senior Visitor Experience Manager for Tate St Ives.

3.4. Method and equipment

A quiet room in non-public area of the gallery was provided for all the participants to meet the researchers and participants arrived via a side entrance before starting the study. This was because we established from the support organisations that many of the participants would not visit spaces such as the gallery due to issues with the stress it would cause and as such we sought to create a safe space before and after the participation in study. Participants were asked to complete a short questionnaire about the types of space they thought they may find challenging to be in. This provided a basic understanding of participant's existing awareness and knowledge of spatial stressors. Participants were then asked to wear a GSR device (Emet Stress Detector) on their fingers (Fig. 2a) attached to a laptop running an accompanying GSR visualisation software called GSR Studio. The study involved a typical 'visit' to the gallery (Fig. 2b); data was first calibrated for a few minutes at the start of the study and then recorded during the first five to 10 min of participants' visits; from when they were just outside the entrance of the museum, to entering the second gallery. Participants were asked to carry the laptop in a shoulder bag and whilst participants walked around the gallery their movements were recorded on a small video camera carried by the researcher who followed unobtrusively from a short distance away, so that they were not aware of the filming. Most participants were accompanied by a carer or guardian and did not report discomfort with being accompanied or filmed. The time stamp of the video recordings enabled the GSR data to be correlated with spatial location to within about 1–2 m during the study. The spaces the participants were required to walk through had a variety of levels of environmental stimulation including different levels of sound, lighting, visual stimulation and number of visitors. These qualities were mapped prior to the study (see Table 2). After walking around the gallery, participants were taken back to the quiet room within the Tate and asked to reflect on their experience. This helped the researcher understand participants' ability to convey and understand their own spatial experience.

3.5. Limitations of the method

We acknowledge that there are a number of limitations to the method described above. The research is presented as a trial study in real world conditions on the possibility of using EDA from a GSR device to understand spatial experience of people with ASD within buildings, and not as a clinical study. The study was undertaken in real world environment of a typical gallery visit, and as such we sought as far as possible to gain qualitative feedback and self report data to support the quantitative GSR data. There were a small number of participants, and although we included a control of two neurotypical participants this was only indicative and not a true control. In terms of the data, the results of this study are presented comparatively showing the difference or similarities between participants rather than as discrete (2018), and given the huge variety in the way ASD affects people (NAS, 2018), we can only hypothesize as to the correlation with emotional response and

[1] https://www.spectrumasd.org/.

[2] https://www.supportincornwall.org.uk/kb5/cornwall/directory/service.page?id=IbG81_sDERw.

Table 3
Audit of environmental features of gallery space identified as potential environmental stressors for people with ASD.

Location in Gallery	Potential Emotional Stressor	Spatial features and characteristics
Outside	None identified	Open, picturesque views of the coast separated by a quiet road.
External Stairs	Blind corners	Angular brick and slab stairs. It is not possible to see where the stairs lead. A sharp, 90° turn is required and there is no visibility.
External Atrium (Fig. 3a)	Unclear spatial configuration/blind corners	Circular atrium overlooked on by several storeys of the gallery. It has multiple accesses.
Lobby	Sensory transition	Quiet with minimal furnishings accessed by two sets of glass sliding doors.
Foyer	Social circumstances	Change in ceiling height and colour use. Stairs, reception desk visible. Presence of reception staff.
Lower Gallery	Lighting/colours and textures	Change in floor surface. Some sculptures. Presence of multiple doors.
Staircase (Fig. 3 b)	Sensory transitions/ spatial configuration	Fairly narrow with multiple winders. Colourful line drawings. Tight corners and several landings to navigate before finding gallery.
Landing	Spatial configuration	Minimal furnishings. It is not obvious which way the galleries are. Minimal signage and several options of where to go.
Lift	Unclear spatial configuration/blind corners	Small lobby and lift with possibility of close-proximity encounters.
Gallery 1 (Fig. 3c)	Lighting/colours and textures	Brightly lit with white floor, wall and ceiling. Colourful paintings and sculpture.
Gallery 2	Lighting/colours and textures	Grey walls with a greater variety of textures and information on display.

participant's autism. In terms of the equipment, we used a a low-cost GSR device that cannot be assumed to have the same level of accuracy as clinical grade equipment. Similarly, we were able to use video recordings to correlate spatial location to GSR data at a high level of granularity (1–2 m) but could not account for the specific stimuli that may have caused an emotional response.

