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Gender differences between the emotions experienced and those identified in an urban space, based on heart rate variability

Daniel Paül i Agustí [a,*], Teresa Guilera [b,c], Montserrat Guerrero Lladós [a]

[a] Departament de Geografia i Sociologia, Universitat de Lleida, Lleida, Spain
[b] Psychiatry Service, Santa Maria University Hospital, Lleida, Spain
[c] Institute for Biomedical Research in Lleida Dr. Pifarré Foundation (IRBLleida), Lleida, Spain

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SUMMARY

The effects that urban spaces can have on people have been analysed by various means. However, in the majority of cases, such analyses have been carried out after the event and based on memories of what was experienced. Such an approach can limit the number of emotions identified. The current research analyses the extent to which emotions identified after an event coincide with those experienced *in situ* (obtained using measurements of heart rate variability). The results highlight relevant differences between the emotions identified *a posteriori* and those experienced at a given moment. Specifically, significant differences in the perception of space according to gender have been identified: spaces in which fear was experienced and identified by men tended to differ from those identified by women.

1. Introduction

The American Psychological Association defines "emotion" as a complex pattern of reactions, involving experience-related, behaviour and physiological elements, through which an individual processes a personally significant matter or event. The academic literature reports several different approaches that have been used for measuring emotions. Based on phenomena such as the reactions of facial muscles, there has been a tendency to consider four basic emotions: fear, sadness, anger and happiness (Jack et al., 2014). These primary emotions, which are considered universal responses, are fundamentally physiological, evolutionarily relevant, and biologically and neurologically innate. In contrast, other emotions, which are largely regarded as secondary, can result from a combination of the primary ones and are generally taken to be socially and culturally conditioned.

Of the primary emotions, fear is the one that has been most investigated. It is one of the most intense and unpleasant emotions and causes apprehension, discomfort, worry, concern for one's own safety, and a feeling of a loss of control. This particular investigation mainly focuses on fear.

Historically speaking, emotions such as fear have been measured using approaches based on behavioural, physiological, and cognitive variables (Lazarus, 1975). More recently there has been a tendency to use a multilevel, multi-disciplinary approach based on three measurable dimensions (Schweiger & Torregrosa, 2016): (1) emotional valence, which describes whether emotions are pleasant (happiness, interest) or otherwise (anger, fear, sadness); (2) activation or emotional intensity (arousal), a field in which biometric sensors are usually used; and (3) dominance, which gives greater importance to the level of self-control over emotions, or even of being controlled by others, and which is also based on various psychometric tools (Mehrabian & Russell, 1974).

Most research has tended to use only a two-dimensional model in which the main variables used are valence and arousal. The two-dimensional valence (pleasure) - arousal model (Prayag et al., 2017) allows us to describe emotions based on their spatial coordinates and is an approach that has been used in numerous experimental psychology studies.

However, this information is often obtained from data collected *a posteriori*: from surveys, newspapers, or photographic record, amongst other sources. Such methodologies imply certain limitations, as their results are based on the memories that people have of their experiences. These memories may vary over time and be affected by other factors, such as: previous or subsequent experiences, the emotional state of the person at the time of compiling their answers, or the environment in which the samples were collected.

These changes in memories are especially relevant when

* Corresponding author.
E-mail addresses: daniel.paul@udl.cat (D. Paül i Agustí), tguilera@gss.cat (T. Guilera), montse.guerrero@udl.cat (M. Guerrero Lladós).

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experiments are conducted outside the laboratory. In a laboratory, the environment can be controlled to create a unique, and easily identifiable experience. In public spaces, the participants may already have first-hand knowledge of the area, have had previous news about it, or even have prior prejudices toward it. All of these factors can condition the experience that they have.

The present research highlights these differences by comparing the emotions experienced by a group of participants at a particular urban space with those that were identified. To be more specific, in the present research, arousal was determined based on a spatial analysis of the level of intensity of the emotions experienced and their activation and measured by heart rate variability (HRV). Based on descriptions of the experiences of the participants (revealed through mental maps and brief written summaries), we identified the different emotions experienced in the urban space. This information was then contrasted with data obtained from the Self-Assessment Manikin (SAM) for valence and arousal, which was obtained at different points along the route.

The research was therefore focused on analysing the relationship between the emotions experienced and those identified in an urban space, with the following objectives:

a. To identify coincidences and divergences in the spatial distribution of the emotions experienced and identified.
b. To locate possible gender-related differences in this distribution.

This study should therefore be viewed as part of a line of research focused on improving our knowledge of the emotional states experienced by people in cities. This is an approach that can be used in any type of urban space and which could help to identify emotionally problematic spaces with a view to improving them and thereby achieving more user-friendly cities.

2. Theoretical framework

2.1. Identifying emotions in public spaces

It is widely agreed that emotions are multicomponential responses that consist of coordinated changes in subjective feeling, motor expression, and physiology (Mauss et al., 2005). It is therefore necessary to differentiate between those emotions which, by definition, are triggered by something specific in an individual's environment, and other affective concepts, such as moods, which may vary for no apparent reason (Rosenberg, 1998). In the current work, emotions were considered to constitute intense feelings of affection caused by a specific stimulus (person, object, event or situation) which resulted in a specific behavioural response (Prayag et al., 2017).

Wu et al. (2019) suggests that HRV, rather than the valence dimension (*i.e.*, positive or negative feelings) can be used as a potential index for discriminating emotions related to approach or avoidance motivation. This is possible because emotions cause changes in HRV (Thayer & Lane, 2000). HRV refers to beat-to-beat fluctuations in heart rate. This physiological phenomenon is caused by the intervention of the autonomic nervous system (ANS), which can be subdivided into the sympathetic system (SNS), whose role is to excite, and the parasympathetic system (PNS), whose action is inhibitive. Kreibig (2010) highlighted this in her studies on fear where she pointed to broad sympathetic activation, in which reactions included cardiac acceleration, increased myocardial contractility, vasoconstriction, and increased electrodermal activity.

Some other authors have also pointed to the possibility of using HRV to measure stress. Stress is an emotional response caused by an external, short-term trigger (Spellenberg et al., 2020). Psychological stress can be defined as a psychological state that occurs when an individual perceives that environmental demands either noticeably tax, or exceed, their adaptive capacity (Cohen et al., 2007). It has been suggested that the sympathetic activation and parasympathetic withdrawal of autonomic nervous functioning during acute stress can be evaluated using HRV parameters (Spellenberg et al., 2020). However, contradictory and inconsistent results have been reported in the relationship between HRV parameters and stress (Oh et al., 2021). It is not, therefore, possible to assert that certain specific HRV parameters represent stress, although some recent studies have pointed to HRV parameters being highly correlated with stress (Kim et al., 2018).

The majority of authors point to a link between emotions and spaces which would make it possible to map emotions (Pánek, 2019). That said, to date, few authors have analysed the relationship between emotions and the physical spaces in which they are produced (Kothencz & Blaschke, 2017). Authors like Lewin (1951) state that people's behaviour could be influenced by personal characteristics as well as by the environment. Lefebvre (1974), on the other hand, highlights the importance of the interaction between emotions and the city. More recently, it has bene shown that every experience at a particular location can evoke an emotion (Mody et al., 2009).

