Using Semi-Automated Shadowing for Analysing Stress-Induced Spatio-Temporal Behaviour Patterns of Passengers in Public Transport Infrastructures

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ABSTRACT

In the course of the scientific project IANUS, we examined the impacts of stress on the physical and psychological condition of passengers in train stations in order to identify relevant determinants and to develop recommendations for reducing stress-inducing factors in public transport infrastructures. We used a combination of biometric measuring of heart rate, semi-automated observation of spatio-temporal behaviour, psychological interviews, eye-tracking and visual field analyses during laboratory and field tests. In this contribution, we focus on the methodology of observing the spatio-temporal behaviour patterns of 35 individuals participating in field tests conducted in Vienna, Austria. The observation datasets have been analysed concerning velocities, route choice, stopping behaviour and related activities in order to identify noticeable patterns and events that can indicate stress-related behaviour. The outcomes were subsequently consolidated with the results of the complementary methods in order to identify stress-inducing factors in transport infrastructures.

Author Keywords

Shadowing, across-method triangulation, pedestrian spatio-temporal behaviour.

ACM Classification Keywords

G.3 Experimental design, H.1.2 Human factors

INTRODUCTION

In the domain of traffic-related research, the impact of stress has primarily been examined in connection with pilot and driver behaviour. Findings have shown that frequent stressful driving encounters may ultimately lead to a dispositional tendency of drivers to experience all driving encounters in a negative manner [2]. The perspective of public transport passengers and the impact of stress on their physiological and psychological health has however largely been disregarded, although the same impact may be assumed when experiencing stressful situations while travelling with public transport facilities.

The aspect described has become of particular importance as today's public transport infrastructures provide a wide range of different services in addition to their primary function as traffic hubs. Due to this development, a growing amount of information is provided within station buildings, forcing passengers to filter out relevant information within limited time. Information overflow, time pressure and the complexity of infrastructures may cause uncertainties and can expose individuals to increased stress. As a consequence, individuals might try to avoid such situations in the future by not using public transport.

This is a development that has to be countered. To do so, it is firstly necessary to identify the key factors that increase stress of passengers in public transport situations. Secondly, the negative impacts of these factors have to be minimized in order to facilitate the completion of different tasks for passengers and augment the attractiveness of public transport usage.

As part of the scientific project IANUS we used a multidisciplinary approach comprising complementary methods to investigate stress-related behaviour of specific target groups. The aim of the project was to identify stress-inducing factors in transport infrastructures and their effects on navigation behaviour of passengers as well as the passengers' strategies of gathering information and coping with stress. In this contribution, we focus on a particular method we used in this multi-disciplinary approach: the observation and analysis of spatio-temporal movement patterns of test subjects. We introduce the method, illustrate selected results and demonstrate how the results were consolidated with data obtained by the complementary methods in the project.

ACROSS-METHOD TRIANGULATION FOR IDENTIFYING STRESS-INDUCING FACTORS

Recent findings have detected considerable divergences in measured physiological stress indicators and subjectively perceived stress levels. After a stressful test situation, test drivers stated to still experience heightened pressure, although no physiological evidence (e.g. high heart rate) could be measured any more [6]. This indicates that a broad set of indicators has to be used to examine stress comprehensively. In order to also take coping strategies and stress-related movement patterns into account, the phenomenon has to be investigated from several perspectives. We conducted experiments with participants of four different target groups in a laboratory environment and during field tests, applying the following methods:

- Questionnaires and personal interviews for gathering relevant information about attitudes, mood and stress coping strategies,
- Eye-Tracking (laboratory tests) and visual field analysis (field tests) for collecting data (visual focus points when orientating under stress),
- Physiological measurements of heart rate in the field tests and additionally skin response, pulse and body temperature in the laboratory environment for gathering information about physiological reactions on stress,
- Observation (shadowing) of spatio-temporal behaviour: semi-automated annotation of trajectories and activities (only for field tests) for identifying potentially stress-induced behaviour.

The selection of relevant target groups was based on previous findings in stress research. In the context of transport, two main individual-related characteristics show high relevance in connection with stress: age and experience in using transport systems. The age of a person is of relevance as the ability to take in and process information decreases with growing age. Stressful situations can aggravate this problem for elderly people and might as well cause specific reactions and coping strategies [1,7,9]. The importance of the second key attribute – whether people are accustomed to using public transport or not – lies in the fact that new situations and environments are generally perceived as more difficult than familiar situations and are therefore more likely to cause stress [4,10]. Taking these two factors into account, we defined four target groups showing combinations of the following characteristics: age groups younger than 35 and older than 55 years, and individuals who either used public transport frequently (several times per week) or rarely (at most several times a year). In total, 65 participants were tested in the laboratory environment and 35 participants took part in the experiments in the field tests. The test subjects had to pass navigation scenarios and fulfil specific tasks.