4. Results

4.1. Spatial audit

The researchers visited the gallery space and undertook a qualitative audit of the potential environmental stressors and features of the space (Table 3). Spaces included a variety of spatial variations such as size, proportion, lighting and acoustics were identified on building plan.

4.2. Pre-visit survey

All participants reported that they 'always' or 'usually' enjoy going to new places and four out of five 'rarely' or 'never' feel worried about going somewhere new, except for P7 who found some of the questions difficult to answer due to their subjective nature, all participants were able to identify their favourite place(s) but did/could not specify any places that they do not like to visit. The scaled questions that related to specific spatial qualities however, seemed to give a less positive account of spatial experience of people with ASD. The answers given by the nine participants with ASD are summarised in Table 4. It can be noted that the participants with ASD have reported feeling much less comfortable in most circumstances than the neurotypical participants.

4.3. Post-visit survey

Only five of the nine autistic participants completed this post gallery interview, and three stated that they felt 'very comfortable' or 'fairly comfortable' in all areas of the gallery despite GSR data and initial questionnaire responses indicating otherwise. Although P8 and P9 were enthusiastic in their answers to questions and positive about their visit, they appeared to struggle to give a reflective answers and elaborate detail. P8 repeated the same phrase 'brilliant actually' in answer to nearly all the questions, and it does not seem likely that anyone would consistently feel so positive in a sequence of spaces that were so qualitatively different. This suggests that P8's responses may not be representative of his actual emotional response during the visit. Similarly, P9 stated that she enjoyed 'all' of the gallery but could not pinpoint any specific features she appreciated. Conversely, P10, one of the neurotypical participants, reported that she 'didn't feel that the entrance was very welcoming … the path wasn't really clear or defined', and this response matched with the GSR data graph that showed an increase in emotional arousal around the time she was on the external stairs. The discrepancy in verbal response and GSR data for the autism participants concurs with Zangwill's (2015) assertion that some people with ASD struggle to conceptualise and articulate their emotions.

4.4. EDA audit

4.4.1. General trends in emotional response

Figs. 4 and 5 shows overlaid graphs of GSR readings; Fig. 4 shows the first visit with two control participants and Fig. 5 the combined data for the autistic participants. The start time is the point at which participants