In recent years, the appearance of portable measuring instruments has made it possible to analyse emotions in public spaces using a quantitative approach (Wilhelm & Grossman, 2010). This methodology has reinforced the connection between emotions and places (Ashkezari-Toussi et al., 2019). A connection has also been made through which emotions help to explain the relationship between people and the urban space (Barclay & Riddle, 2021).

However, despite these advances, there are still relatively few studies that focus on these methodologies (Pignatti Teixeira et al., 2020). Generally speaking, the existing works tend to have two main limitations principals:

1. They try to find homogeneous relationships between emotions and spaces, ignoring certain types of behaviour associated with specific groups (Fathullah & Willis, 2018).
2. They take a homogeneous approach to analysing the whole of the city, which makes it difficult to observe very specific relationships in certain specific urban environments (Weijs-Perrée et al., 2020)

These limitations imply ignoring the fact that each citizen may have different relationships with the urban space (Greenberg Raanan & Shoval, 2014). It is therefore necessary to obtain group data which is as varied as possible in order to faithfully reproduce the preferences and needs of the whole of the population (Carmona, 2019). Only in this way will it be possible to identify in which urban spaces it is necessary to take action in order to improve the quality of life of local citizens (Sefcik et al., 2019).

2.2. Public space, perception and gender

One of the fields in which the study of emotions in the public space can have a positive effect is in designing interventions that effectively contribute to devising more effective ways of implementing a gender-sensitive agenda in urban planning (Carpio-Pinedo et al., 2019). Designing the city therefore becomes another aspect of the reproduction of traditional power relations.

Public spaces are not neutral; they are politicised, sexualised, subjective, and gendered (Xu, 2018). This approach to how different genders use physical space is not new. Several authors have worked on the perception of public space and how it can arouse different emotions in citizens. The theory of structuring, suggested by Gidden (1984), has already analysed human behaviour based on a series of 'rules' and 'resources'. He pointed out that there is a dynamic relationship within society that is based on meaning, values and power over space and that: "as actors draw upon rules and resources in specific spatial contexts which are themselves ordered in ways which effect the production and reproduction of central features of our society such as gender and social class inequalities" (Shilling, 1991, p. 24). Other authors, including Bourdieu and Latour, have contributed similar theories (Bargeman & Richards, 2020). These theories have tended to be criticized by other

authors, who have pointed to an apparent denial of conscious decision-making by the actors involved (Archer, 2003).

Some studies have highlighted differences in the perception and use of public space due to what has been referred to as the "geography of women's fear" (Valentine, 1989). This is something that feminist theories have denounced since the 1970s. It is related to emotional costs, and also to the possible costs that may affect women in their professional and economic fields of action (Kern, 2020). As a consequence, there has been a progressive change in the way that public policies are orientated at the city level. This has implied a move from a relatively uniform and standardised model of benefits and services to one characterised by policies that give more attention to the growing visibility of new actors (Carpio-Pinedo et al., 2019). Several other works have appeared in this context, including some that have highlighted the lack of attention afforded to the needs of women in the city.

Authors such as Sánchez de Madariaga and Roberts (2013) have highlighted that around the year 2000, gender transversality became widely recognised as a tool for improving urban planning systems. However, despite this, there has been persistent resistance to taking into account the diverse needs and realities of women and men in the field of urban planning. To avoid this situation, a series of measures have been taken to improve women's perception of safety in the city. These have included improvements in visibility, informal surveillance, planning, signage, crowd management, and community participation (Michaud, 2002).

These focuses have made it possible to identify how men and women attribute different meanings to environmental spatial stimuli, which subsequently affects their behaviour (Carpio-Pinedo et al., 2019). By way of example, various authors have highlighted how women often show higher levels of fear and anxiety than men in the urban environment (Ceccato & Hansson, 2013). This is a situation which has been associated with phenomena such as the presence of activities, the level of street lighting, the maintenance of urban areas, and the use of public spaces (Women in Cities International, 2010).

In the present work, we will focus on analysing gender differences between the emotions experienced and those identified, specifically relating to the role of fear in public spaces. This is a methodology that has hardly been used in academic literature but which can provide important information about the emotions that different urban spaces generate. Identifying these emotions may help to improve the design of public spaces and to prevent the creation of areas that generate negative emotions. In this way, it should be possible to achieve a city which is more user-friendly for all of its citizens.

More specifically, the research will focus on analysing the feeling of fear that is generated in certain public spaces within the city. Fear is considered a protective emotion which is important for survival. The common reaction to fear is a process triggered by the perception of threat. It is characterised by several physiological changes: faster heart beats and respiratory rates and increases in blood pressure and muscle tension.

Until relatively recently, it was assumed that in situations of fear, men and women would react in the same way. However, studies have shown that women are more likely to experience greater fear than men, regardless of the situation (Taylor et al., 2000). Similarly, women more readily identify expressions of fear and disgust, both audially and visually, indicating gender-related differences in the multisensory perception of the expression of emotions (Collignon et al., 2010). Furthermore, as a direct consequence of this situation, women are more likely to develop anxiety disorders (McLean & Hope, 2010), report a greater number of fears, and perceive and report fears that are more severe than those identified by men (Davey & Matchett, 1994). In contrast, men more readily express anger in the same situations (Brody et al., 1995).

However, the majority of studies point to the reporting of emotions being potentially determined by gender stereotypes: evidence of fear in a man may be considered inappropriate behaviour (Fabes & Martin, 1991). A study conducted in 25 countries, which used questionnaires, verified that women emotionally express themselves in more intense and varied ways than men (Pennebaker et al., 1996). However, these differences were not verified when other instruments, such as keeping a daily record of emotions, were used (Seidlitz & Diener, 1998). Along these lines, one piece of work that particularly stands out is that of McLean and Hope (2010), who examined the relationship between gender role and fear under experimental conditions. Although their findings did not support the hypothesis that men do not report fear as much as women and that differences in gender roles encourage this information bias, women did report a greater incidence of subjective anxiety than men.

More recently, fear has been analysed as a sociopsychological process (Chataway & Hart, 2018). It has been observed that the processes related to fear are very familiar for men and women. This suggests that there is a need to improve our understanding of the complex interactions between affective, behavioural and cognitive phenomena. Despite these similarities, it has been noted that women express higher indices of fear, which tend to be associated with greater concerns about sexual harassment and aggression (Pettitt et al., 2017). These phenomena show the importance of analysing this variable as a key element for improving the day-to-day life of the population as a whole.

3. Methodology

3.1. The characteristics of the sample

The study involved 71 participants and was carried out between November 2019 and March 2020. One sample was lost, as a result of technical problems, so the final analysis was based on 70 cases. This was a group of 39 women and 31 men, aged between 19 and 24 years old. The consent of all the subjects was obtained after they had been provided with an explanation of the experiment. Each participant signed a consent form in which they declared that they had been informed of the use that would be made of the data collected and of all their rights in this respect. The data were processed anonymously, using a numeric code.

This number of participants was in line with other studies, such as those by: Millar et al. (2021), based on the experience of 12 cyclists; Shoval et al. (2018), who analysed the behaviour of 68 tourists in the city of Jerusalem; and the pioneering work on the Emomap of the city of Mannheim by Zeile et al. (2009), which formed part of an anonymous project involving 20 aspiring urban planners and architects.

