Walking in the City: An Experimental Pedestrian Stress Test for Marienplatz in Stuttgart, Germany

Céline Schmidt-Hamburger[1], Peter Zeile[2]

[1]Karlsruhe Institute of Technology, Karlsruhe/Germany · celine.schmidt-hamburger@kit.edu
[2]Karlsruhe Institute of Technology, Karlsruhe /Germany

Abstract: In an experimental study with 15 participants, stress measurements of pedestrian traffic were conducted in the urban environment of Stuttgart's Marienplatz. Stress was measured with sensor wristbands. In addition, standardized questionnaires were used to incorporate personal dispositions into stress generation. Heat maps, group comparisons, and exploratory cluster analyses were used to obtain circumstantial evidence of stress emergence. Four stress factors were identified (*lack of space*, *interruption of the desired line*, *noise*, and *quality of infrastructure*). Individual factors associated with stress here include gender, knowledge of the place, and psychological factors. Cluster analysis also suggests three groups that are homogeneous in their experience of stress. The results of the study will be used to better understand stress as an inhibiting factor for choosing walking as a mode of transportation. In the future, the findings can help to better integrate the human scale into the data collection and implementation of (digital) urban planning projects.

Keywords: Pedestrians, stress, data gap, psychobiology

1   Introduction

When looking at the use of road space by road users, it quickly becomes apparent that pedestrian traffic remains a residual factor and has so far received rather scant attention (Umweltbundesamt 2018). However, walking has not only become more important in leisure time, but walking is also becoming more common as a means of transport (KNIE et al. 2021). This raises the question of the relevance of good pedestrian infrastructure. The positive effects are manifold. Walking is healthy (UMWELTBUNDESAMT 2018) and does not contain financial, linguistic or cultural obstacles. Walking promotes the revitalisation of public space and ensures participation in public life (AUSSERER et al. 2013). Strengthening walking as a means of transportation can also contribute to a reduction in air and noise emissions. The increase in walking is inhibited by factors such as air quality, urban planning obstacles, accident risks with other modes of transport or even old habits in the choice of transport (UMWELTBUNDESAMT 2018). The role of walking is particularly present in cities. Dense development, higher noise and pollutant emissions, and increased traffic volumes impact the everyday life of pedestrians (GEHL 2018).

Another prominent dynamic in the urban context is the steadily increasing incidence of stress-related diseases. In addition to the prevalence of cardiovascular diseases, mental illness such as depression are increasingly observed (ADLI 2017). Subjective factors related to stress sometimes influence, even unconsciously, the choice of transport (ZEILE et al. 2021). The increasing global urbanization underlines the relevance of knowledge generation about stressors in urban space. Against this background, the focus will be on pedestrian traffic. The promotion of pedestrian traffic is a central component of future urban and transport planning. Therefore, the aim of this thesis is to answer two research questions:

1. Which structural and social factors lead to the emergence of stress among pedestrians in urban spaces?

2. What role do social and psychological characteristics play?

The practical part of the measurement of pedestrians' stress was conducted at Marienplatz in Stuttgart. This location is interesting for answering the research questions because it is characterized by a high mix of uses and its status as a transportation hub, making it well-suited for the study. The study can be considered a prototype for further research in the area of urban pedestrian stress.

This study is embedded in the (NRVP-) project "Cape Reviso" which investigates the causes of conflicts and stress in pedestrian and bicycle traffic in order to be able to address them in (digital) traffic planning (WÖSSNER et al. 2020).

2   Theoretical Background

2.1   Stress, an Emotional Construct

Stress theories differ in terms of adaptability and operationalizability. Stress always arises when, depending on the theoretical underpinning, the physique (stress-as-a-reaction) or psyche (stress-as-a-stimulus or stress-as-a-transaction) has to muster resources to process environmental stimuli. The most prominent is the transactional stress model according to Lazarus (1999), but at the same time, it is also the most complex, since stress always arises situationally in the interaction of people and the environment. On the other hand, there are stress-as-a-reaction models (Selye 1956, Cannon 1932), which examine the physical reactions to an external stimulus (BERCHT 2013). Critical here is the assumption that a stimulus "stresses" all people equally (LYON 2005). The third group of theories, which understands stress as a stimulus, focuses on the psychological effects. Here, it is assumed that there are "critical life events" (HOLMES & RAHE 1967) that objectively trigger stress to some extent (BERCHT 2013). Due to developments in emotion research in this field, the stress-theoretical basis of this paper is more in line with models from the stress-as-a-reaction perspective. However, subjective components are included in the data collection and analysis.