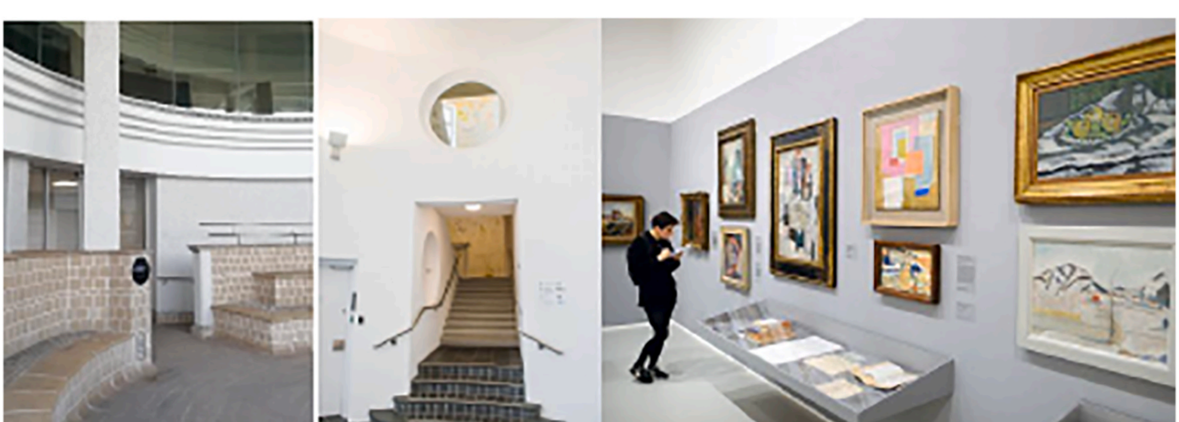
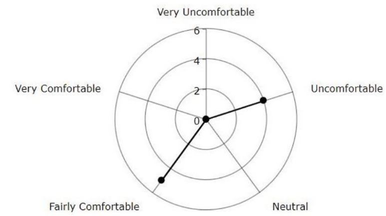
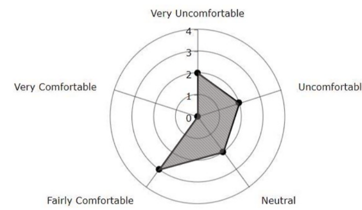
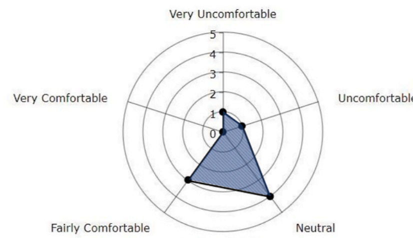
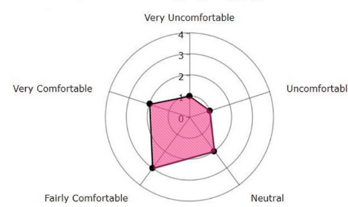
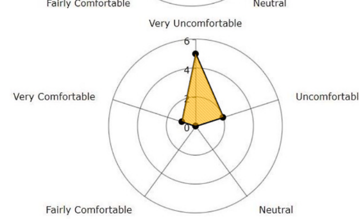
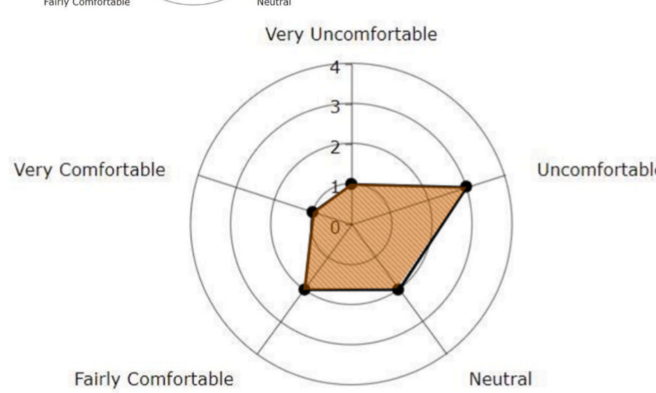


Fig. 3. Photos of three gallery spaces (**a**) Main entrance; (**b**) Main stairwell to gallery c) typical gallery space.

Table 4
Star self report response to spatial qualities.

Lighting (Response to question: How comfortable do you feel in places with bright lights?)	
Acoustics (Response to question: How comfortable do you feel in places that are loud or have lots of different sounds?)	
Colours and Textures (Response to question: How comfortable do you feel in Rooms that have lots of different textures or colours?)	
Spatial Configuration (Response to question: How comfortable do you feel when you don't know where you are going to be next?)	
Social Situations (Response to question: How comfortable do you feel in places where there are lots of people?)	
Blind Corners (Response to question: How comfortable do you feel when you cannot see round a corner?)	

turned to enter the ramp or external steps leading into the gallery.

All participants had higher emotional arousal (which can be correlated with higher stress levels) at the end of the visit than at the beginning, but all the autism participants had higher arousal than the two neuro typical participants. This suggests that the participants experienced increased stress levels as their visit progressed, but these levels were higher for all the participants on the autism spectrum. For six out of the nine participants, stress levels appear to increase continuously throughout the visit; neither decreasing significantly nor returning to the starting level. Interestingly, two of the participant's (P1 and P4) stress levels decreased during the first few minutes of the visit but then increased rapidly on entering Gallery 1. P6's GSR graph also shows some decreases in stress levels whilst she was outside of the main gallery space.

