Hindawi
Journal of Advanced Transportation
Volume 2022, Article ID 7245301, 14 pages
https://doi.org/10.1155/2022/7245301

Research Article

Waiting Behavior and Arousal in Different Levels of Crowd Density: A Psychological Experiment with a "Tiny Box"

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Received 11 November 2021; Revised 24 February 2022; Accepted 29 March 2022; Published 16 May 2022

Academic Editor: Mehdi Nourinejad

Crowd density, defined as persons per square meter, is a basic measuring unit for describing and analyzing crowd dynamics and for planning pedestrian infrastructure. However, little is known about the relationship between crowd density and psychological stress and well-being. This study uses an experimental approach to determine whether higher crowd densities result in higher levels of stress in participants. In this experiment, which was a case study at the university, participants ($N = 29$) wait in a wooden box of 1 m_2 for three minutes. Two, four, six, or eight participants are present simultaneously in the box. It is varied whether participants are supposed to remain silent or to speak with each other. Stress is conceptualized as arousal and measured as skin conductance level/electrodermal activity (EDA). A questionnaire is administered after the experiment, and the positioning of participants in the box is videotaped. The results show that the correlation between crowd density and physiological arousal is more complex than expected. The specific social situation in the box appears to play a more important role than merely the number of people waiting there. Furthermore, our data indicate a temporal trend: participants seem to adapt to the crowd density in the box. Video data analysis reveals that participants choose their positioning and orientation in the box carefully, but that this social choreography works less smoothly in higher densities. This study shows promising results for using EDA as a measurement of arousal in the context of crowd research. However, the limitations of this method and the experiments conducted are also discussed in detail to further improve this approach.

1. Introduction

The world's population is growing more and more and people are moving to the cities, so more often we find ourselves in situations where it is very crowded. We deliberately seek out such situations by going to concerts and festivals, for example. But also in everyday life, we find ourselves more often in situations where there are many people, for example on the way to work in buses and trains, as well as while waiting at the train platforms. Crowded situations with limited space always pose a safety risk—and they can be stressful. To better assess such situations, it is important to know more about individuals' experiences in crowded situations. It is generally assumed that the denser a situation is the more uncomfortable and stressful it is perceived to be. However, little is known so far about how people experience crowds of different densities. Currently, information on crowd density can already be found in the "pedestrian level of service" (PLOS). However, PLOS only considers situations in which people are walking, not those in which they are waiting. In addition, the values reported in PLOS, which are based on technical findings, were not developed based on psychological research on experienced stress. To address these knowledge gaps, in this study, we examined how participants experience staying in different densities. For this purpose, we had different numbers of people (2, 4, 6, 8 people per square meter) wait together in a wooden box of one square meter. We measured stress with the physiological parameter of electrodermal activity (EDA), and the subjective experience of stress with a questionnaire, and we also studied how people use the space in different densities.

The introduction summarizes research on (a) crowd density, (b) the basics of EDA, and (c) the use of EDA measurements in transportation research with a focus on pedestrians.

1.1. Crowd Density: Comfort and Behavior. Crowd density is a central parameter in research on pedestrian traffic and crowd dynamics as well as crowd control. In the research area of pedestrian and crowd dynamics, density is measured by persons per square meter. Whenever pedestrians are part of transport systems—as walking or waiting travelers in stations or as passengers of buses, elevators, or trains—density can be used to describe, compare, and analyze the utilization of the infrastructure. Furthermore, in combination with speed, density can accurately describe the dynamics of crowds in spatial structures. This is usually depicted in the fundamental diagram [1–4].

In addition, crowd density is an important quantity for planning and managing pedestrian infrastructure and for evaluating its safety. An estimated number of participants in combination with a fixed maximum density enables us to determine the required space of an infrastructure. In traffic engineering, this is usually depicted in the "pedestrian level of service" (PLOS, [5]; for an overview, see [6]). The PLOS, however, only looks at density in combination with the flow (walking behavior). No criteria are defined for waiting behavior.

Some studies in the context of PLOS have added psychological measurements, but again, only for density in combination with the flow (studying walking pedestrians; [7, 8]). But whether the correlation between increasing density and decreasing comfort in a stationary waiting crowd is linear or is defined by thresholds is unknown.

In psychology, density is not directly studied but, rather, the meaning of space in social situations is addressed in the research field of "personal space" [9]. In situations with unlimited space, people deliberately choose how closely they approach others depending on the relationship with that person, the context (for example, at a concert, while commuting), and the kind of interaction (for instance, talking or reading) they are engaged in. Even minor deviations of what is considered a socially acceptable distance from one another are noticed and often accompanied with feelings of discomfort. However, interestingly, people are also able to adjust their perception of personal space to the specific spatial situation. For example, in a train compartment at rush hour, it is acceptable for complete strangers to be standing very close to each other. Even in situations with reduced space where personal space boundaries cannot be maintained, people still choose their exact position in relation to others. Based on an experimental study, Ezaki et al. [10] described five principles that guide people when choosing their position in an anonymous situation with reduced space (an elevator):

(i) flow avoidance (not standing in the way of people behind them)

(ii) boundary preference (as little contact to others as possible)

(iii) distance cost (not having to walk too far)

(iv) angle cost (not turning too often or too early)

(v) alignment of head direction toward entrance/exit

Additionally, from a more qualitative sociological perspective, Hirschauer [11] adds several observations on behavior in an elevator:

Travelers

(i) anticipate the number of co-travelers and choose their position accordingly,

(ii) mark their territory ("my side"),

(iii) maximize the distance to others, while remaining equidistant to everyone at the same time (showing no preference for any one of the travelers),

(iv) turn halfway toward others (neither showing their back—which makes them vulnerable and is often seen as impolite—nor facing each other), and

(v) direct their view either toward the floor or far away (for instance, toward the floor indicator).

1.2. Basics of EDA Measurement. An objective method to measure stress and cognitive load in individuals is to observe the change in EDA. This is a method from the field of psychology, which is already widely used in transportation research, where stress is the measurement of EDA in reality and in virtual reality [12–21]. This method is one of several physiological indicators of arousal and shows changes in sweat secretion from the hands. Our hands have two types of sweat glands: one is used for thermoregulation of the body while the other is controlled by the sympathetic nervous system, which increases the ability to act when subjective stress increases and is responsible for the fight-or-flight response [22]. This reaction is a primal instinct to ensure human survival in threatening situations and is accompanied by an increase in arousal. Arousal therefore means a general activation of the body. In a situation where we are—in everyday language—"stressed," arousal is higher. But arousal is also high in exciting and joyful situations, which can also activate the sympathetic nervous system. Hence, physiological arousal is an indicator of discomfort or stress, but by itself, it cannot be used to uniquely identify it. The negative or positive quality of arousal can also be assessed on the basis of subjective data, such as questionnaire data. The advantages of using a physiological response as a measure of discomfort are threefold: it allows us to measure the response continuously (whereas a questionnaire can only be administered once in the procedure), it can reveal levels of discomfort, which participants themselves are unaware, and it does not interrupt participants by asking them to reflect on their own well-being. The disadvantage of EDA measurement is its sensitivity to artifacts such as motion artifacts [23].

Using EDA as an indicator of physiological arousal, Boucsein [24] distinguished two parameters, skin conductance (SCL) and skin conductance response (SCR). These parameters are based on the two components of EDA. One is the rapidly changing phasic component (SCR) and the other is the tonic component characterized by a slow shift (SCL).