3.2. Designing the itineraries

The research was carried out in the Historic Centre of the city of Lleida: a medium-sized Spanish city, with 140,400 inhabitants (2020). The city's Historic Centre has an area of 15 ha and contains a mixture of historic and modern sub-areas. This used to be the functional centre of the city, but transformations during the 20th century resulted in it losing many of its urban functions and much of its population. In 1887, it had 21,000 inhabitants, but now has only 7000. A relatively high percentage of its population are immigrants and/or people with low incomes. Even so, part of this area still maintains an important level of commercial activity and symbolic functions.

To analyse the emotions that this urban space produced in the participants, we designed a walking itinerary of 3.1 km. We sought spaces that exhibited an important degree of morphological and social variety (Fig. 1). The objective was that the participants should pass through spaces that formed part of the daily life of the city. At the same time, however, we wanted them to go to places that were not usually visited because they had an image, within the urban context, that was associated with certain problems. With this contrast of spaces, we sought to put the participants in situations that were not completely under their control. We thought that these situations were more likely to produce emotional reactions.

Fig. 1. Study area. Route and images of the different public spaces analysed, based on images captured by the participants. Cartographic base: Cartographic and Geological Institute of Catalonia.

To be more specific, the study focused on five points in the city, with the following characteristics:

1. Plaça del Dipòsit (square): a square with an area of 1900 m^2. This has a small area of trees and some urban amenities (a fountain and some benches). The area around the square mainly consists of abandoned buildings or ones that have already been demolished. The square is a meeting place for the city's immigrant population, and particularly for men of African origin.
2. Carrer Companyia (street): a 100-m-long, narrow street (with a width of only 3 m in certain places) with several curves. The housing in this area is in quite poor condition and there are some points with the presence of prostitution.
3. La Cuirassa: a 6000m^2 green space, without trees, inaugurated in 2008, which contains some archaeological remains. It is a place which is not used very much by local citizens.
4. Park of Santa Cecília: a large green area, of 22,000 m^2, with trees. This has various different spaces: for sports, games and walking. Its social use varies during the day: it is a meeting point for children after school, a leisure area for groups of young people, and a space for walking dogs, amongst other things.
5. The main, pedestrian-only, commercial axis: a 500-m stretch of the city's main shopping street. This area contains a large number of commercial premises, including traditional shops and chain stores. The streets are very busy during the day, but have little transit at night.

The participants did the routes on different days and independently. They were organised into pairs and followed a pre-established route which was indicated on a map that was given to them at the beginning of their walk. The participants wore sport-style sunglasses, equipped with cameras, microphones and USB flash drives. These recorded images allowed us to subsequently analyse the routes taken and to verify that no external phenomena could have affected the results obtained.

3.3. *Measuring emotional activation (arousal) through fluctuations in cardiac rhythm*

The measurement of arousal through observed fluctuations in cardiac rhythm is based on the intensity of the stimuli received by the participant (Roessler et al., 1966). In this study, the time that elapsed between each pulse beat (RR), which is known as the Heart Rate Variability (HRV), was geolocated. States of emotional arousal modify this equilibrium and can be measured through changes in HRV (Appelhans & Luecken, 2006). HRV provides a good, and objective, tool for assessing emotional responses (Lane et al., 2009). This approach allowed us to obtain an important quantity of data: 446,946 different measurements.

For the current research, we used the Root Mean Square of Successive Differences (RMSSD): the square root of the average value of the sum of the differences to the square of all the consecutive RR intervals. This provided a good representation for the spatial study of emotional activation (Paül i Agustí & Guerrero Lladós, 2022). Following Michels et al. (2013), we interpreted low RMSSD values as being synonymous with situations of stress. Wu et al. (2019), on the other hand, noted that the RMSSD was significantly higher in the amused state than in those of fear, neutral feelings, or anger, and that HRV was greater for feelings of

anger than of fear. Although both anger and fear belong to negative emotions, anger is often associated with approach motivation, while fear is linked to avoidance motivation, or "freezing up" (Harmon-Jones et al., 2013).

To collect the data used in this study, all the participants were equipped with a Heart Rate Sensor (HRS) and an Android smartphone, which had been specifically prepared for this purpose. To avoid any possible interference, the first 15 min of the exercise was treated as a "warm-up period" (Kim & Fesenmaier, 2015).

Our HRS was a Polar Electro H7. Participants' heartbeats were monitored to the millisecond and transmitted to a IoTool application installed on a smartphone. This was done in real time, using Bluetooth technology, with the application serving as a datalogger. The IoTool also acted as a geo-localizing device, registering both latitude and longitude *via* the GPS incorporated into the mobile phone. The heartbeat and geolocation data were then exported in the form of CSV rows. The HRS registers were subsequently processed, using Matlab R2016b, to obtain the RMSSD. To avoid excessive variability in the RMSSD values, the metrics were calculated based on 60-s window values, which moved at a rate of approximately 1 s per RR. This window was based on work that showed that HRV parameters were not significantly affected by shortening the duration of the time-window in question from 300 to 60 s (Cataldi et al., 2014). The GPS and RMSSD values were finally re-synchronized using the "time" field.

3.4. Obtaining valence and arousal (self-assessment manikin: SAM)

The Self-Assessment Manikin (SAM) was developed by Bradley and Lang (1994). It is a pictographic, non-verbal, instrument which makes it possible to measure emotions on a two-dimensional scale: valence and arousal. As in other studies (Guilera et al., 2020), in order to measure the emotions experienced, it was necessary to use a version of the SAM that had been adapted for studies involving a Spanish population (Redondo et al., 2007). This involved using 5 human figures with a classification scale of 9 points for each dimension. For the valence dimension, the SAM ranged from 1: "unpleasant" (represented by a figure frowning) to 9: "pleasant" (represented by a happy figure). For the arousal dimension, the SAM ranged from 1: "calm" (represented by a sleepy figure) to 9: "excited" (represented by a figure with their eyes wide open and showing irritation). In this study, the participants were asked to complete the SAM scale at four different points along the route: near the Dipòsit Square, Santa Cecília Park, near Companyia Street, and in the main commercial axis. To facilitate the task, four examples of the SAM were included with the instructions that were given to the participants to help them to follow the route.

3.5. Obtaining qualitative information (fear, anger, happiness and sadness)

At the end of the route, the participants returned to their point of origin, removed the various devices and completed a self-reporting questionnaire. This had two parts:

The first asked them to: "Write, a comment on the emotions that you felt during the route (fear, anger, happiness or sadness)". All of this information was then fully examined, and when an exact match to any of the emotions was found, the corresponding point was located on the map. The participants were not given any specific definition of how to characterise these emotions. In this way, we sought to collect their spontaneous reactions, rather than to condition their responses.

The second part asked them to "Draw, a mental map of the route (you can also write down comments, ideas, drawings...)". Here, the aim was to encourage the participants to express the different emotions that they had experienced along the route, but in a different way. The process of registering this information was the same as in the previous case. When participants added an emotion to the map, they also registered which area of the map they were referring to.