4.4.2. *Correlation between GSR data and specific spatial features*

Results indicate a clear correlation between specific spatial features and a sudden increase in emotional arousal (or stress 'peak'). The spatial

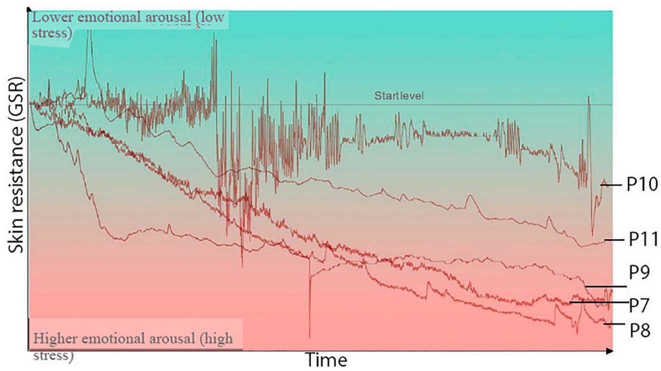


Fig. 4. Graphs of GSR readings for first visit only with five participants (P8–P11)- three on the autism spectrum and two neurotypical (start indicates the time when the readings were started at same location at the entrance to the gallery, Red is higher emotional response).

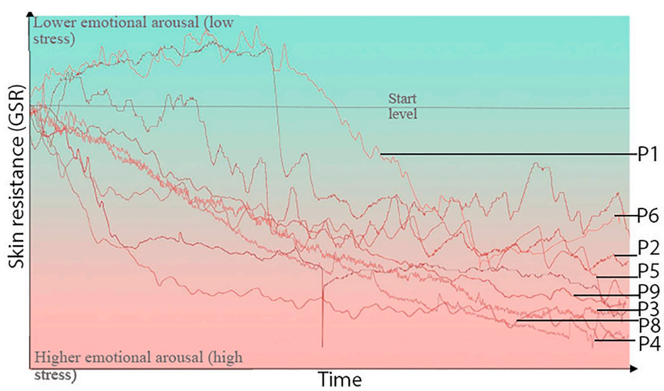


Fig. 5. Graphs of combined GSR readings for autism participants only (P1–P9) (Red is higher emotional response-it should be noted that this is not a direct measure of stress).

and environmental features that seem to cause the 'peaks' can be linked to the potential spatial stressors identified in Table 3 above and are summarised as blind corners, social circumstances, spatial configuration and sensory transitions. These appear to correlate with the location and characteristics of the environmental features that were identified on the spatial audit. The data shows that in addition to the areas already noted, the external access slope (Fig. 6a), and door to Gallery 1 (Fig. 6b and c) seemed to be heightened environmental stressors for all the autistic participants.

Other spaces that caused a stress peak response in a number of participants were the transitional spaces between galleries. The GSR reading graphs for each participant, highlighted 'stress peaks' and their possible cause. Each peak is colour coded in association with one of the identified spatial stressors. More in-depth analysis of participant's individual GSR data graphs indicates a clear correlation between specific spatial/social features and sudden increase in emotional arousal (or stress 'peak') (see Figs. 6–8).

It can be noted that all autistic participants experienced multiple sudden increases in emotional arousal (stress peaks) on encountering blind corners (orange), particularly at the top of the entrance steps. A dramatic example of this can been see on P7's GSR data graph when he entered the lift. Social interactions (yellow) seemed to produce 'stress peaks' in two of the participants; visible on P5's and P7's GSR data graphs at the reception desk and later when speaking to other visitors or the researcher at the end of the study. All the autistic participants seemed to express confusion during their visit due to spatial configuration (blue). This occurred largely in relation to use of stairs. Finally, P3's and P5's GRS data graphs showed 'stress peaks' as they transitioned between areas of differing sensory stimuli (green). Conversely, P7 seemed to relax as he made the transition from inside to out. During the post-gallery interview he was stated that at this point he 'knew where he was going' so felt more at ease. This may also support findings of Gaines et al. (2016) who suggest that clear lines of vison, such as that through the Lobby and Foyer at the Tate are more relaxing for people with ASD.