To calculate the SCL parameter, several tonic values are combined over a period of time. For the SCR, the deflections of the phasic component over a certain value are counted. It should be noted that a distinction is made between event-related SCRs and non-specific SCRs (NS.SCRs). Event-related SCRs are responses to a specific stimulus (such as a sudden noise) while NS.SCRs occur in the absence of a specific stimulus. The average value of NS.SCRs is three to seven per minute [24].

1.3. EDA in Transportation Research. In the field of traffic research, EDA is mainly used in studies dealing with the stress level of car drivers in different situations [16, 21, 25], and also in studies of people in trains and on platforms [12, 13]. The results from studies on stress measurement in car drivers can be neglected here due to the lack of physical proximity to other persons. For studies on trains and platforms, the focus is on the cognitive load of orientation rather than being in a crowded situation. However, there are also EDA studies that focus on the stress levels of pedestrians and everyday situations. These often focus on the well-being or perception of a city or a walk [14, 15, 17–20]. In the past, EDA has also been considered in the context of crowd density [15, 18]. First, a study was conducted in which people had to walk assigned routes in the city, and the density or proximity to other people was measured with a distance meter in front of the chest. In the study, conducted in Hong Kong, Engelniederhammer et al. [15] found negative arousal when the personal space of the walking person was violated. However, this effect was observed only for some of the routes chosen. Consequently, in this study, violation of a person's personal space leads to increased arousal only in combination with the respective external conditions. As mentioned above, EDA is a very sensitive measurement method that has long been used only in the laboratory. Since in field studies it is very difficult to control all environmental factors and artifacts resulting from motion and noise (in the Hong Kong study, the environment moderated the effects on EDA). This aspect is not discussed further in the work of Engelniederhammer et al. [15], but should also be considered. LaJeunesse, Ryus, Kumfer, Kothuri, and Nordback [18] also found the influence of the environment on the stress level of people in their study. For example, subjects were found to have higher stress levels in locations associated with higher density because there is a combination of offices, retail, and residential areas. Again, it is not clear whether this is related to the higher density on the sidewalk or to the noisier environment. Our experimental approach seeks to minimize the effects of the environment and focus more on density.

1.4. Present Study. The present study uses a standardized space—a tiny box of one square meter—and systematically compares the effect of different densities on the arousal and comfort of the participants. The densities we chose are based on bottleneck experiments with crowds, in which densities between two and ten people per m^2 were measured [26]. In a test run, however, we found that ten people do not fit in the tiny box, so we chose to vary between two and eight persons per m^2. It looks at the relationship between density and comfort/arousal by keeping other potentially influential factors constant. Most participants did not know each other. The context was a neutral experimental setting in a university building. We systematically alternated between conditions where people were speaking and remaining silent to determine whether explicit communication changes the behavior and the comfort/discomfort in the tiny box. Even though we instructed subjects to talk, we did not expect everyone to be equally engaged in conversation all the time. Especially in the larger groups, we expected some people to talk while others only listened.

We measure comfort/discomfort both subjectively and objectively, subjectively by means of questionnaires and objectively by measuring electrodermal activity (EDA). Body positioning of people in the tiny box is recorded with cameras from above. In test runs prior to the experiment, we found that up to four people were still able to selectively choose a position in the box. With six or eight people, some people have to involuntarily take uncomfortable positions. Therefore, we suspect that densities greater than four are judged to be particularly uncomfortable.

We make the following hypotheses:

(1) Comfort decreases with increased density in the box. We expect a higher number of NS.SCRs and a higher level of SCL for higher densities. In the questionnaire, we expect participants to label densities higher than four as uncomfortable.

(2) It is more comfortable to speak while waiting in the tiny box than to remain silent. Therefore, we expect a higher number of NS.SCRs for participants who "remain silent." In the questionnaire, we expect participants who "remain silent" to rate the experience in the box as more negative. Moreover, we expect all participants to agree with the statement that speaking makes the situation more comfortable.

(3) Participants position themselves in the box as follows: (a) they prefer standing along the boundary; (b) they position themselves equidistant to others; (c) they do not face each other directly while "remaining silent"; (d) they face each other when "speaking"; (e) if they do not face each other, they look toward the entrance/exit, and (f) they avoid showing their back to others.

2. Materials and Methods

2.1. Participants. The subjects were recruited through calls for participants in university lectures, in Facebook university groups, and on notices. A total of 35 people participated in the study. After checking the EDA signals for artifacts, such as zero lines or extreme fluctuations due to movement or contact problems of the electrodes, we excluded six participants from further analysis. Of the remaining 29 participants, 14 (48.28%) were female and 12 (41.38%) were male, while three (10.34%) did not specify their gender. The gender distribution is not evenly distributed in the individual conditions because we did not hypothesize any gender effect. This is a student study. The average age of the participants was 22.33 years (±3.55) (Table 1). Subjects received €5 for participating.

2.2. Procedure and Experimental Paradigm. The experiments use an innovative type of experimental design. The authors are not aware of any experiments to date that examine the correlation between arousal and density in an experimental setting. The experimental setup consists of two boxes, each with a surface area of 1 m^2. The boxes have three fixed sides and one that is movable and functions as a door. The sides are 150 cm high. The wall height was selected so that the test persons do not "hang out" with their shoulders over the area of 1 m^2. Since the experiments were filmed from above, a ceiling height of over 4 m was used (see Figure 1). Therefore, the experiments took place in a corridor at the Ruhr-University Bochum.

The EdaMove 4 from Movisens was used to record the electrodermal activity. The system uses two electrodes. These electrodes are placed on the palm of the hand after the area has been cleaned with an alcohol pad. The sensor is worn on the wrist and is connected to the electrodes via cables. The sensor is attached to the nondominant hand.

The subjects were given the sensors after arriving at the experiment site. Subsequently, the subjects answered questionnaires about demographic information and the frequency of being in crowds or commuting. The subjects all experienced four different levels of density. These density levels are two, four, six, and eight people/m^2. Each time, they wait in the box for three minutes. After each waiting phase, the subjects left the box. As mentioned above, no attention was paid to gender distribution when filling the box. Furthermore, two conditions were distinguished interindividually: speaking and remaining silent. In other words, participants took part only in the speaking or in the remaining silent condition. This between-subject design in relation to speaking/being silent was chosen to minimize habituation effects. In both conditions, all four density levels were applied. After the experiment, the test persons were given another questionnaire in which they had to evaluate their experiences in the box (for an overview of the processes, see Figure 2).

The experimental procedure was approved by the Ethics Council of the German Psychological Society (DGPs).

2.3. Questionnaire. The questionnaire the subjects filled out after the end of the experiment consisted of eight questions. In retrospect, however, we found that not all questions captured the experimental process accurately and therefore we decided to use only a selection of questions (for the whole questionnaire see Table 2). The problem with the screened-out questions was that the subjects had only completed the questionnaire after the entire experiment. This meant that it was no longer possible to trace back which density they were evaluating with the answer. In the further analysis, five questions will be used (No.: 2, 3, 5, 6 & 7, see Table 2). Two of the questions were answered by all the subjects, while another two of the questions were answered only by the subjects who experienced the speaking condition, and one only from the subjects who remained in the silent condition. One of the four general questions was answered using a five-point Likert scale (1 strongly disagree; 5 strongly agree). The question is "The physical proximity to other test subjects made me feel uncomfortable." In the second relevant question, the subjects indicated the density level that made them feel uncomfortable. Subjects who were allowed to communicate during the experiment were asked whether they actively communicated verbally with other subjects and whether communication made the situation more comfortable. The questions were again answered using a 5-point Likert scale. Subjects in the silent condition were asked if they would have liked to talk. It is a single-choice question (no/yes) with the option of an open-ended response if they wish.