2.2   The Mobility Behaviour of Pedestrians

Human perception, and thus also (mobility) behavior, is determined by several factors. These can be divided into exogenous and endogenous influences. If the influencing factors originate from the environment, we speak of exogenous factors. In this case, the built or natural environment stimulates human sensory perception (ŚLESZYŃSKI 2012). Based on empirical findings, in this work, these are divided into lack of space (confinement), resistance (barriers), the quality of the environment and noise. These directly form the basis for the working hypotheses.

Lack of space: Insufficient width of sidewalks leads to insufficient distances during encounters and a high density of people. The distances to the roadway or the presence of obstacles can also trigger a feeling of crowding (ŚLESZYŃSKI 2012). In addition, so-called near misses can influence pedestrians' subjective perception of safety. The critical value is 150 cm, which corresponds to the legal minimum distance for overtaking (ZEILE et al. 2021). The lack of

space can thus trigger stress in pedestrians if the situation is assessed individually (SPIEGEL 1992). *(H1): Lack of space leads to stress among pedestrians.*

Barriers: Pedestrians, aim for a route that connects their starting point to their destination as directly and briefly as possible. The preference for short and direct routes often leads to shortcuts where convenience is more important than safety. Pedestrians use this imaginary route or "desire line" (ŚLESZYŃSKI 2012) to get around. The response to a disruption in the individual's desire line is to increase speed, wait, or swerve to maintain personal distance (LEE & KIM 2017). Barriers change the perception of space and influence individual desire lines. This can trigger stress (SPIEGEL 1992). *(H2): The interruption of the desire line leads to stress among pedestrians.*

Noise emissions: The effect of noise can be equated with a stress reaction from a volume of 65 decibels. Stress hormones are released and blood pressure and heart rate increase. Continuous noise can trigger illnesses such as hearing damage, cardiovascular disease and psychological problems (ADLI 2017). *(H3): Noise emissions lead to stress among pedestrians.*

Quality of environment: The condition of the environment correlates with pedestrian stress responses. Environments characterized by a high mix of uses or industries may be associated with the experience of stress (LAJEUNESSE et al. 2021). Furthermore, unclear routing/guidance systems (AUSSERER et al. 2013), slopes, suboptimal road surfaces or poor visibility also contribute to a devaluation of the quality of the walking infrastructure, which can discourage people from walking and, in extreme cases, cause negative emotions. The demands on the quality of the environment can vary depending on age, mobility impairment, knowledge of the place, or the purpose of the trip (ŚLESZYŃSKI 2012). *(H4): Low quality of infrastructure leads to stress among pedestrians.*

Endogenous factors, "the inner milieu", also determine the strength of the effect of stressors by mitigating or increasing the likelihood of stress occurring. In terms of gender, women are thought to experience stress more quickly than men. A walking or visual impairment can also promote stress (DÖRRZAPF et al. 2014). Furthermore, an advanced age tends to favor stress. Regarding the purpose of travel, commuters are assumed to be more stressed because they prefer a fast and direct connection to their destination (SCHOON 2010). If a mode of transportation is used on a daily basis, it is assumed that stress is less likely to be induced if the mode of transportation is chosen voluntarily. Not only the familiar mode of transportation but also the familiar environment can influence the occurrence of stress. Stress is triggered more quickly in unfamiliar environments than in places that are frequented more often (AUSSERER et al. 2013). Finally, psychological predispositions may have a supporting or reducing effect on the stress response (SCHANDRY 2016). These psychological factors include personality, control beliefs, and risk tolerance. The relevance of including psychological characteristics is also based on the importance of individual evaluations of stressors (KOVALEVA et al. 2012).

3   Methodology

This paper attempts to draw as comprehensive a picture as possible in answering the question by using triangulation between methods (FLICK 2008). The subject of the study, the stress of pedestrians, is investigated qualitatively and quantitatively. Triangulation was used in the study for data collection (standardized as well as open questionnaire, sensor data), analysis (spatial and statistical) and interpretation.