5. Discussion

Results obtained from this study illustrate a correlation between emotional response and internal location which suggests that people with ASD find the built environment more stressful than the neurotypical. It is also evident that some people with ASD may not be able to accurately convey their own emotions in relation to space. This study has provided information that could help the Tate St Ives work towards a more inclusive visitor experience. The development of the EDA Audit method also acts as a methodological framework which could be implemented in other public institutions to provide usually unobtainable insight into the spatial experience of people with ASD.

Fig. 6. Heightened emotional response points (**a**) ramp walkway up to main entrance; (**b**) main door entrance to gallery space front view(**b**) main door entrance to gallery space side view.

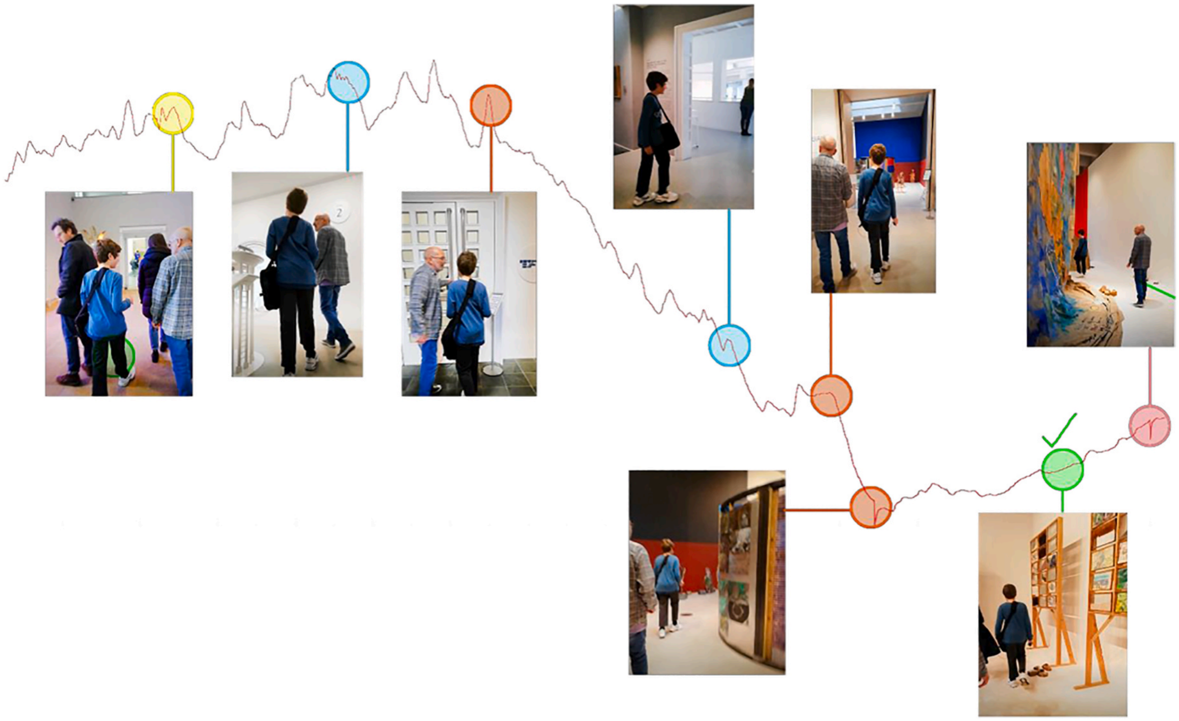


Fig. 7. P1's EDA audit: (**a**) stress peak at main gallery entrance; (**b**) stress peak at second gallery entrance.

5.1. Audit of physical and envionental features and emotional response

Findings indicate that people with ASD experience a negatively changing emotional response to the internal environment of the Tate, St Ives over the course of a visit. Perhaps most significant is the overall increase in stress levels experienced by people with ASD from before to after visiting the gallery. One explanation for the increased stress of participants with ASD could be the presence of bright lighting and sometimes echoing acoustics (Beaver, 2011; Humphreys, 2005; Mostafa, 2016) throughout the gallery. Whilst it was initially assumed that the presence of these features would cause 'stress peaks' as they were encountered, it seems more likely that they actually contributed to the overall increase in stress level throughout the visit. We speculate that this could be due to an accumulation of stressful stimuli over the course of the visit in which the participant was not able to fully recover (Gillott and Standen, 2007). Although it is likely that bright lighting and large, echoing spaces (leading to echoes) are necessary to effectively exhibit art, effects of overstimulation could be mitigated by providing 'quiet opening' times when visitor numbers are restricted, as has been successfully trialled at a number of museums including the V&A (Kids in Museums, 2018).