Table 1: Participant demographics.

Demographics	Study ($N = 29$)
Female (%)	48.28
Age M (SD)	22.33 (3.55)
Origin	
Germany (%)	96.6
France (%)	3.4
Education level	
High school diploma (%)	79.31
Bachelor (%)	10.3
Master (%)	6.9
Apprenticeship (%)	3.4
Experience in local traffic M (SD)	4.21 (2.18)
Experience being in crowds M (SD)	5.21 (1.18)

Note. M = mean, SD = standard deviation.

For the analysis of the questionnaire data, after checking for normal distribution using Levene's test, *t*-tests were used to determine differences between the silent and speaking conditions. The questions which were only filled out in the speaking or silent condition could not be compared with a *t*-test. We only provide descriptive statistics instead.

2.4. Skin Conductance. Skin conductance is measured with the aid of an ambulatory system from the company Movisens (EdaMove 4). For the measurement, two electrodes are attached to the nondominant palm, one below the thumb and the other below the little finger. The skin under the electrodes was cleaned with alcohol pads. The signal was recorded at 32 Hz and the unit of measurement is microsiemens (μS). The curve in Figure 3 shows the EDA signal (of a selected participant) for three minutes of each experimental condition at the different densities.

The raw data were preprocessed using Python (version 3.7). The preprocessing was done according to the example of Gashi et al. [27]. The data were downsampled from 32 Hz to 4 Hz. The data were then cleaned of electrical noise using a first-order Butterworth low-pass filter with a cut-off frequency of 0.6 Hz. Using the convex optimization approach [28], the data were separated into tonic (red curve) and

Figure 1: The figure shows the setup of the experiment, with the two boxes side by side and the camera above them. The figure also contains the dimensions used.

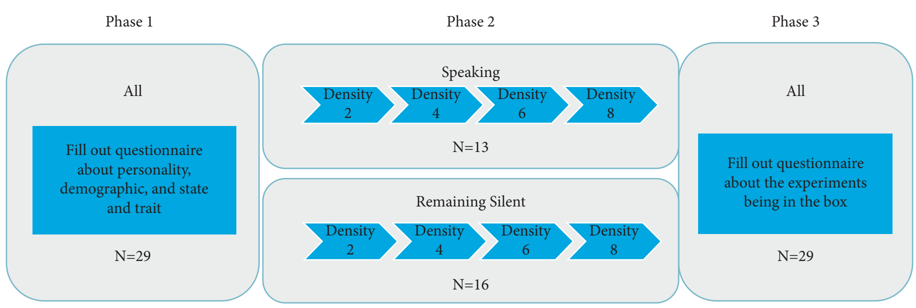


Figure 2: The figure shows the procedure of the experiment. While phases 1 and 3 were carried out by all participants, phase 2 shows the split into the two conditions. Nevertheless, the procedure in the condition is the same, too.

Table 2: Questionnaire items.

Question	Scale	Mean (SD) speaking	Mean (SD Remaining silent
1. I felt uncomfortable over the course of the experiment due to the (increasing) density of people.	5-Point-likert scale	2.94 (1.12)	3.15 (1.21)
2. The physical proximity to other subjects made me uncomfortable.	5-Point-likert scale	2.81 (1.05)	3.08 (1.19)
3. At what number of people in the square meter did you find it uncomfortable?		6.27 (1.98)	7.54 (0.88)
4. I perceived myself as a disruptive factor over the course of the experiment.	5-Point-likert scale	2.44 (1.36)	2.08 (0.86)
5. I actively engaged in verbal conversation with other subjects.	5-Point-likert scale		4.33 (0.49)
6. Communication has made the situation more pleasant.	5-Point-likert scale		4.54 (0.52)
7. I would like to have a conversation. (%)	Single-choice	68.75	

Note. SD = standard deviation.

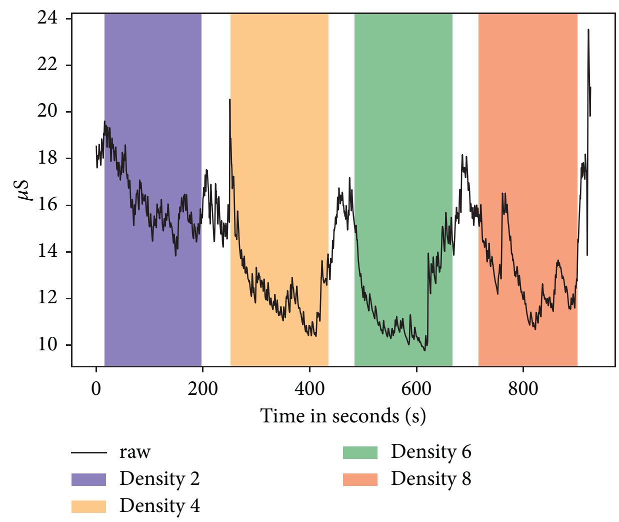


Figure 3: Overall representation of the EDA signal during the whole experiment of a selected person. The colored areas show the different experimental runs, starting with a density of two (purple), then four (yellow), six (green), and eight (red).

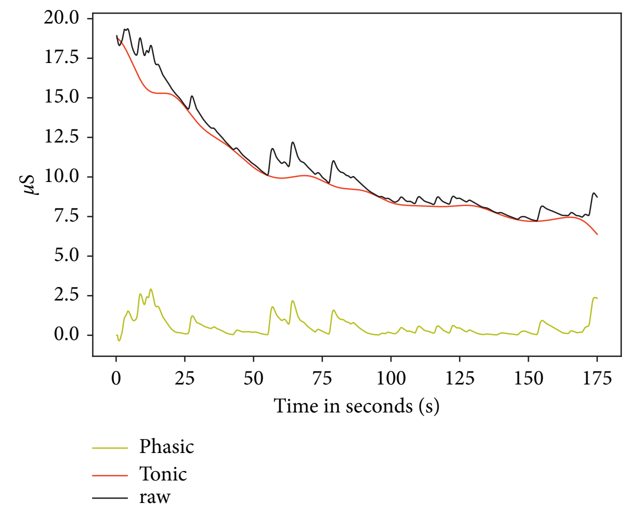


Figure 4: Representation of the EDA of the selected person before (raw) and after separation into phasic and tonic data (density 8 p/m^2 only).

phasic (yellow curve) components (see Figure 4). This is done for every density separately. Raw, tonic, and phasic data are shown in Figure 4 below. Using the algorithm of Taylor et al. [29] adapted to our data structure, the number of peaks (NS.SCR) exceeding the limit of 0.01 μS in each of the experimental periods were counted.

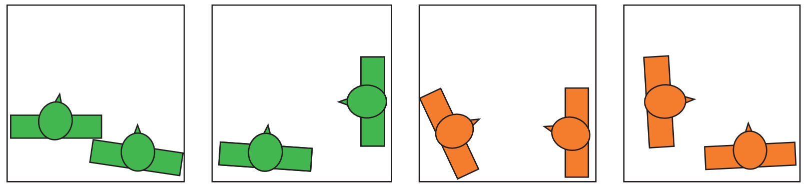
Repeated measures analysis was used to assess the significance of the effect of density level on the mean SCL and the occurrence of NS.SCR. The normality of SCL and NS.SCR in the four different densities was tested using the Kolmogorov–Smirnov test for each density separately. Since the sample contains more than 25 individuals, a violation of the normal distribution assumption is negligible. Therefore, repeated-measures one-way analysis of variance (ANOVA) could be performed to test for significant differences between the density levels. In the event of violation of the sphericity assumption, the Greenhouse–Greisser correction is used. Subsequently, the repeated-measures ANOVAs were tested using a post-hoc t-test. The Bonferroni method was used to correct for multiple comparisons. The analysis of the differences between the densities in the two conditions was also carried out with the aid of a repeated-measures ANOVA after checking for normal distribution. If the normal distribution assumption is violated, nonparametric tests are used. Because of the exploratory design, we decided to conduct post-hoc tests even when the repeated ANOVA is not significant. Chen and colleagues [30] recommend conducting both tests in order not to miss any interactions, as they differ in data basis and also in sensitivity.