The dependent variable of this empirical study is the emotional construct stress. Measuring stress in terms of response is feasible, although theoretical limitations must be accepted. Biological indicators are used to identify moments of stress. When confronted with a stressor, the human organism regulates endogenous stress responses to establish homeostasis. These responses are detectable through a variety of body-related parameters and are recognized as a proven method for measuring stress from external stressors. These include the increase in electrodermal activity (EDA) and the decrease in skin temperature (KYRIAKOU et al. 2019, SCHANDRY 2016). Based on the functioning of these biosignals, Kyriakou et al. (2019) developed an algorithm that can detect people's moments of stress (MOS) using wearable biosensors. The biosensor wristband "E4" from the company Empatica was used to measure the biosignals. The data is collected in an app (e-diary) on a smartphone. The result is a database in which one line corresponds to one second of the measurement period and provides information about a MOS (yes/no) and its geographic coordinates, which can thus be read and visualized in a geographic information system (GIS). To check whether the exogenous stressors influence the MOS, a mixed-methods approach was chosen. Camera recordings were used to examine causal factors for the occurrence of a MOS.

A standardized questionnaire based on validated scales of mobility in Germany (2019) from the BMVI (NOBIS & KUHNIMHOF 2018) and the Leibniz Institute for Social Sciences (GESIS) was developed to record endogenous factors. The questionnaire was used to collect information about the person and his or her sociodemographic background as well as psychological characteristics in addition to (pedestrian) traffic behavior. The personality of individuals is traditionally determined on the basis of the so-called Big Five, which consists of the characteristics extraversion, neuroticism, openness, conscientiousness and agreeableness. The Big Five are considered to have good predictive power for certain aspects of life. The level of control beliefs describes a person's belief that he or she has control over various situations and that these are the result of his or her actions (internal) or that fate, coincidences, or powerful others are responsible for the occurrence of certain events (external) (RAMMSTEDT et al. 2012, KOVALEVA et al. 2012, BEIERLEIN et al. 2014). The degree of control belief is a relevant factor in the evaluation of a stress reaction (BROSSCHOT et al. 1994).

The study to measure pedestrians' stress around Stuttgart's Marienplatz took place in July 2021. According to conflict points between road users and an analysis of accident sites involving pedestrians, a route of three kilometers was defined for the measurement. The 15 participants were asked to complete the questionnaire in advance. After the test run with the wristband and the cameras, participants were subsequently given a questionnaire ex-post on which they could mark subjectively perceived stressful or relaxed locations.

For the data analysis, a so-called global heat map of all MOS was first created. Subsequently, various further heat maps were created according to hypotheses and the endogenous influencing factors in order to obtain a more differentiated picture. This makes it possible to gain insight into the locations where a large number of MOSs of different individuals occurred. Finally, these were also compared ex-post with the information from the questionnaires. Further analyses focusing on the endogenous factors of the participants were performed by appropriate statistical analyses. In the first step, an overview of the distribution of the expressions was obtained. For this purpose, the distributions of the expressions and the MOS were examined (cf. Table 1). The table shows extreme values in parts. These should be read against the background that this is not a representative sample and that the homogeneity of the group can be classified as quite high.

Table 1: Distribution of the shares of the subgroups and their MOS, own calculations

Variable	$N_{participants}$=15 (%)	N_{MOS}=379 (%)
Age (>31)	20	17.94
Gender (female)	66	70.45
Commuters (pedestrians)	53	58.33
Extensive Walkers	13.33	12.66
Local knowledge	33.33	31.13
Big Five personality traits		
Extraversion (above average)	66.66	63.06
Neuroticism (above average)	93.33	94.20
Openness (above average)	53.33	49.60
Conscientiousness (below average)	86.66	88.39
Agreeableness (below average)	53.33	50.13
Conviction of Control		
Internal (below average)	73.33	70.45
External (below average)	80	82.06
Risk-Affinity	53.3	56.2

For further analysis of the relationships between the endogenous factors and the development of MOS overall and subdivided by exogenous factors, mainly group comparisons were performed. For this purpose, the percentage of MOS is compared with the percentage of the sample. The sign of the difference can be read as an indication of a disproportionate or disproportionate susceptibility to a stress response. It is hypothesized that this is an indication of subjective appraisal mechanisms that play a role in stress generation. In a further exploratory step, a hierarchical cluster analysis was performed according to Ward's method in order to obtain a more accurate picture of different "stress groups" (BACHER et al. 2010) within the sample. To ensure the comparability of the variables, they were z-standardised.