As expected, links can also be made between specific spatial features and emotional response (ie. 'stress peaks'). The features that most noticeably trigger 'stress peaks' can be categorised into four in accordance with the features reviewed previously in this paper.

- Spatial sequence: As suggested by Shell (2017) and others, it seems a lack of clear spatial sequence and places with multiple route options, such as the stair landing of the Tate can cause stress for people with ASD who usually prefer single-directional circulation (Gaines et al., 2016).
- Social interactions such as speaking to staff members at reception or gallery entrances can also be challenging, concurrent with findings of Gaines et al. (2016). Other unexpected interactions like receiving instructions from the researcher also caused an increased emotional response.
- Blind corners, including on stairs, lifts and the Tate's entrance seem to be a prominent feature that causes a stress peak and then rise in stress, possibly due to limited ability of people with ASD to 'elaborate a mental image' (Sánchez et al., 2011) of what may lay beyond what they cannot see.
- Sensory transitions and spatial transitions in general, also seem to cause increased stress, a result that is in line with the findings of Mostafa (2015b) and others.

5.2. Inclusive building design

The EDA Audit results indicate that people with ASD found the Tate gallery visit stressful. This is a significant departure from the impression given by the post-gallery interviews in which two out of the three participants with ASD reported feeling 'very comfortable' in all the gallery spaces. This can be caused by the prevalence of Alexithymia among people with ASD which causes difficulties in identifying, processing and describing one's own emotions (Heaton et al., 2012; Hill et al., 2004). It is possible that participants were not aware that they were feeling stressed so reported seemingly unrepresentative emotions. Research shows that people at the higher-functioning end of the ASD spectrum (like those who participated in this research) are often aware of their own social limitations (Gaines et al., 2016) and may try to compensate by 'acting normally' or feigning a positive experience.

The discrepancy in objective and self-reported results suggests that EDA Audit has provided an insight into spatial experience of people with ASD that would not be available using traditional methods of self-reported user consultation. As Heylighen advocates, those with different abilities are 'most vulnerable to exclusion by inappropriate design' but also 'able to detect misfits (i.e. disabling barriers in the built environment) that most architects are not even aware of' (2008: 539). This highlights the need for a collaborative approach between architectural practice, academic research and user groups to ensure that appropriate methods of understanding all potential users' needs is implemented. GSR technology, already used to assist people with ASD could offer an unobtrusive, accessible means of doing this.