Furthermore, we conducted one post-hoc analysis not covered by our initial hypothesis: unexpectedly, the EDA data showed a typical trend in many experimental runs. To analyze this temporal progress, we subdivided each experimental run of 150 seconds into three-time windows of 50 seconds each. The differences between time windows within a density were also checked using repeated-measures ANOVA. Here, too, a Bonferroni correction was used for multiple comparisons. In the event of violation of the sphericity assumption, the Greenhouse–Greisser correction is used.

2.5. Video Data of Positioning in the Box. All experimental runs were videoed from above (camera: Sony X3000). The orientation of heads and shoulders is clearly visible in these videos. We waited until everyone had found a position and orientation in the box and then took a screenshot of the situation. This screenshot was turned into a pictogram to anonymize the data. Because in most experimental runs the positioning and orientation of participants did not change after they had taken their initial position, here we will only analyze one positioning/orientation per run. In the results section, we will describe how participants position themselves in the box and analyze this behavior by referring to the principles listed in the literature [10, 11]. Exemplary runs are shown in Figures 5–8. In the pictograms, the door of the box is always at the top. During the experiments, the investigators were waiting approximately 7 m away from the box, in the direction of the door. Therefore, participants who watched the door could also observe what the investigators were doing (for example, indicating the end of the experiment).

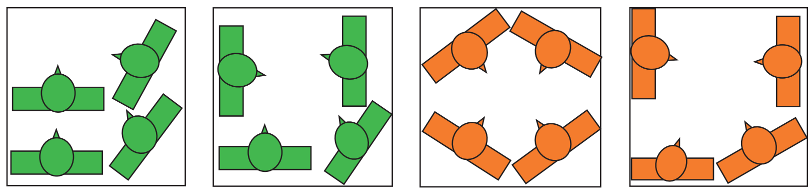
3. Results

3.1. Results: Questionnaire. The ratings in the questionnaire differentiate between the perception of the overall experiment in the conditions of speaking and remaining silent. The first question shows no difference between the two groups—in both cases, participants find the physical proximity in the experiment equally unpleasant. Overall, density 8 is most often perceived as unpleasant. The mean value of the total sample is 6.86 (SD. = 1.67). However, this differs between the two conditions. Thus, subjects in the group remaining silent are more likely to perceive the density as unpleasant



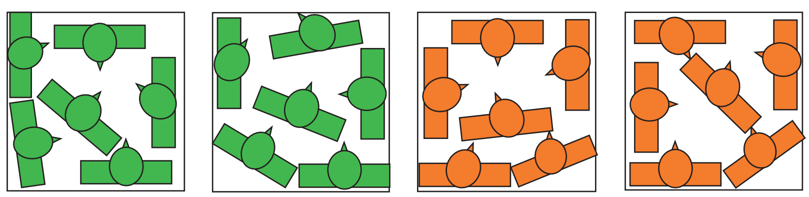
(a) (b) (c) (d)

Figure 5: 2 p/m^2, green: remaining silent, orange: speaking, door at the top.



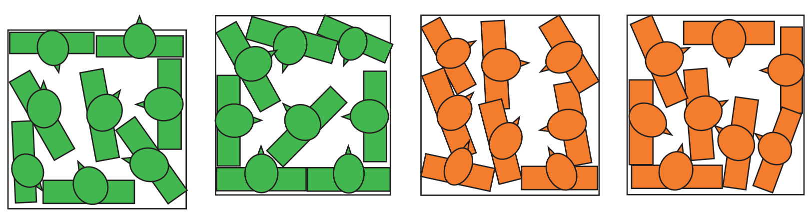
(a) (b) (c) (d)

Figure 6: 4 p/m^2, green: remaining silent, orange: speaking, door at the top.



(a) (b) (c) (d)

Figure 7: 6 p/m^2, green: remaining silent, orange: speaking, door at the top.



(a) (b) (c) (d)

Figure 8: 8 p/m^2, green: remaining silent, orange: speaking, door at the top.

compared with the subjects in the group speaking ($t_{19.86} = -2.25$, p 0.04). Looking at the absolute frequency distribution, it can be seen that in the group remaining silent, two subjects considered density 2 to be unpleasant ($M = 6.27$, SD = 1.98), while in the speaking condition only densities of 6 and 8 are indicated as unpleasant ($M = 7.54$, SD = 0.88). The subjective perception also shows that the subjects who were allowed to speak had the impression that speaking made the situation easier ($M = 4.54$, SD = 0.52). Similarly, the majority of people in the silent condition assume that the possibility to speak would make the situation easier ($M = 0.64$, SD = 0.5).

3.2. Results: Skin Conductance. When looking at the graph, not only can clear differences between the density levels be observed but also similar time-dependent progressions in sections (see Figure 9). The similar trends at the beginning and the end of the experimental conditions (the grey areas at sec 0–15 and 165–175) are not included in the further statistical analyses of the density since these trends can be explained by the experimental procedure itself: walking into the box and starting the experiment is accompanied by higher arousal. During the last few seconds, participants could already see that the experiment was almost over (examiners were preparing to stop the experiment) and were probably relieved—resulting in a decrease in arousal. The remaining two and a half minutes are considered in the following analysis both as a whole and divided into smaller sections of 50 seconds each. The duration of 50 seconds is selected on the basis of the characteristics of the SCL, which does not lend itself to a shorter recording time due to it only changing slowly [31]. Both the differences between the densities and the differences between the time segments within a density are considered.

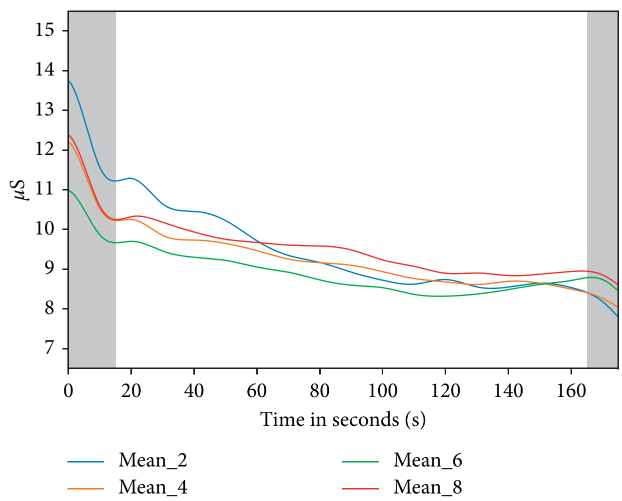


Figure 9: Plot of graphs of SCL averaged over all subjects for each density.