4. Results

4.1. RMSSD

In the general sample (Table 1), we observed a clear differentiation between the values registered for men and for women. In the RMSSD, the value for women was 14.19 % lower than that for men. As noted in the section on methodology, we followed the lead of Michels et al. (2013) in interpreting low RMSSD values as being synonymous with situations of stress. It was therefore clear that women experienced a higher degree of stress than men, throughout the route. This is further reinforced when we consider the standard deviation. The values for women were lower and therefore more closely grouped around values that would be associated with high levels of stress. Men presented different values along the route. This was in line with the findings of previous research which showed that male subjects had higher median RR intervals than females (Spellenberg et al., 2020). Other studies showed that female subjects had higher perceived stress and lower HRV parameters than males (Brugnera et al., 2018). These differences could be attributed to differences in emotion regulation strategies (Kelly et al., 2008).

Their valence registers were 13.01 % lower than those of men, which implied that they considered the route less pleasant than the men did. In the case of arousal, the value registered was 17.34 % higher amongst women than men, indicating that they felt greater discomfort. These results show how the trends of the three variables were interrelated and points to a significant difference between the emotions experienced along the routes by men and women.

If we analyse the territorial distribution of RMSSD values, we also find some differences. To be able to compare the 446,946 different individual measurements, we treated the data with a Geographic Information System (ArcMap 10.8.1). The objective was to obtain a map that would simplify the values obtained at each of the different points. To do this, we used the spline with barriers tool. This interpolates a raster surface, using barriers, from points, using a minimum curvature spline technique (ArcGis, 2022). To be more precise, the tool compares the weighted sum of 12 neighbouring cells with the current value of a central target cell to calculate a new value for the target cell. In the case of barriers, they were limited to a distance of 20 m from the axis of the planned route. In this way, we sought to prevent external points and other parts of the route interfering with the calculation. With regard to defining the resolution of the output cell we established a 5 m^2 grid.

The results obtained showed that women tended to present lower RMSSD values (Fig. 2), implying greater stress, along a stretch of the route characterised by a network of narrow pedestrian streets, where there were a lot of immigrants in the streets. Interestingly, along this section of the route, the highest RMSSD value, which implied the lowest stress value, was registered at the only point on the route with a different morphology: the gardens of *La Cuirassa*, a green space, which is open and little transited.

In contrast, in the case of men (Fig. 3), the lowest RMSSD values were mostly associated with streets suitable for road traffic, but without any adjacent constructions (spaces where there were generally fewer people on the street). We also observed low values associated with the Santa Cecília Park, a green area with numerous trees.

In order to compare the two distributions, we obtained a spatial representation of the differences between the RMSSDs for men and women (Fig. 4). To be precise, we used the raster calculator tool to obtain the differential values for each cell based on the two previous rasters. The area around Carrer Companyia, which is characterised by narrow, medieval streets for pedestrian use, tended to cause more stress in women than in men. In contrast, more open spaces, and also the stretch of the route running through the commercial area, which corresponds to the largest concentration of shops, generated more stress in men than women (even so, this higher level of stress than that found in men was still considerably lower than the maximum levels of stress

Table 1
Descriptive analysis of the sample variables.

	RMSSD		SAM			
			Valence		Arousal	
	Average	Standard deviation	Average	Standard deviation	Average	Standard deviation
Men	0.01666	0.16439	5.95238	1.93823	4.20238	2.24698
Women	0.01430	0.02521	5.17816	2.27087	4.93103	2.08423
All	0.01520	0.02231	5.70260	2.15516	4.39780	2.15952

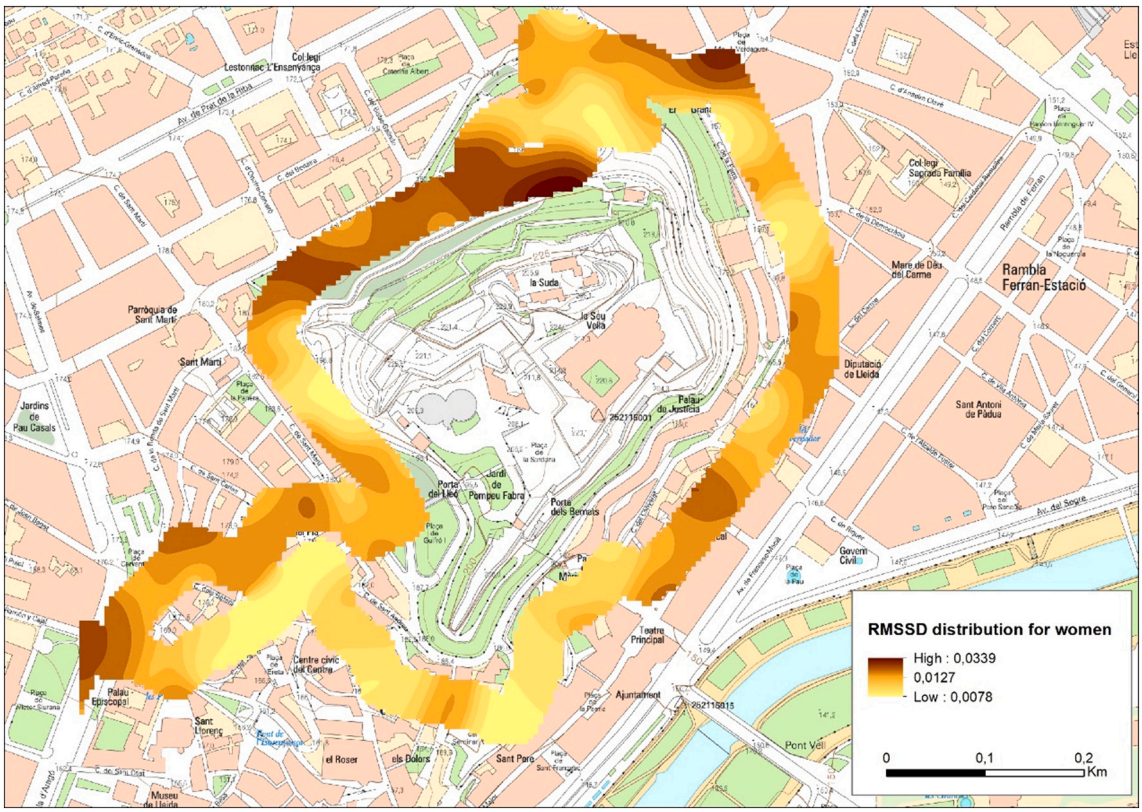

Fig. 2. The RMSSD distribution for women computed from the original point data.

registered by men in certain other areas).

This continuity in the levels of high and low stress was not observed at another point along the route: the pedestrian section of the commercial axis. In this space, the stress levels of both men and women were continually changing, but without following any apparent pattern.

Finally, it should be noted that there were few points where the RMSSD values for both men and women coincided; this would seem to underline the need to analyse RMSSD from a distinctly spatial perspective.

4.2. SAM

Differences between the responses obtained for men and women were also observed in our analysis of valence and arousal, which were also identified using SAM. The results show how 20.51 % of the women showed extremely low values for valence when identifying their experience as “unpleasant”; this compared with 8.6 % of men. 21.37 % of the women exhibited extremely high values for arousal, indicating their experience would be classed as “excited”, compared to 16.13 % of the men. In contrast, 38.71 % of the men exhibited extremely high values of valence, which indicated that their experience was “pleasant”, as opposed to 29.91 % amongst the women. With respect to arousal, 46.24 % of the men exhibited extremely low values, which indicated that their experience was “calm”, compared to 22.22 % of the women. These data implied that women tended to identify unpleasant and excited experiences more than men. In contrast, men tended to identify more pleasant and calm experiences than women.