4   Discussion of the Results

The 15 data sets comprised a total of 379 MOS, which corresponds to an average of 25 MOS per respondent. The actual range of MOS values was between 18 and 36. After the spatial analysis of the MOS and their causes, statements could be made about places perceived as "stressful" on Stuttgart's Marienplatz according to established hypotheses (cf. Fig.1). As exogenous factors, *lack of space*, *interruption of the desire line*, *noise* and *quality of infrastructure* were identified and reviewed as causes for the development of MOS. It turns out that all these factors individually, but also in combination, can indeed be causal for stress. In addition, information about places subjectively perceived as stressful was extracted from questionnaires ex-post.

It was found that *lack of space* was the most common stressor related to the built environment for pedestrians, resulting in an MOS (68%). This was followed by *noise* (40%) and *interruption of the desire line* (32%), and finally the *quality of infrastructure* was also identified as a
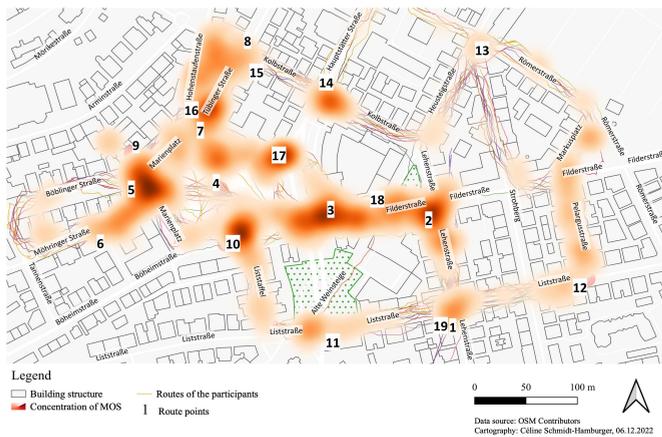
Fig. 1:
Heatmap of MOS around Marienplatz

cause for some MOS (12%)[1]. Thus, this seems to play a lesser role in causing stress compared to the other exogenous influencing factors. The study situation may have played a role here, with participants possibly paying less attention to their surroundings than to completing their task. For the majority (66%) of MOS, a combination of multiple stressors was decisive. In summary, Figure 2 gives an overview of the locations with the highest concentration of stress points, which can be assigned to the individual hypotheses. It was particularly noticeable that most of the MOS were located at major intersections around Marienplatz). Due to their separating effect, these correspond to the stress factor *interruption of the desire line*, since the pedestrians were interrupted on their route there. *Noise* also closely linked to large and therefore busy intersections. The *lack of space* also has an effect at large intersections, e. g. due to cars passing closely, as well as in areas of side streets where the sidewalks are very narrow and especially when there is a confrontation with other pedestrians, some of whom are also pushing strollers or similar. MOS also occurred in areas of "shared space" of pedestrian and bicycle traffic due to *lack of space*.
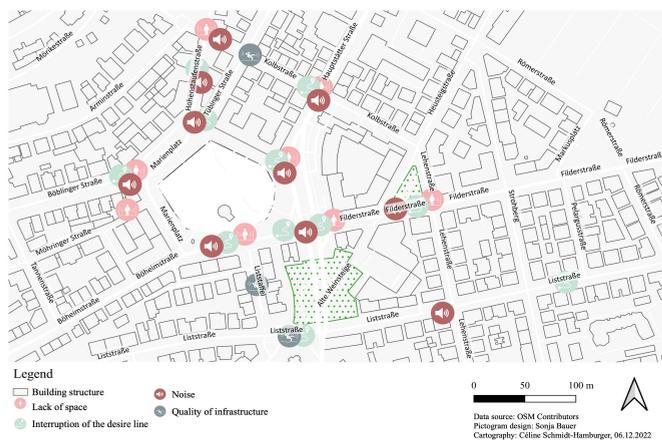

Fig. 2:
MOS by cause

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[1] The percentages of MOS add up to more than 100%. This is due to the fact that an MOS can have several causes.