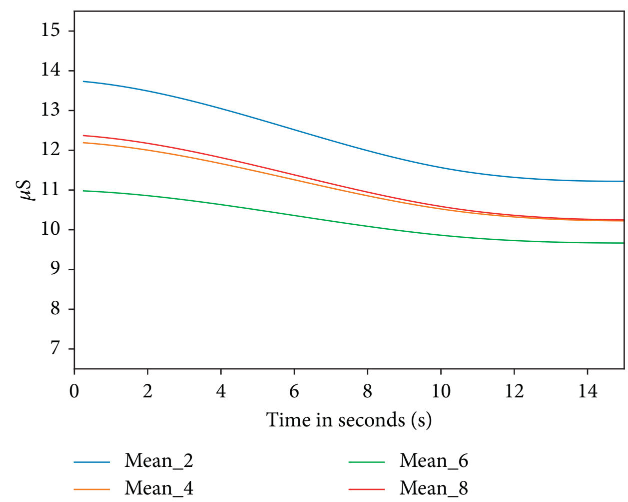


Figure 10: Plot of graphs of SCL averaged over all subjects for each density in the first 15 seconds.

3.2.1. The Beginning and the End. If we look at the first 15 seconds after the door was closed, we see a very similar curve for all densities: a drop in the curves to a lower excitation level can be observed (see Figure 10). This drop might be due to a wide variety of factors. First, it could have to do with the decrease in excitation. Another possible explanation might be the decrease in or the omission of motion artifacts since the subjects enter the box, position themselves, and then stop, which in turn causes the motion artifacts to stop. It is interesting that the excitation level in density 2 is initially significantly higher than in the other densities. This might be explained by the fact that each subject goes through condition 2 first and thus does not know what to expect next. The very low excitation level in density 6, on the other hand, is somewhat difficult to explain.

If we look at Figure 11, we can see that in the last ten seconds of an experiment run, the graphs equalize again. It shows that the graphs all flatten. One possible explanation for this is that there is a kind of a relief because the subjects realize that the experiment is coming to an end. Nevertheless, it is interesting to see that density 2 is the lowest (in contrast to in the first few seconds when it was the highest), while density 8 is the highest. Also, the sorting of densities 6 and 4 shows a more hypothesis-compliant representation.

3.2.2. Differences between Densities. Overall, it is very interesting to see that density 6 is initially the lowest and only rises after three-quarters of the experiment and then stagnates again. Density 8 starts at a medium-high value and, as soon as the blue line representing density 2 has dropped, it is no longer overtaken by any other density. Therefore, it can be noted that density 8 apparently leads to the highest long-lasting excitation. Looking at the mean values of the whole experiment time, we see no significant differences between the mean values of the different density levels though (for the graphs look at Figure 12). In the post-hoc test, however, there is a significant difference between the mean values of

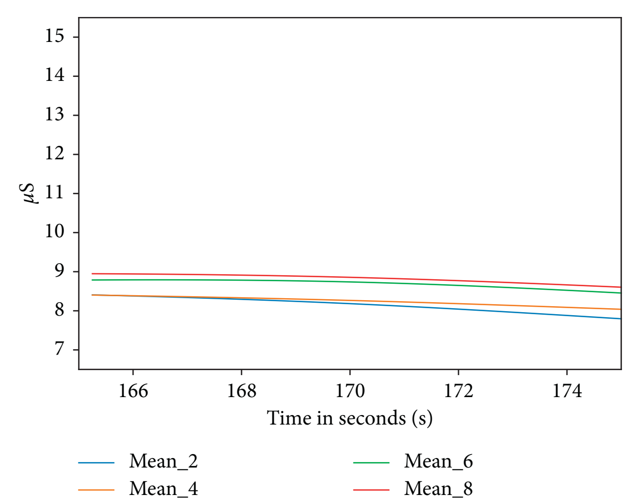


Figure 11: Plot of graphs of SCL averaged over all subjects for each density in the last ten seconds.

density 6 ($M = 8.82$, $SD = 3.82$) and 8 ($M = 9.42$, $SD = 3.85$, $p < 0.01$;) see Table 3 for more means and standard deviations).

It is clear that density 2 decreases the most. The run starts at the highest value of 11.2 μS and decreases to the overall lowest value of 9.4 μS. There are several possible explanations for this strong variation. One is that subjects experience run density 2 first and thus nervousness about what is coming next keeps arousal high. In a randomized experimental design in which the subjects do not always experience the run with density 2 first, it could be that this high starting value of 11.2 μS is not reached. Alternatively, some form of adaptation might also be a factor. Perhaps being in the box with only one other person makes people feel particularly uncomfortable initially because it is not possible to hide behind someone else. But, perhaps the habituation effect with one other person in the box is also stronger because it is easier to get accustomed to one other person than to several people.

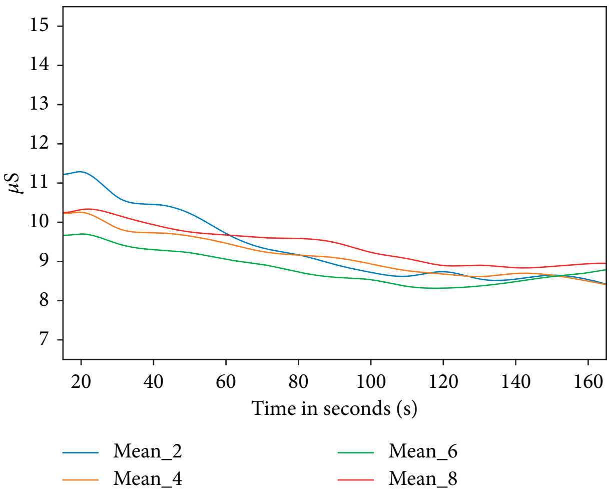


Figure 12: Plot of graphs of SCL averaged over all subjects for each density for the time range relevant to the analysis.

3.2.3. Time-Dependent Trends between Different Densities. Due to the different time-dependent courses of the SCL graphs, we decided to look at the courses section by section. There is a significant difference in the first 50 seconds of the experiment ($F_{1.64,\ 46.0} = 4.083$, $p = 0.03$, Greenhouse–Geisser corrected). Furthermore, when looking at the post-hoc test, we find the difference between densities 6 ($M = 9.34$, $SD = 3.83$) and 8 ($M = 9.97$, $SD = 4.00$, $p < 0.01$) to be significant. In a (post-hoc) paired t-test of the second time period, there was also a significant difference between 6 ($M = 8.63$, $SD = 3.74$) and 8 ($M = 9.39$, $SD = 3.90$, $p = 0.02$). Each of the significant results showed that the SCL value of density 8 was higher than that of density 6.

In addition to the SCL, we also looked at the NS.SCR, but there were no significant differences in the number of NS.SCRs for different densities over the entire period. If we look at the NS.SCRs for the particular time periods, we see that there is a significant difference in the number in the first time period ($F_{3,84} = 3.21$, $p < 0.03$). The NS.SCRs differ between densities 4 ($M = 6.07$, $SD = 2.43$) and 6 ($M = 5.03$, $SD = 1.66$, $p < 0.03$), with more deflections in density 4 (for an overview about the results, see Table 3).

3.2.4. Differences between Time Segments within the Different Densities. As already mentioned above, Figure 10 shows a clear drop in the curves if the values of different time periods are compared within a particular density. Significant differences between every time period are found in densities 2 ($F_{1.18,\ 33.11} = 30.55$, $p < 0.001$) and 8 ($F_{2,\ 56} = 13.65$, $p < 0.001$; for mean values have a look in Table 3). Meanwhile, the means of the time periods 1 and 3 differ significantly in densities 4 ($F_{1.34,\ 37.49} = 11.98$, $p < 0.001$) and 6 ($F_{1.47,\ 41.1} = 8.29$, $p < 0.01$). These results also confirm the visual impression that all the graphs are falling.