These values were also unevenly distributed over the area analysed (Fig. 5). For women, the lowest valence values and highest arousal values, which respectively indicated the experience as being “unpleasant” and “excited”, tended to particularly concentrate around the Plaça del Dipòsit and at the Santa Cecília Park. For men, although these points also showed important concentrations, the values were more evenly distributed.

In the case of low arousal values and high valence values, which indicated that the experience was “pleasant” and “calm”, there were comparable distributions of the results obtained for men and women.

4.3. Identifying the emotions experienced

At the moment of identifying the emotions experienced along the route, differences were once again observed between men and women (Table 2). When it came to clearly expressing an emotion (referring to it) women tended to express fear and sadness more readily than men. In contrast, men tended to more readily express happiness and anger.

When we mapped the points where the participants clearly identified

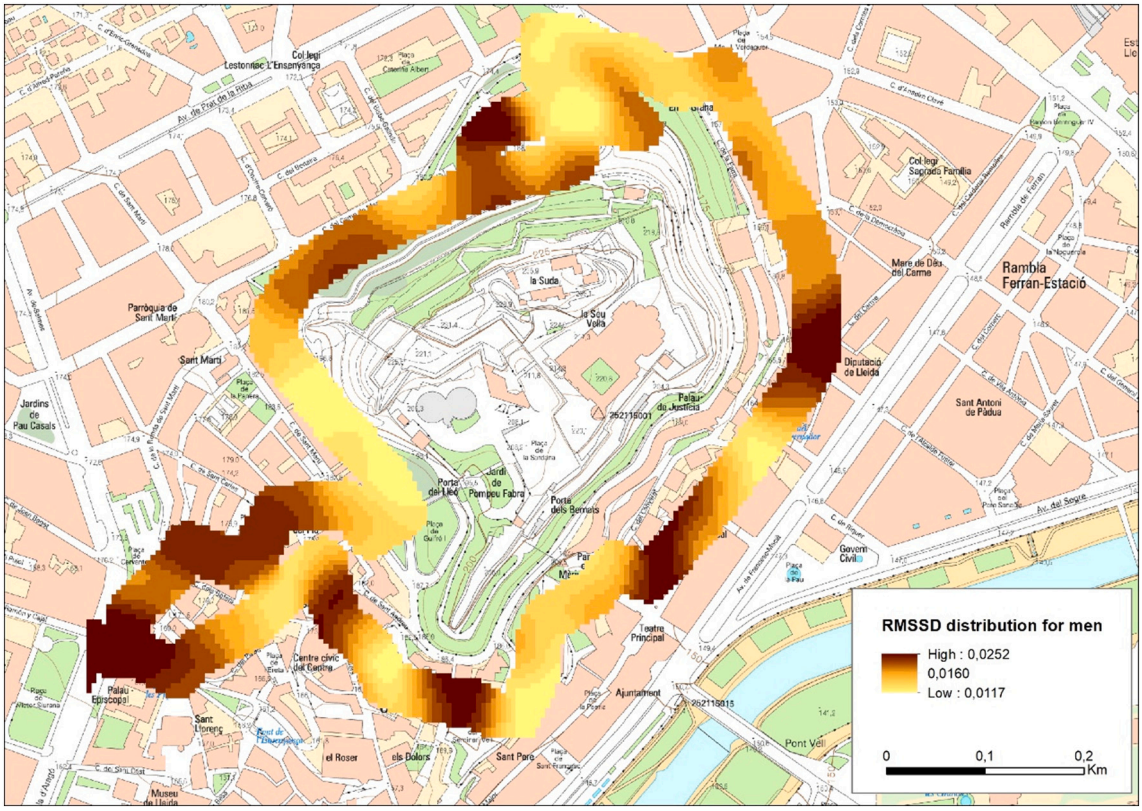

Fig. 3. The RMSSD distribution for men computed from the original point data.

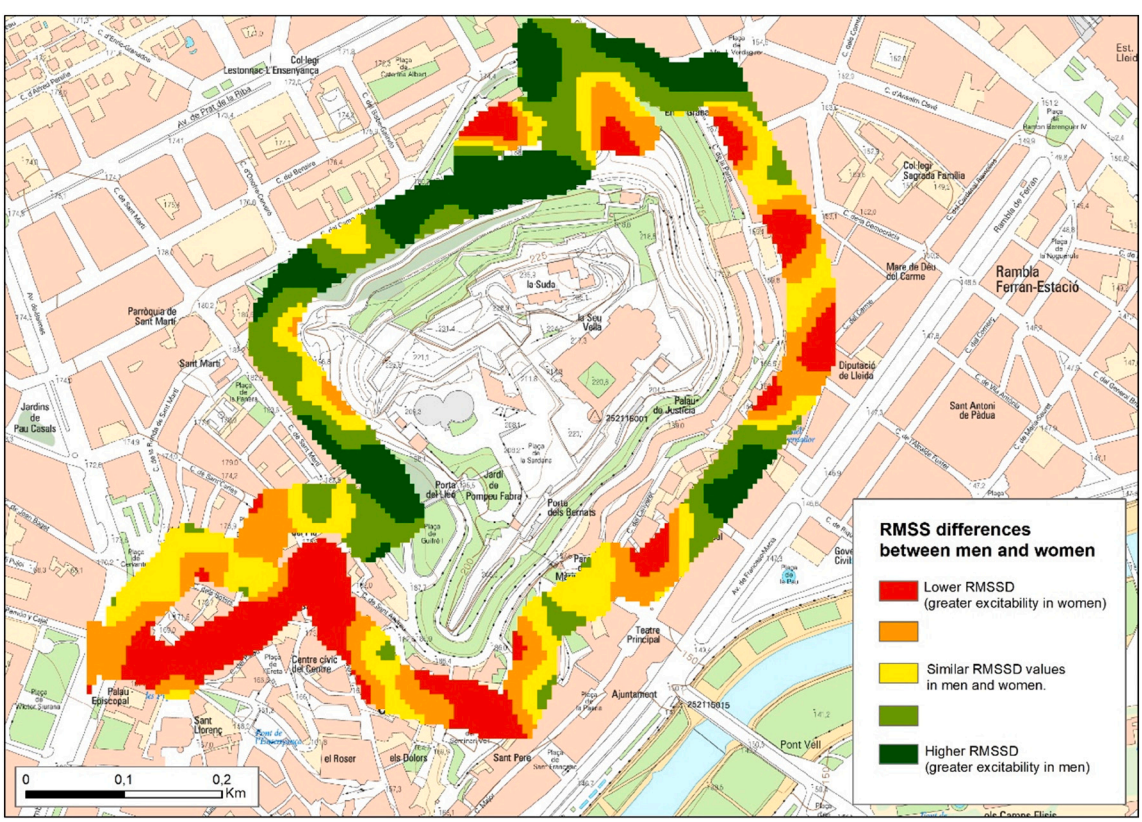

Fig. 4. Comparison of the RMSSD values for men and women computed from the original point data.