SHADOWING SPATIO-TEMPORAL BEHAVIOUR

Observing and analysing the spatio-temporal movement patterns of the test subjects was a main part of the field tests. In general, observation techniques provide an essential link between different empirical methods in behavioural research. When investigating stress, this link gets of particular importance, as it is an especially complex phenomenon. We connected movement observation and analysis to the results of physiological and psychological measuring (for the importance of observations in stress-related studies see [3,8]).

Several potential indicators for stress-induced behaviour can be identified through observation. For our study, we specifically focused on motion-related indicators such as

- unusual speed levels (high speed – hurrying, or very low speed – hesitating, indicating uncertainties),
- frequent stops for gathering information, or
- uncertainties in route choice (e.g. changes in direction, turning back)

Collection of Trajectories During Field Tests

To collect the required spatio-temporal data, we used the method of "shadowing" [5]. "Shadowing" is a form of tracking where researchers follow the test subjects and annotate the test subjects' individual trajectories and related activities on a map. In the course of this study, this was done by means of special software installed on a tablet PC, which allowed annotating the information in digital form. During the field tests, participants had to follow instructions describing a specific scenario: they had to find a particular destination in the city by using predetermined modes of public transport (subway, railway), buy a ticket in the connecting station and reach a bus at the final station within limited time. While completing the tasks, they were additionally equipped with physiological measuring instruments and a mobile eye-tracking system. This allowed the annotation of their movement behaviour, heart rates and visual fields. Furthermore, they were interviewed before and after the experiment to collect data concerning general stress coping strategies and the current mood before and after the test. The shadowing data subsequently served as basis for comprehensive evaluation of the whole data set. Figure 1 illustrates an example of a typical trajectory: the line represents the path the participant followed. In addition, two stops are marked (in front of a ticket vending

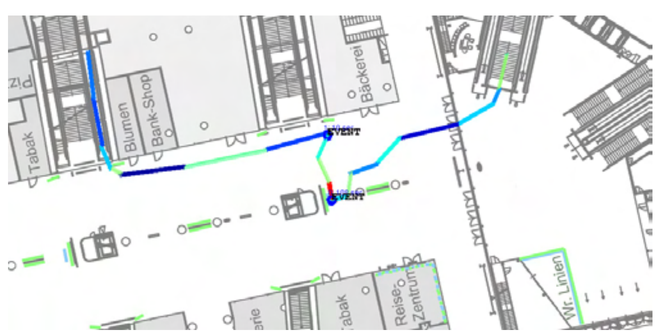

Figure 1. Example of trajectory (coloured sections of the line represent different velocities).

machine and an information display).

The use of technology in this phase (digital map on a tablet PC, tracking software) offers mainly two major advantages: firstly, a large investigation area can be covered without having to handle a large paper map, and secondly, all points drawn in the map are recorded with time-stamps and map coordinates, which allows calculating average speeds and detecting stops for each trajectory. Additionally, the system allows annotating specific activities carried out by the participants when they stop (e.g. gathering information from a public display) and their duration.

The collected shadowing datasets finally included:

- Trajectories of the path a participant followed (including place and time of stops) and
- Activities the person performed on the way through the stations (e.g. gathering information, buying a ticket, waiting) including time and place of each activity.

Data Analysis and Identification of Noticeable Motion Patterns

After data cleansing, we analysed the collected datasets with respect to three indicators: velocities (differences in individual speeds, velocity histograms), stops (frequency, duration, position of stops and activities carried out during stops) and unusual route choice or significant changes in direction. The aim was to select datasets with noticeable behaviour in one or more categories for a subsequent detailed interdisciplinary analysis.

Velocity Histograms

To detect unusual speed patterns, we compiled speed histograms of each trajectory, showing the proportional amount of time (of the total time a test subject needed for completing the field scenario) an individual walked at a velocity within a specific speed interval. Figure 2 shows all histograms compiled from trajectory datasets collected in the connecting station.

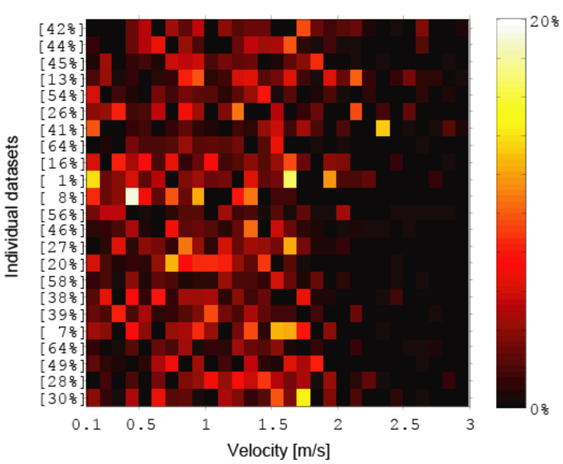

Figure 2. Velocity histograms for all participants (at connecting station; velocity intervals in 0.1 m/s steps between 0.1 and 3 m/s).