3.2.5. Effect of Verbal Communication. In our experiment, we also tested the effect of verbal communication. The conditions of remaining silent and speaking can be compared only relative to each other since it is not the same test persons in the two conditions (interindividual differences between EDA levels can be relatively large and therefore, a direct comparison of the absolute level between individuals is not advisable).

It is noticeable that the EDA data differ in their trends in the densities and conditions (see Figure 13). While in the silent condition, the trends of different densities are very similar, and the speaking condition shows somewhat different trends.

As mentioned above, the first 15 seconds and the last ten seconds were excluded from the analysis. But when we look at the first 15 seconds, we also see some peculiarities when the data are separated. In the silent condition, densities 2 and 8 start at the same high level and have the same progression until second 18. Density 4 also starts similarly high, while density 6 starts lower. Overall, arousal in all densities drops in the last ten seconds. In the speaking condition, it is noticeable that densities 2 and 8 have a typical progression in the first 15 seconds, while densities 6 and 4 have a less steep drop immediately after the start. The last ten seconds also differ. Here, densities 2 and 6 drop much more steeply than densities 4 and 8.

If we look at the areas to be analyzed in the silent condition, we notice that the trends of densities 4 and 6 are the same from second 35 to second 160. After second 160, densities 4 and 6 separate. Overall, densities 4 and 6 have the lowest slopes (density 4: $M = 8.07$, $SD = 3.03$; density 6: $M = 8.02$, $SD = 3.06$). Density 8 shows the highest slope of SCL ($M = 8.84$, $SD = 3.34$), and so density 8 seems to result in the most excited state. There is also a significant difference in the post-hoc test between densities 6 ($M = 8.02$, $SD = 3.06$) and 8 ($M = 8.84$, $SD = 3.34$, $p = 0.04$) in the whole time and in the first time period (density 6: $M = 8.07$, $SD = 3.03$; density 8: $M = 8.02$, $SD = 3.06$, $p = 0.04$). Interestingly, the second highest graph is density 2 ($M = 8.44$, $SD = 3.60$); being alone with another person without being allowed to speak also seems to be stressful. In addition, the NS.SCR in density 2 shows an increased level of excitation in the first 50 seconds compared to density 6 ($X_3 = 10.75$, $p = 0.01$). Over the whole time range, a falling graph can be observed for all densities. The ANOVAs show a significant change in time for all densities (density 2: $F_{2,\ 30} = 27.24$, $p < 0.001$; density 4: $F_{1.19,\ 17.81} = 9.48$ $p < 0.01$; density 6: $F_{1.47,\ 41.10} = 8.29$, $p < 0.01$; density 8: $X_2 = 16.125$, $p < 0.001$). Densities 2, 4, and 6 differ significantly between time ranges 1 and 2 (density 2: $p < 0.001$; density 4: $p < 0.001$; density 6: $p < 0.01$; density 8: $p < 0.05$) and 1 and 3 (density 2: $p < 0.001$; density 4: $p < 0.05$; density 6: $p = 0.03$; density 8: $p < 0.001$). This result indicates a significant drop in excitation at the beginning and a less significant drop at the end. In the NS.SCR, there is a difference seen in density 8 ($F_{2,\ 30} = 5.66$, $p < 0.01$). Moreover, the number of NS.SCRs in time period 2 ($M = 4.94$, $SD = 1.77$) is significantly lower than in time period 1 ($M = 6.19$, $SD = 2.14$, $p < 0.05$).

In the speaking condition, density 2 shows a significantly different course than the other densities. The graph starts with the highest value and ends with the lowest value. It seems to be most arousing to talk to one other stranger. Over time, the

Table 3: Mean parameters SCL and NS.SCR for the whole time and for different time periods.

	Density 2	Density 4	Density 6	Density 8
SCL				
Whole time-mean	9.34 (4.07)	9.15 (4.20)	8.82 (3.82)*	9.42 (3.85)*
Time period 1-mean	10.45 (4.49) ‡	9.78 (4.27)	9.34 (3.83)*	9.97 (4.00) ‡*
Time period 2-mean	8.96 (3.92) ‡	9.04 (4.25)†	8.63 (3.74)†*	9.39 (3.90) ‡*
Time period 3-mean	8.60 (3.99) ‡	8.63 (4.27)†	8.50 (4.05)†	8.89 (3.81) ‡
NS.SCR				
Whole time-mean	18.41 (6.04)	18.66 (7.35)	16.76 (5.80)	17.48 (5.91)
Time period 1-mean	6.07 (2.09)	6.07 (2.43)*	5.03 (1.66)*	5.72 (1.96)
Time period 2-mean	5.83 (2.00)	5.90 (2.78)	5.66 (2.54)	5.41 (1.99)
Time period 3-mean	5.90 (2.61)	5.24 (2.82)	5.52 (2.56)†	5.90 (2.58)†

Note. In the brackets is the standard deviation †: Significant difference in comparison to time period 1 within one density, ‡: Significant differences between all the different time periods within one density, *: Significant difference in comparison to density 6 between the density but within one time period.

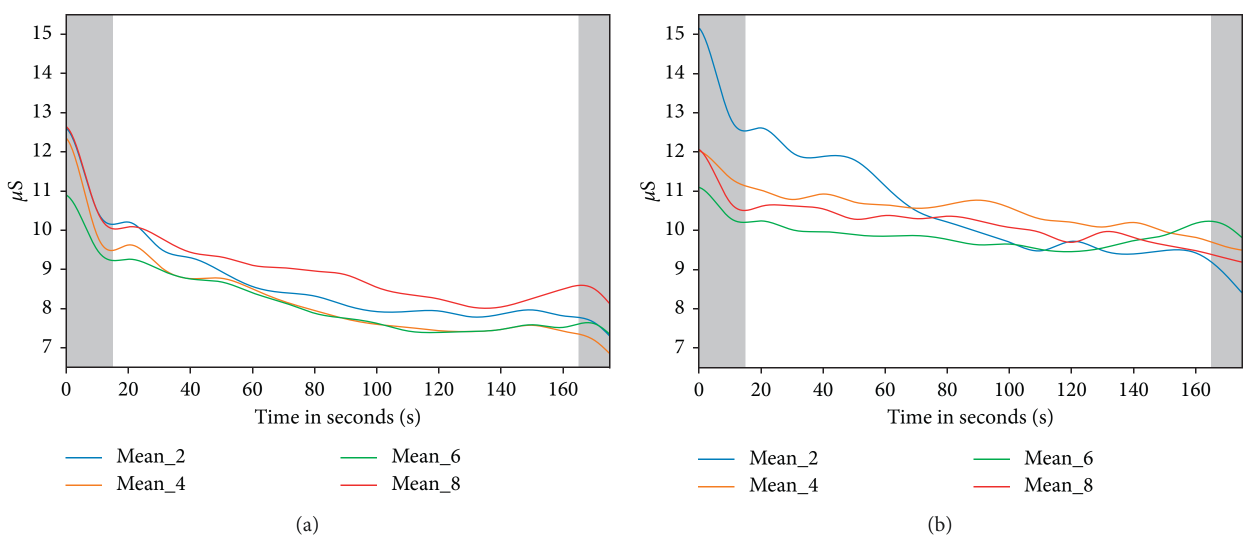


Figure 13: (a) Representation of the SCL averaged over all test subjects in the silent condition for all densities. (b) Representation of the SCL averaged over all test subjects in the speaking condition for all densities.

level of arousal decreases and the subjects become accustomed to the situation and verbal communication. Unlike in the silent condition, density 4 is high and relatively stable. Also, significantly more NS.SCRs are found in density 4 than in density 8 in the first time period ($F_{3,\ 36} = 3.38$, p 0.03). One explanation might be that a conversation with three people could be arousing because it is stressful. Another explanation may be that the communication itself is arousing. Compared to the silent condition, the arousal in densities 4 and 6 do not drop so much, but in density 6 the arousal also increased from the lowest to the highest. Only in density 2 ($F_{1.12,\ 13.48} = 13.06$, $p < 0.01$) do the time periods 1 ($M = 11.87$, SD = 5.13) and 2 ($M = 9.98$, SD = 4.31, $p < 0.01$) and 1 ($M = 11.87$, SD = 5.13) and 3 ($M = 9.49$, SD = 4.28, $p < 0.05$) differ. Also, the ANOVA of density 8 shows a significant difference ($F_{2,\ 24} = 3.78$, $p < 0.05$). However, the post-hoc test of density 8 shows no significant difference between the time periods; in the NS.SCR, too, no differences are found between the various time periods.