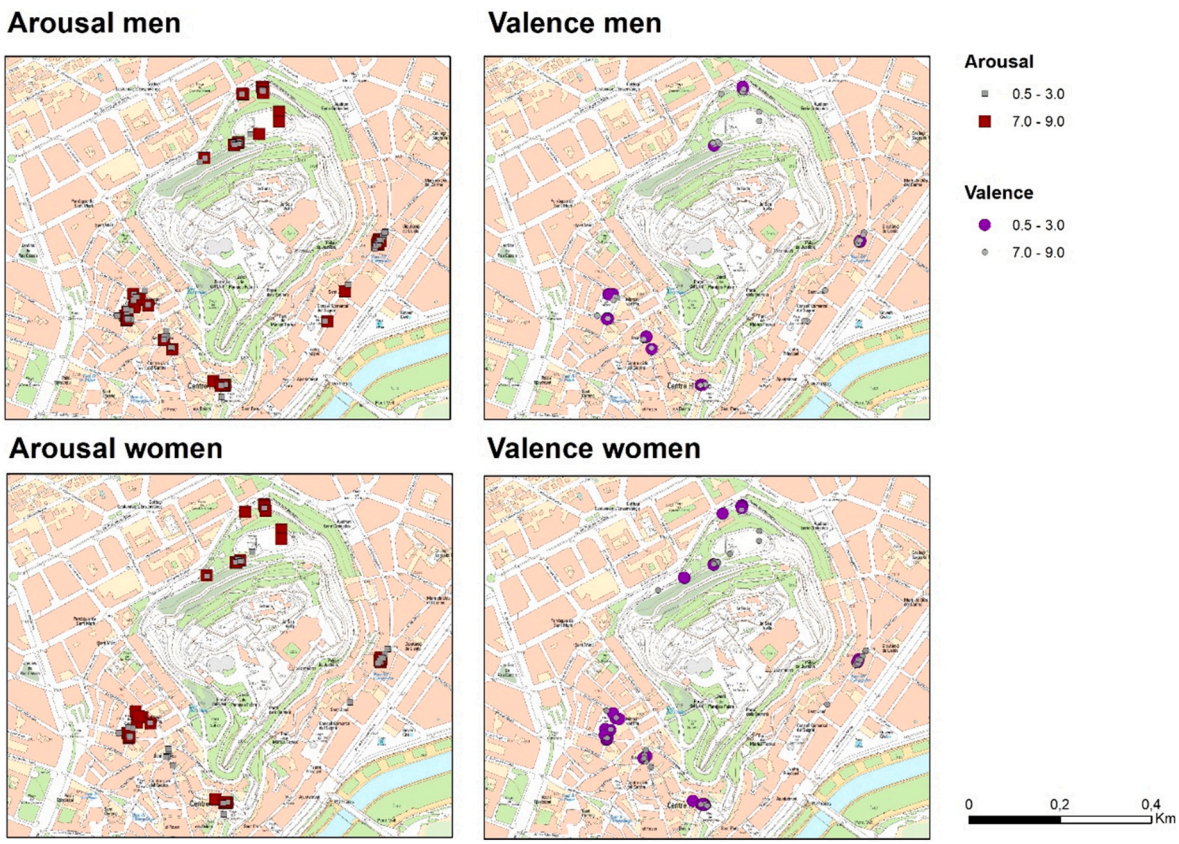

Fig. 5. Extreme SAM values.

Table 2
Descriptive analysis of the emotions clearly identified by the participants. The number of points where the emotion was identified and the percentage of the total for RMSSD values along the route.

	Fear (%)	Anger (%)	Happiness (%)	Sadness (%)	Total number of RMSSD values
Men	4126 (2.43)	604 (0.36)	2281 (1.34)	452 (0.27)	170,011
Women	16,814 (6.07)	314 (0.11)	3037 (1.10)	1165 (0.42)	276,935
Both	20,940 (4.69)	918 (0.21)	5318 (1.19)	1617 (0.36)	446,946

fear, which was the value with the greatest territorial distribution, and compared this with the points that coincided with low RMSSD values and low SAM values for valence (from 1 to 3) associated with an "unpleasant" experience and high values for arousal (values from 7 to 9) associated with an "excited" experience, certain coincidences could be observed.

Both women (Fig. 6) and men (Fig. 7) tended to highlight certain points coinciding with places in the medieval part of the city (around the Plaça del Dipòsit square and in Carrer Companyia). However, in the case of women, there was a greater distribution of different values. The references to "fear" were clearly more widely distributed across the area analysed. Furthermore, this feeling of fear tended to coincide with spaces where low RMSSD values were registered.

For men, on the other hand, there was little relationship between low RMSSD values and the different emotions that they claimed to identify. This means that there were points with low RMSSD values (high arousal) where no specific emotion was highlighted. Or, conversely, this may indicate points that caused fear and arousal, but where there was no observable coincidence with low RMSSD values.

5. Discussion

The results obtained allowed us to identify gender-related differences in how emotions, and especially fear, are perceived in the urban space. This was achieved by using objective calculations based on RMSSD. These readings were then contrasted with more subjective evaluations relating to the same problems.

The comparison of RMSSD values with valence/arousal SAM values and the perception of the participants showed how RMSSD could provide a good indicator for identifying situations that the different participants associated with feelings of fear. This relationship had already been noted by Michels et al. (2013) in the case of children aged between 5 and 10 years old. However, other authors had linked stress to high RMSSD values (Orsila et al., 2008). The results of this research show a coincidence between low RMSSD values and situations that generate a high degree of stress; this coincided with the conclusions drawn by Michels et al. (2013). Furthermore, this work extends the age range within which this relationship has been confirmed, as we worked with people aged between 19 and 24 years old.

Associating the perception of stress by the participants with low RMSSD values and with feelings of fear also allowed us to highlight how what was experienced by women on public thoroughfares tended to cause them a higher level of stress than what was experienced by men (their RMSSD values were 14.19 % lower than for men). This coincided with the valence of the experience (13.01 % lower) and the arousal (17.34 % greater). This evaluation coincided with that obtained using questionnaires by Pennebaker et al. (1996), but differed from that provided by approaches such as recording emotions on a daily basis (Seidlitz & Diener, 1998). Overall, the results point to a greater tendency for women to experience the emotion of fear in public spaces. This is a tendency that has persisted in recent decades. This is something that should make us reflect on the effectiveness of our gender equality policies relating to public thoroughfares and the very evident failure to