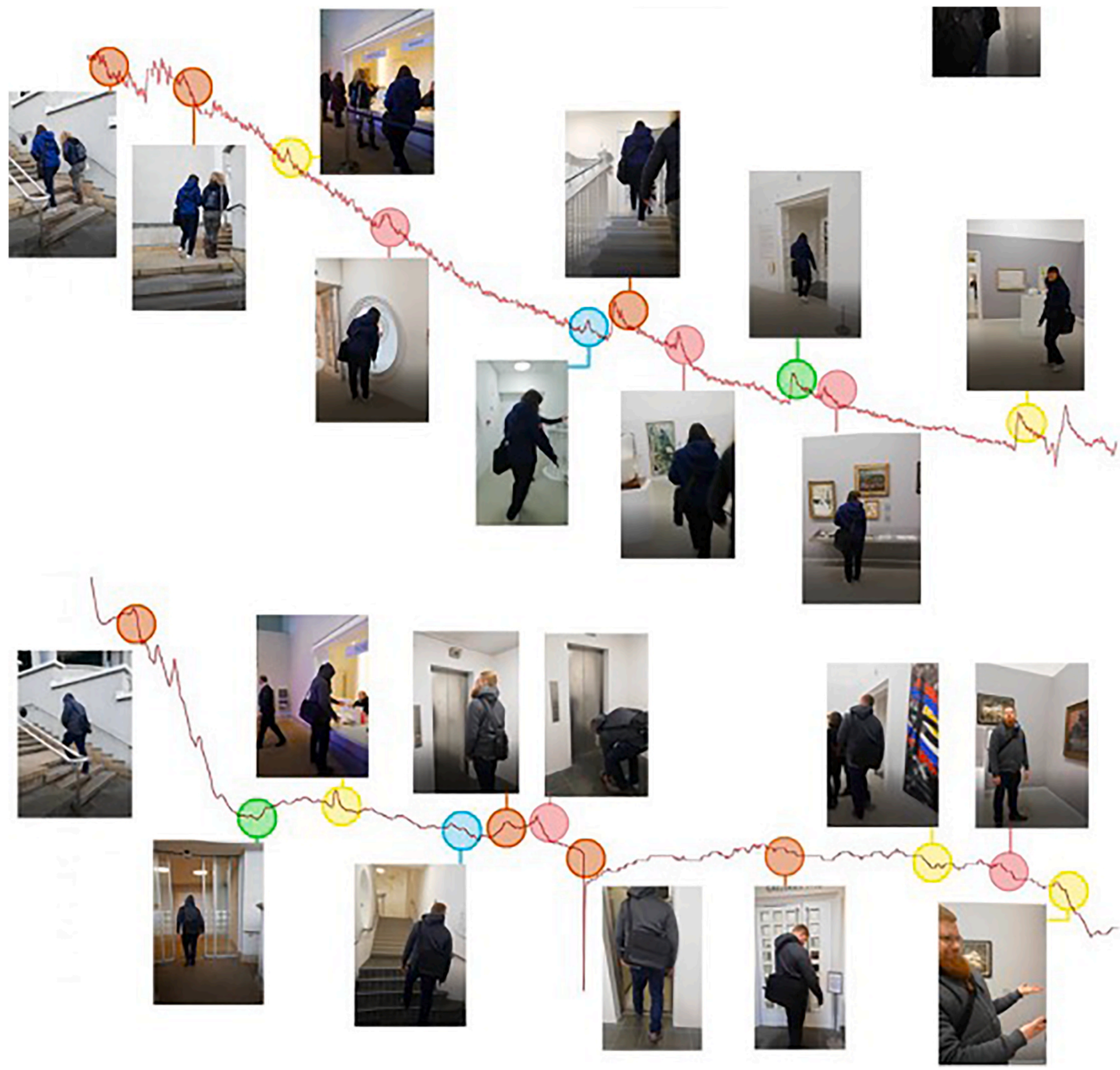


Fig. 8. P5 and P7's EDA audit: (**a**) stress peak at main gallery entrance; (**b**) stress peak at second gallery entrance.

6. Conclusions

There has been a significant lack of research into how architects can design inclusively for people with ASD (Sánchez et al., 2011; Beaver, 2011; Shell, 2017). This is partly due difficulties in gaining self-reported insights into their spatial experience (Baumers and Heylighen, 2015). From the results it was possible to generate a list of general and more specific features within the Tate St Ives that appear to cause stress to people with ASD. However, there is scope for the EDA Audit methodology used here to be repeated in other venues who wish to gain a more in-depth understanding of their visitors' experience. The development of the EDA (Electrodermal Activity)Audit method would also be possible to collate data gathered in multiple locations over time to build a much-needed broader understanding of spatial stressors for people with ASD. This would provide a quantitative evidence-based framework for design for ASD that would build on Mostafa's (2016) ASPECTSS framework, filling the need identified by Smith (2009) and others (Gaines et al., 2016; Beaver, 2011; Imrie and Hall, 2001) for a greater research and practice focus on inclusive design for ASD and other neurodivergences. As designers look to embrace the previously excluded, 'seeking resonance' between themselves and future building users, it is important that accurate requirement information from all users is considered (CABE, 2006). The EDA Audit method could give those who have previously been unable to contribute to the design and organisation of the built environment a voice, allowing them to exercise their 'right to participate' in the decisions about what is built, a step towards inclusive design.

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