When we compare the trends of the densities between the two conditions, it is evident that in the silent condition, density 8 is associated with the highest SCL values, while in the speaking condition, density 4 leads to increasing SCL values. In contrast, density 4 has a similar trend as density 6 in the condition of remaining silent. Interestingly, density 6 leads to the lowest SCL values in both conditions. It seems that density 6 in both conditions creates an environment that is perceived as even less arousing initially due to enough anonymity either in the silent condition or enough communicators in the speaking condition so that individuals who do not wish to speak do not feel compelled to do so. However, in the speaking condition, there seems to be a change of perception at the end and the subject becomes more aroused. This may be due either to the communication and the loss of anonymity or the density.

3.3. Results: Qualitative Analysis of Positioning in the Tiny Box. When two participants wait in the box, they show a clear preference for the side of the box which is opposite the entrance. We assume that this is so they can keep an eye on the entrance and the investigators. Furthermore, the first person who enters does not stand in the way of the second person. All participants turn after they have entered the box and then wait in a position in which it is possible to see the entrance. The arrangement we saw most often in both experimental conditions is shown in the second and fourth pictures (see Figure 5): participants form a right angle. This appears to be an attractive arrangement because both participants can simultaneously observe the entrance and the other person in the box. A difference between the experimental conditions of speaking and remaining silent is shown in pictures a) and c), respectively. In picture a), both participants are facing the door. Because of the limited space, one is standing behind the other, but off-center. In picture c), the speaking participants are facing each other, although not completely. They are slightly oriented (upper body or head) toward the door. We assume that the distance between them is too close to comfortably face each other directly.

When four participants stand in the box, all parts of the box are used, not just one side (see Figure 6). There is again one configuration, which seems to be comfortable for speaking and remaining silent. As shown in pictures (b) and (d), participants form a U shape to watch each other and the entrance. The other two configurations shown in pictures (a) and (b) are different for remaining silent and speaking. The positioning in picture (a) allows everyone to watch the entrance. Unlike in the U shape, no-one is facing anyone else directly. However, two participants show their back to others which Hirschauer [11] and Ezaki et al. [10] have identified as uncomfortable. In picture c), participants form a circle in which everyone seems to have an equal part in speaking. But, this means two participants are unable to watch the entrance.

When six people use the box, there are always five people around the edge and one person in the middle (see Figure 7). The person in the middle is always looking in the direction of the entrance although his/her body is not directly parallel to the entrance but always slightly turned. In some of the experiments where people remain silent, one person next to the door turns their back to the others and looks in the direction of the door/investigators (see Figure 7, picture b). In some of the speaking experiments, three or four participants form a circle while the others are standing behind the circle and are thus excluded (see, for a group of four, Figure 7, picture c).

In the experimental runs with eight participants, six people have chosen to stand next to the edge of the box. If six people choose this position, two of them have to overlap. The other two or three participants are standing in the middle. Only in one run could everyone (potentially) see the door (Figure 8, picture c). In the other runs, one or two participants were facing the other direction. In every run, some participants were showing their backs to the others. In the speaking condition, groups of two, three, or four can be identified. However, also in the remaining silent condition, some participants are positioned as if they were speaking to each other. In general, several participants seem to be in awkward positions. For example, the person in the bottom left-hand corner in picture a). They are deliberately looking away from the door—probably to avoid eye contact with the person who is standing to their right. Also, in the same picture, the person in the bottom right-hand corner is turning their head quite a lot, probably also to not look in the direction of the person to their left. There seems to be less avoidance of eye contact in the condition speaking.

In all experimental runs (2–8 p/m^2, remaining silent and speaking), a positioning in which two participants directly face each other as in the picture below (see Figure 14) is rare. A slight turning of the body or the head direction is always observable. It is more likely that participants almost face each other in the speaking condition than while remaining silent. Furthermore, this is also most likely in situations where groups of four form a circle (Figure 6, pictures c and d, Figure 7, picture c).

4. Discussion

The present study examines the correlation between density and arousal as well as between density and positioning of persons in personal space injuries. For this purpose, a varying number of subjects are admitted into a 1 m^2 box. While the subjects are in the box, arousal is measured using EDA devices. All subjects pass through densities of two, four, six, and eight persons per m^2. We distinguish between two conditions in which subjects are allowed to communicate verbally and in which they are instructed to remain silent.

Concerning the results for the correlation between arousal and density, contrary to our hypothesis, we found no significant decrease in comfort with increasing density in the box. We expected a higher number of NS.SCRs and a higher level of SCL for higher densities. When we look at the total time, we only find a significant difference between densities 6 and 8. This finding fits our hypothesis, but what contradicts our hypothesis is that density 6 has the lowest SCL mean overall. The SCL means for densities 2 and 4 are also higher; one possible explanation for this could be that being with five other people is less stressful than being with fewer people due to a certain level of anonymity. Density 8 might be experienced as particularly stressful simply because of the physical closeness. If we compare the separate time periods, the significant difference between densities 6 and 8 remain in periods 1 and 2. In the third period, the mean values equalize. This could indicate a habituation effect. We also expected higher numbers of NS.SCRs with increasing density, but there is only a significant difference between the number of NS.SCRs in densities 4 and 6 in the first period. This could also be explained by the lack of anonymity, but why this is only evident in the first 50 seconds cannot be explained and requires further clarification. Also, when analyzing the questionnaires, we thought that participants would describe densities higher than 4 as unpleasant. In fact, the mean value of the densities showed that only densities above 6 were perceived to be unpleasant (M = 6.86).

Something we did not expect but that still has an interesting effect on the data is time. Overall, all graphs of the SCL show a downward trend, which is particularly pronounced for densities 2 and 8. For densities 4 and 6, the graphs do not drop so sharply toward the end. A kind of adaptation seems to take place up to a certain point. It would be interesting to know whether the graphs of densities 2 and 8 continued to drop during test runs longer than 3 minutes.

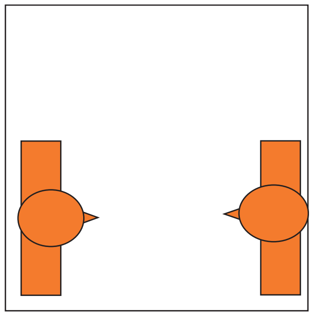


Figure 14: Facing each other directly.

Does this trend continue or is the adaptation over after a certain time and, perhaps, does the situation become more annoying and hence stressful again? Do different density levels create different time-dependent trends if a longer time period is observed (i.e., ten minutes)?