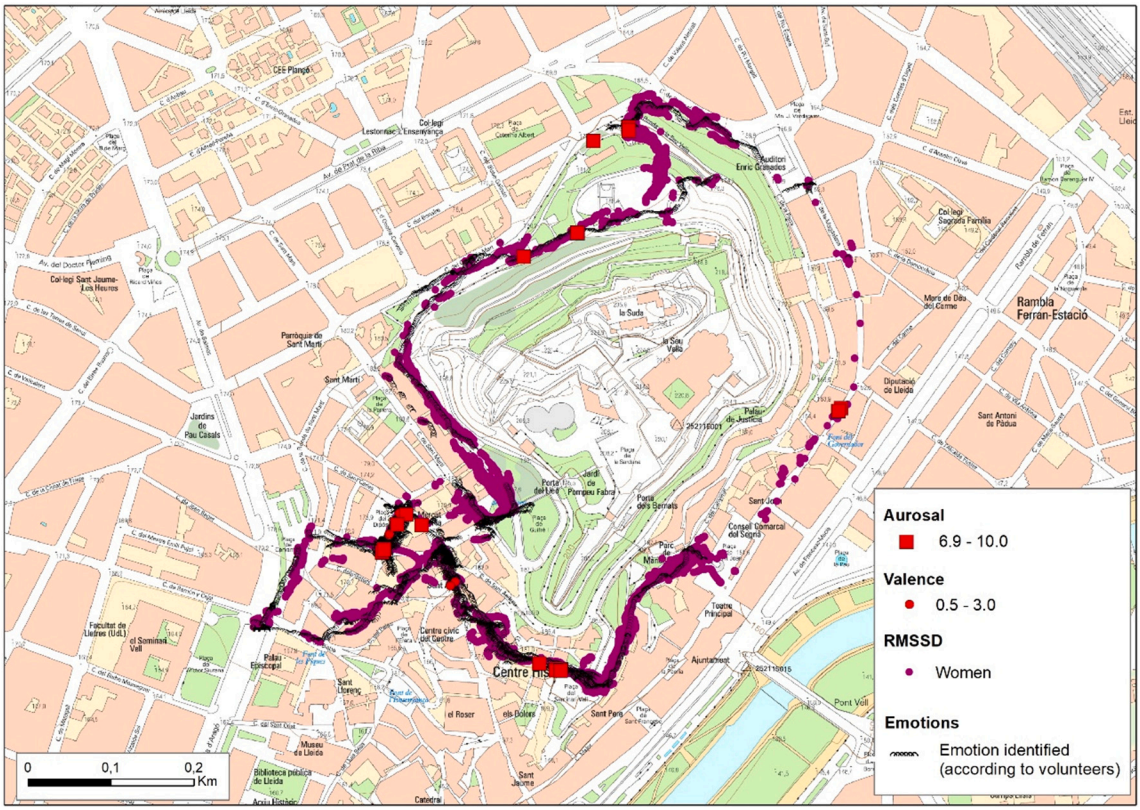

Fig. 6. Location of the points where fear was identified and the RMSSD values were low (lowest decile - women - 23 volunteers).

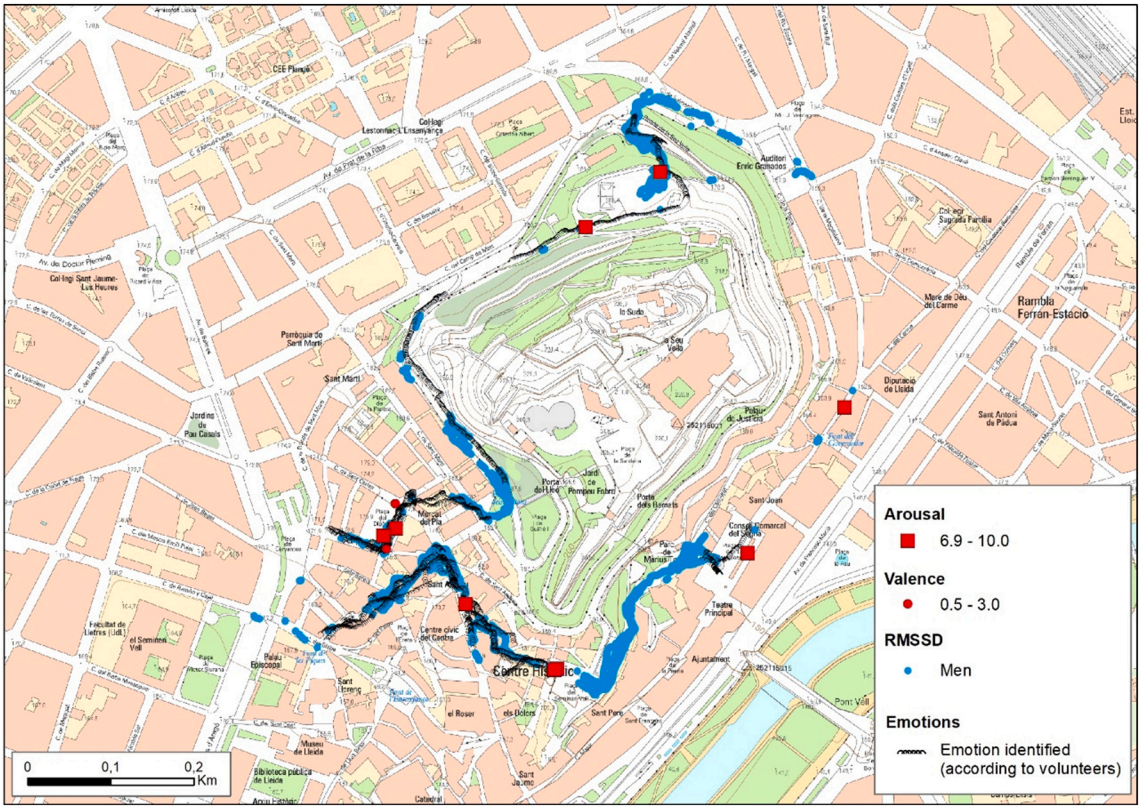

Fig. 7. Location of the points where fear was identified and the RMSSD values were low (lowest decile - men - 11 volunteers).

apply the urban planning principles outlined by authors such as Michaud (2002).

Even so, the data presented above do not imply that the whole city causes more fear in women. The results obtained allow us to identify spaces particularly associated with feelings of fear and to also find points that generate more stress in men than in women. In the case of men, open spaces tended to cause a higher degree of stress; in women, narrow streets with the presence of other people were what generated the greatest stress. This points to an adaptation of women's behaviour in public space as previously highlighted by authors such as Valentine (1989) or, more recently, in the case of tourist behaviour, by Paül i Agustí (2021).

Comparing RMSSD and valence/arousal SAM data and collecting information from the participants also provided interesting input for reflection. The values assigned by different women tended to coincide more than those assigned by different men. From this finding, it was possible to deduce that women more readily expressed the intensity of the discomfort that they felt in public spaces than men did. On the other hand, the responses of men tended to be more moderate and everything would seem to indicate that they found it more difficult to express the intensity of any feelings of discomfort caused in them by their surroundings. In this aspect, these results, which were obtained outside the laboratory, coincided with those obtained, under experimental conditions, by McLean and Hope (2010). Although it has not been possible to confirm the hypothesis that men do not report fear, we were able to note a higher degree of subjective anxiety in women.

The comparison between the types of space that caused important feelings of fear with those associated with more positive emotions allowed us to make a series of recommendations for those responsible for the management of public spaces (Table 3). These recommendations are in line with those made by other authors, who have pointed to the need to take into account the differences between men and women in spatial studies (Leszczynski & Elwood, 2015). They have also underlined the importance of being aware of the different kinds of geographies that may form part of the public space (Graham, 2020).