In a more in-depth analysis consisting of descriptive statistics and cluster analysis, the socio-psychological characteristics of the participants were compared with the MOS (cf. Tab. 1). The aim was to attribute a regularity of stress reactions to them in order to obtain a more accurate picture of stress evaluation. Some suspected influencing factors proved to be irrelevant for further analysis, as there was no variance in the participants' response behavior or no fluctuations in the MOS could be attributed to them. Interesting findings emerged about gender and habit (knowledge of the place), which, according to theory, proportionally led to more or less MOS, but also about psychological characteristics. Individuals with higher than average levels of agreeableness, higher than average levels of internal locus of control beliefs, and higher than average levels of neuroticism were found to have relatively more MOS. The latter finding is consistent with research findings that neurotic people are highly susceptible to stress (MEDICAL TRIBUNAL VERLAGSGESELLSCHAFT 2021). People with a higher internal locus of control may have a moderating effect on MOS because they are more likely to believe that they can control the consequences of their actions. Presumably, this could also increase feelings of stress, as these individuals may also see responsibility in themselves. Conversely, the results are similar for the components of above-average extraversion, openness, conscientiousness, external locus of control, and risk-taking. Individuals with these characteristics recorded less MOS. The strongest effect was seen here for extraversion, which seems plausible, as does the influence of the other factors. People who are strongly extravert tend to also believe control is external and this allows them to externalise stress feelings.

Finally, a cluster analysis was performed to form any groups according to socio-psychological characteristics that show statistical similarities in terms of the emergence of stress. Three clusters could be formed, described in terms of their characteristics as hesitant loners with a pioneering spirit (cluster 1), security adventurers (cluster 2), and insecure loners (cluster 3):

Cluster 1: Six female participants who are moderately knowledgeable about the location. They are on average more extraverted and neurotic, rather less open, rather less conscientious, as well as rather less compatible than average. They have above-average internal control beliefs, below-average external control beliefs, and tend to be more risk averse. On average, the cluster members had more MOS (28) than participants from the other clusters and the global average.

Cluster 2: Six participants who are familiar with the location. Members of this cluster are less extraverted, more neurotic, more open, less conscientious, and rather less compatible than the average. They have rather below-average internal control beliefs, rather above-average external control beliefs, and are risk averse. The participants have an average number of MOS (25) compared to the other clusters and the total score.

Cluster 3: Three male participants who are unfamiliar with the location. Members of this cluster tend to be more extraverted, less neurotic, more open and conscientious, and more compatible than average. They tend to have above average internal and average external locus of control beliefs and are more risk averse. Participants in this cluster have lower average MOS compared to the other clusters and the overall score (20).

There are a few critical points to note at this point. The homogeneity of the group is very high. To obtain a more diversified picture, a broader coverage of participants would have been necessary, especially regarding age, people with mobility impairments and more socio-economic/cultural diversity. The choice of Stuttgart's Marienplatz should also not be viewed uncritically. The choice of the square is certainly justified, but it is already well-designed and centrally located. However, the question arises as to whether it makes sense in the context of

the city as a whole to improve a suitable location based on a large number of studies or to examine more peripheral locations that often escape general attention but are of central importance for many groups. Especially for groups that often do not participate in the urban discourse and thus do not call science, politics and administration onto the scene.

5   Conclusion and Outlook

To generate more knowledge about the interaction of stress and walking, a triangulating process was used to collect measured stress data along with information on participants' sociodemographics, mobility behavior, and psyche to conduct a comprehensive analysis of stressors in the field. Heat maps were used to show that the most relevant stressors in this study were *lack of space*, *interruption of desire line*, and *noise*. The analysis of the supporting hypotheses showed that, firstly, women were more likely to feel stressed in this study. People who are knowledgeable about the location tend to feel less MOS. In terms of psychological characteristics, the factors neuroticism, agreeableness, and internal locus of control were found to be more likely to promote the development of stress. If people are more extraverted, open, conscientious, willing to take risks, and have a higher degree of external control, they tend to have less MOS. In addition, hierarchical cluster analysis allowed us to calculate three cluster groups (hesitant loners with a pioneering spirit, safety adventurers, and safety-conscious loners). These clusters suggest a more detailed examination of the impact of planning projects related to the built environment on specific groups. The goal of this subdivision was to allow for a more nuanced consideration of the "human factor" in the measurement of stress, while using grouping to avoid working with individual case studies.

The results of the study shed light on the development of stress among pedestrians on Stuttgart's Marienplatz. Not only were infrastructural stressors identified, but the inner milieu of people was also included in order to be able to examine the perception of stress in more detail. In addition, the mix of methods proved to be appropriate for capturing, mapping and interpreting these different levels of information and relationships. Although this study cannot be considered representative due to its sample, it can serve as a stimulus for further research of this kind and contribute to a diversified database. As mentioned above, walking can be made more attractive by reducing stress, thus contributing to more sustainable, healthier and socially just cities.

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