Furthermore, we need to consider what time domains are interesting and relevant to real-life scenarios. For example, a short-term stay in higher densities, such as in an elevator, usually lasts no longer than 50 seconds to two minutes. On the other hand, there are also situations in daily life that lead to a longer stay of people in higher densities, such as when travelling by train, but it must be reconsidered how high the densities in the train realistically become (perhaps densities of four people per m^2 are already sufficient).

The subjects who were allowed to speak believed that it made the situation easier to handle, while the subjects who had to remain silent were sure that speaking would have improved the situation. The evaluation of the density perceived as unpleasant also shows that if people remain silent, the threshold of density perceived as unpleasant is lower than if they are allowed to speak. Therefore, we expect a higher number of NS.SCRs for the condition "remaining silent." But this effect could not be found. The visual comparison of the graphs in the two conditions shows that the graphs in the silent condition do not differ as much as the graphs in the speaking condition. Also, it becomes clear that the relative relation to each other is different. Thus, in the speaking condition, the graph of density 2 shows a special trend. This trend can be explained by the fact that standing together with another person and being forced to enter into verbal communication leads to a situation of enormous initial arousal. But when the situation continues, it leads to habituation and a clear decrease in the graph. Contrary to expectations, density 4 shows a constant trend, which does not decrease and is constantly the highest compared to the graphs of densities 6 and 8. One possible explanation for this is that the conversation with three other people is very stimulating. Looking at the positioning of the people in the box (see Figure 5), we see that four people form a group and try to interact as a group. This is potentially more engaging than with more participants because this leads to the building of subgroups or enables participants to not get involved in the conversation. Another limitation of the data in the speaking condition is that talking can produce motion artifacts and can also produce more dynamic signals.

When we look at the data in the silent condition, we see that density 8 is the highest, and so in this condition the factor of limited space seems to be relevant. The second highest graph is density 2, which could be explained by a lack of anonymity. Densities 4 and 6 do not differ in terms of their trend. In the comparison between the two conditions, it is clear that density 6 is associated with the lowest arousal in the first two time segments. The third time segment of density 6 differs between the conditions. While in the silent condition, the graph remains low, and in the speaking condition it increases noticeably while the other graphs vary. Overall, there is an effect of verbal communication, which needs to be explored in more detail.

In addition to arousal, we also looked at the positioning in the box and found that people prefer to stand along the edge. There are also differences between the two conditions: in the silent condition, people do not stand directly opposite each other so as to avoid any possibility of verbal communication. On the other hand, people in the speaking condition face each other in order to be able to communicate—yet they do not face each other directly but always include a slight twist, probably because the distance is too short. If people do not have anyone facing them, they orient their gaze toward the entrance/exit. Overall, they avoid showing their backs to others. In densities of 6 and 8 p/m^2, the social choreography of positioning seems to become more difficult and not as smooth. Some people end up showing others their back or their face is very close to others. The results of the observation are very much in line with the hypotheses and similar to the results of Hirschauer [11]. The effect of the box and the walls is debatable. It is questionable whether the picture that emerges in our study would be the same if the number of participants and the size of the box were changed. These effects should be analyzed in further studies.

5. Conclusion

The overall performance of the experiment shows that it is possible to collect EDA signals and that the experimental setup worked. It also shows that EDA data collection is possible in crowd research. Although EDA is a difficult method to use since it is susceptible to motion artifacts and environmental factors such as temperature, it is well suited to experimental designs such as that used in this study which does not generate too much motion because participants were standing still in the box. However, the effects of beginning and end suggest that experiments with moving participants may be more problematic.

In sum, the results of the study regarding arousal are not conclusive and require further investigation. Various factors should be taken into account in further research. First, with only 29 people, we have a relatively small sample for two conditions. If the effects are not strong, more people are needed to determine the differences. Second, a major methodological problem is that we did not collect a baseline. This would allow us to determine whether people in the tiny box are stressed at all, and it would also allow us to standardize the data so that we can compare the data from the two conditions (speaking and remaining silent) in absolute rather than relative terms. Third, one possible explanation for the lack of difference between the densities is that even the density of 2 persons per m^2 is high and is not so common in everyday life on a permanent basis. Consequently, even being together with one other person in a space measuring 1 m^2 could be stressful and lead to increased arousal. What contradicts this theory is that density 6 contains the lowest value for both SCL and NS.SCR. Nonetheless, future studies should also explore sending only one person into the tiny box or building larger boxes in which densities less than 1 person/m^2 can be created. It can be deduced from our initial results that increasing densities do not simply decrease comfort. The correlation is more complicated than expected and probably mediated by the social situations created: a lower density might be more comfortable because more space is available but also less comfortable because it creates a direct interaction situation between two strangers. In situations with four participants, a complex social choreography might take place which governs who needs to interact at what time and with whom. Larger densities reduce space and lead to involuntary body contact but, at the same time, they enable individuals to "disappear" in the crowd.

Measuring the subjective experience with the questionnaire did not work so well in this study. To capture this better, a new questionnaire should also contain questions that are answered after each round to obtain a more detailed assessment of the valence of being in the box in different densities. This will also give us a chance to compare valence and arousal.

5.1. Suggestions for Further Experiments. To test whether the box itself has any effect on the person, we would like to repeat the experiment again, but with lower densities and without the box at all (just with marks on the floor). It must also be noted that a sample of 29 people in a total of two conditions is relatively small. The experiments should be repeated with a larger sample. Another criticism is that the duration of the experiment toward the end shows a rather hypothesis-compliant progression of the different trends. It is worth considering how the length of the experiment duration affects the progression of the graphs. To check this, the experiment needs to be repeated with some variations of the dwell time. If a result conforming to the hypothesis is seen at a longer dwell time, it confirms that higher densities are indeed more arousing than low densities, but there is also initial excitement about being in an experiment at all and the effect of the density is not evident until later. The effect of time on the relationship between density and well-being and stress, in general, is one of the particularly interesting aspects of our finding. It should certainly be picked up in further studies.

In addition, our study did not consider the effect of group composition due to the small number of subjects. Since the collection of sociodemographic data in this study only served to capture the homogeneity of the sample. Differences in the sociodemographic data of individuals certainly influence the perception of stress in different density situations. However, to specifically investigate and include these influences, one would need a much larger sample, which would have to be selected very precisely beforehand. As mentioned above, when repeating the experiment, care should be taken to collect a baseline to have a comparative value and to be able to standardize the data properly.

Moreover, the questionnaire should be changed and questions asked after each round to obtain a more reliable subjective assessment of the experience. Also, the striking downward trend at the beginning of the experiment should not be ignored. Besides the effect of movement, it should also be considered that being given instructions is always a factor that might lead to a potential increase in arousal. This instruction effect should always be taken into account when planning the course of the experiment.

This experimental study shows that the relationship between comfort or stress and density is more complex than expected: both time and the social and communicative situation created in the box seem to mediate the "higher density = higher stress" effect. This is directly relevant for applied contexts: densities are probably not "good" or "bad" in isolation, but are perceived as more or less pleasant depending on time, context, and social interaction. Therefore, no general rule for a PLOS can be derived from our results in the sense of "above a certain density it becomes stressful for people waiting." However, it is clear that such a concept should definitely include the waiting time. Furthermore, the complex relationships between density and stress should be further explored.

Data Availability

The data used to support the findings of the manuscript are available from the corresponding author (Mira Beermann (mira.beermann@rub.de)) upon request.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

Acknowledgments

The study was part of the project "CroMa—Crowd Management in Verkehrsinfrastrukturen." The project was funded by the German Federal Ministry of Education and Research under grant number 13N14531. The funders had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript, or in the decision to publish the results.

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