They have also highlighted the utility of approaches that use HRV as an instrument that can partially validate findings obtained using more qualitative methodologies (Kothencz & Blaschke, 2017). To a certain extent, this is an example of using big data to incorporate new discussions about epistemological challenges and opportunities (Ferreira & Vale, 2022). This reaches beyond the habitual tendency to limit the use of big data to the analysis of the financial value that can be extracted from such data (Rose et al., 2021).

In this way, with the support of HRV, it should be possible to design more user-friendly cities that will foster greater well-being and feelings of safety, especially amongst women.

These are questions that must be taken into consideration in studies based solely on the collection and analysis of subjective data. While subjective data results tended to coincide with those points at which participants had identified more clearly negative experiences (low RMSSD, high arousal, low valence and user identification as spaces instilling fear), the same was not true of spaces that generated weaker emotional reactions. Adopting a qualitative approach was not enough to correctly identify these spaces, particularly in the case of men. Combining the approaches used in this study produced better distributed results and helped us to identify a greater number of areas that generated stress than an approximation based on a single source.

We must highlight some of the limitations in this research. Carrying out research in public places imposes certain limitations. The physical effort required to complete the route was taken into consideration, as this was a factor that could have affected the HRV (Shoval et al., 2018). The route chosen was 3100 m long, with a net variation in altitude of around 30 m. In order to prevent the effort involved in walking potentially influencing our measurements, some members of the group did the route travelling clockwise, while others did it travelling anti-clockwise. In this way, it was possible to compare the effects of slopes and tiredness and to take these into account when conducting a general review of the data. However, given the fact that the participants followed their routes independently, there may have been some minor differences and these could plausibly have influenced the amount of effort made by each participant.

Table 3
Main stimuli in the built environment, emotional responses and recommendations relating to the physical space.

Predominant urban morphology	Group most affected	Recommendations to foster greater well-being
High levels of stress (associated with fear)		
Narrow pedestrian streets	Women (and some men)	The creation of quite large open.
Areas with trees of over 1 ha in size	Women (and some men)	Favour the creation of spaces that combine various types of gardens. Incorporate clear signposting to indicate the way out of areas of trees.
Spaces without ground-floor activities	Women	Avoid constructions that create long areas of wall without any openings.
Large spaces dedicated to parking	Women	Avoid the use of large areas for parking. Combine these with uses such as parks and gardens.
Streets with narrow pavements	Women and men	Promote the use of single-level streets which give priority to pedestrians. Install elements that regulate the speed of vehicles. Prevent parked vehicles from creating spaces that cause limited visibility.
Pedestrian crossings	Women and men	Regulate traffic lights in order to prevent pedestrians and vehicles coinciding at the moment of crossing the street.
Low levels of stress (associated with well-being)		
Places with open spaces	Women (and some men)	Create open spaces in squares, and especially in those with area greater than 1 ha.
Streets with wide, tree-lined pavements that are open to wheeled-vehicle transit	Women (and some men)	Plan wide pavements and single-level streets.
Streets with commercial and catering uses	Women (and some men)	Favour mixed uses on the ground floors of buildings. Encourage activities that generate pedestrian traffic (without causing major agglomerations).

Source: own research.

It is also important to add that, when initially contacted, the participants were asked whether they had any cardiac problems; anyone who did would have been excluded from the study. There were no other controls of potential underlying health issues. We could not, however, completely rule out the possibility of some participants having had undetected cardiac problems.

Finally, we must underline the fact that any given situation could have generated different responses in different people. Other studies have solved this problem by using prior laboratory calibration based on a number of different scenarios. Such calibration makes it possible to eliminate variability so as to be able to reliably compare individual results. However, the methodology used in our research did not permit us to make such comparisons. Even so, the fact that the trajectories, ages, previous training and origins of our participants were similar allowed us to observe changes in average values. This is an approach that has already been used by other authors, including Zeile et al. (2009) and Shoval et al. (2018). However, the homogeneity of our sample also implies that the results obtained with our group could have been different from those that would perhaps have been obtained with others.

6. Conclusions

The current research shows the utility of research methodologies that go beyond the manual collection of data based on valence and arousal. The inclusion of variables derived from HRV allows qualitative information to be nuanced, which offers a more complete approximation of the emotions that people experience in the urban space. This approach makes an important contribution to our knowledge of emotions associated with public spaces: it makes it possible to easily obtain quantitative information about the emotions experienced by the population. It is a methodology that can be applied in multiple urban contexts and which makes it possible to identify spaces that generate negative emotions in citizens.

The study therefore contributes to an improvement of our knowledge of emotions experienced in public spaces and provides tools to help avoid urban design based solely on aesthetic criteria. It offers a tool for geolocating spaces that cause feelings of fear. In this way, it is possible to identify urban spaces which are not very user-friendly form the point of view of their impact on people's feelings. This is particularly relevant issue at a time in which the feelings that public spaces provoke have gained greater relevance. Since the COVID-19 pandemic, it has been possible to observe an exponential increase in panic attacks and in the fear of going out into the street. Studies like this allow us to go further and to improve the design of public spaces by incorporating criteria related to the welfare and mental health of the population, and especially those of collectives such as women and young people.

This work demonstrates how the inclusion of real-time data collection methods can enable us to obtain data that complement mental maps based on memories of personal experiences. In this way, it is possible to prevent the passing of time adversely affecting the evaluation of an experience lived in a specific environment and at a particular time. This research uses a methodology: real-time data collection, which has been widely studied in laboratories, but which is only now just beginning to be applied in public spaces.

Our findings show that the fear values personally identified do not always coincide with those actually experienced. This is a matter of great importance when it comes to planning cities. If we do not take into account the emotions generated by a space, this could adversely affect its utility for the population as a whole. For example, green zones could be created that would not be used and shopping areas that would not attract customers. Applying the proposed methodology would permit progress in the design of urban spaces and help make them more citizen-friendly.

We must also underline the fact that, as in studies based on other methodologies, our results show significant differences in the perception of space according to gender. The spaces in which fear was experienced and identified more by men tended to differ from those identified by women.

Along these lines, an area for future research should be the analysis of whether the observed differences can also be found in other groups, such as older people and those of different origins. It is also necessary to highlight the fact that the results show that women tend to more readily express the emotions that they experience than men. This is a something that could lead to diverse and divergent interpretations of public space. With this in mind, future studies could perhaps examine the differential behaviour of men and women in the public space in greater depth thanks to data obtained from the RMSSD.

Finally, it will be necessary to work on the analysis of other emotions. This research focused on fear as the most commonly identified emotion. Future research should analyse other emotions, such as sadness, anger or happiness, in order to help improve our knowledge of the emotions that urban spaces generate in people. Future studies may also focus on other gender identities beyond the difference between men and women analysed in the present article. In this way, it will be possible to improve our knowledge of the emotional states of people in cities and to create what would be more citizen-friendly cities for the whole of society.

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CRediT authorship contribution statement

Daniel Paül i Agustí: Conceptualization, Methodology, Software, Validation, Investigation, Resources, Data curation, Writing – original draft, Writing – review & editing, Project administration, Funding acquisition. **Teresa Guilera:** Conceptualization, Methodology, Formal analysis, Investigation, Writing – review & editing, Supervision. **Montserrat Guerrero Lladós:** Conceptualization, Methodology, Software, Data curation, Visualization.

Declaration of competing interest

None.

Data availability

The data that has been used is confidential.

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