Each line shows the histogram of an observed participant with higher intensities (lighter colors) indicating higher percentages of time; the values on the left represent the amount of time a person spent without moving. We used the histograms and additionally the average velocity of each participant to identify unusual patterns.

Stop Detection

The analysis of stopping behaviour included the detection of stops (defined as staying within a radius of 3.25 m for at least 5 s) and the analysis of annotated activities performed during those stops. To identify unusual behaviour, we focused on activities indicating uncertainties (e.g. high amount of time for gathering information) and stress coping activities (e.g. pacing up and down).

Route Choice Analysis

To identify unusual route choice,, we qualitatively compared the routes of all participants and selected examples of differing paths or changes in direction that were obviously due to foregoing incorrect decisions.

Consolidating Shadowing Results and Complementary Empirical Results

Based on this analysis of the shadowing results, we integrated the data gathered with the complementary methods for better interpretation. We employed video footage recorded with the eye-tracking system and used the contained visual fields of the test subjects to specify durations of activities and to include information concerning the situational context (e.g. dense crowds forcing individuals to deviate from the direct path). We furthermore made use of information collected in the interviews to interpret the participants' behaviour in general and with regard to specific situations and movement patterns.

This multidisciplinary view made it possible to select specific datasets showing noticeable behaviour patterns for further analysis. We subsequently examined the heart rates of participants selected based on observation results with particular focus on special registered events and specific information extracted from the interviews. This enabled a comprehensive view on stress-inducing factors and their effects on behaviour patterns of individuals.

The results show in many cases correlations between increasing heart rates and (partly upcoming) events (e.g. during periods of uncertainty or shortly before a train reached a station where the participant had to leave the subway). However, crediting this effect solely with psychological stress may not reflect the real picture: increasing heart rates may also result from e.g. stronger physiological activity (e.g. due to ascending a staircase). Some of the heart rate rises, though, are not connected to any changes in physical activity, as we found out by checking additional data from observation and video

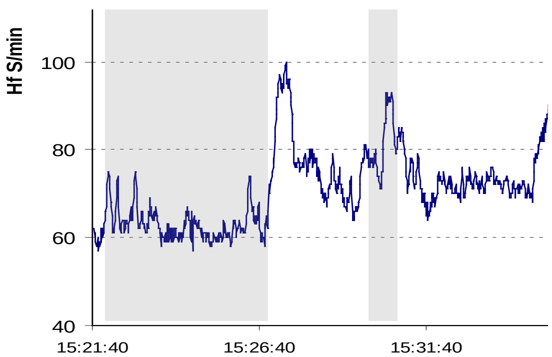

Figure 3. Example of heart rate measurements during the beginning part of a field test.

footage. This shows clearly that it is essential to consider multiple data sources in order to deduce comprehensive interpretations in this context.

Figure 3 shows an example of heart rate values measured during the first sequence of a field test. The background shading marks consecutive phases of the test: the first section represents the baseline at rest which had been measured before the test started; the following section shows the heart rate during the beginning of the test. The next (short) section shows heart rate values measured during the participant passed the subway station to catch a train, and the last section covers the time the participant was riding on the subway train.

Considering the general influence of the test setting on the participants' stress-levels, it has to be stated that most participants reported to have experienced merely minor pressure during the experiments. Due to the artificial setting of the test scenario (participants did not really fear negative consequences in case of not reaching the final bus station in time) it was difficult to induce a realistic level of pressure on the participants. Still, the combined test results confirm interrelations between observed behaviour and measured stress indicators. It can be assumed that in test settings where a higher level of stress can be provoked, even more significant results can be expected.

CONCLUSION AND FUTURE DEVELOPMENTS

Results from this study and similar research settings confirm that observations are a valuable extension for investigating behaviour in especially complex situations. In particular, the semi-automated shadowing approach presented in this paper allows collecting a broad range of location- and time-related data for comprehensively analysing spatio-temporal behaviour patterns of pedestrians in different contexts. However, some limitations have to be accepted. The accuracy and completeness of the data strongly depends on the observer's tracking ability (a lot of training is required). Uncontrollable impacts of the situational context (high crowd densities, limited visibility) will also influence data quality to the worse. Finally, the method is very time-consuming and labour-intensive, and the presence of the observer may influence the participants' behaviour. Still, for tracking individual pedestrians within an infrastructure, semi-automated shadowing provides very good results especially in combination with complementary empirical methods for investigating pedestrian spatio-temporal behaviour.

For future applications of the method, we currently develop additional features such as annotating the duration of activities and annotating activities that are taken while in motion (for this study, this information had to be included based on video footage analysis), or the automated synchronisation of additionally collected data (such as "thinking aloud" voice recordings).

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