

Perceived Safety in T-bana environment

A project made for the Human Perception course DM2350 at KTH

Supervised by Christopher Peters

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ABSTRACT

Perceived safety on subway platforms depends on both environmental and social factors, yet studying these in real environments is challenging. This study used virtual reality (VR) to examine how actor type, crowd density, caregiver presence, and platform safety barriers influence perceived safety. The participants experienced multiple VR scenarios based on a Stockholm T-bana platform and rated their perceived safety on a Likert scale, with additional written feedback. Results showed that glass platform doors increased perceived safety, while children near the platform edge, high crowd density, and absence of caregivers lowered it. Interactions between social and environmental factors were distinct, with the lowest safety ratings occurring when children were unsupervised in crowded conditions without protective barriers. These findings highlight VR as a safe tool for studying human perception and emphasize the importance of considering

both physical infrastructure and social context in public transport design.

1. INTRODUCTION

Public transportation systems are essential to daily life in large urban areas. In the Stockholm region alone, approximately 700,000 people rely on public transport daily to travel to work, school, and other activities [4]. During peak hours, subway stations and platforms become heavily crowded, placing passengers in close proximity to platform edges where the risk of accidents is highest [5].

While these environments are often perceived as routine, perceived safety in public transport settings is shaped not only by objective risk but also by social and perceptual factors. Previous research has shown that individuals' safety judgments are influenced by crowd density, the presence and behaviour of others, and environmental design features [6]. In particular, situations involving vulnerable

individuals may trigger heightened concern, even when no immediate danger is present.

Perceived safety in public transport environments is influenced not only by objective risk but also by environmental design and situational factors, which can trigger anxiety and affect passenger behaviour [9]. This highlights the importance of studying both social and structural cues when assessing safety perception

Virtual reality (VR) offers a promising method for studying such perceptual processes in realistic yet controlled environments. By allowing researchers to systematically manipulate social and environmental cues without exposing participants to real-world risk, VR has been shown to provide ecologically valid insights into human perception and safety judgment [7].

This study investigates how social and environmental factors on subway platforms influence perceived safety. The research question aims to determine how actor type (child vs. adult), crowd density, caregiver presence, and the presence of glass platform doors affect perceived safety on a subway platform. We hypothesize that participants will feel least safe when a child stands close to the edge, especially in crowded conditions without a caregiver or safety barriers, while adult actors, lower crowd density, a caregiver, and platform doors are expected to increase the perceived safety.

KEYWORDS:

Virtual reality, safety perception, subway platforms, crowd density, social context, child safety

2. BACKGROUND

This section reviews previous research on perceived safety, social and environmental factors on subway platforms, and the use of virtual reality to study these phenomena.

2.1. Safety and Crowd Density on Subway Platforms

Subway platforms are environments where crowd density varies substantially throughout the day. Observational studies have shown that during peak hours, passengers are more likely to stand closer to the platform edge, increasing exposure to potential hazards [5]. High crowd density has been associated with reduced personal space, limited situational awareness, and lower perceived safety in public transport environments [6].

2.2 Social Presence, Vulnerability, and Risk Perception

Perceived safety is strongly influenced by social cues, including who is present in an environment. Research in traffic psychology suggests that adults often perceive children as particularly vulnerable due to their limited ability to identify and respond to dangerous situations [8]. Young children also exhibit significantly poorer skills in recognizing traffic-related risks, which may contribute to heightened

concern when children are observed near potential hazards [1].

Recent work has highlighted that the presence of vulnerable road users can alter perceived risk even when objective danger remains constant [2]. However, the specific effect of children standing near subway platform edges has not been systematically examined in controlled experimental settings.

2.3 Virtual Reality for Studying Safety Perception

Studying safety perception in real subway environments poses ethical and practical challenges. Virtual reality provides a safe alternative by enabling the recreation of realistic public transport settings while allowing precise control over environmental and social variables. Previous research has demonstrated that VR-based simulations can evoke safety judgements that closely resemble those formed in real-world environments, supporting their use in perception and risk-related research [7].

3. METHOD

This section describes the participants, software and scene modeling, survey measures, and experimental setup used in the study.

3.1 Participants

Seven students, aged 18–32, took part in the study. All participants reported normal or corrected-to-normal vision. Prior experience with virtual reality was noted

but was not an exclusion criterion. Participation was voluntary, and informed consent was obtained from all participants. Participants were informed they could withdraw at any time without providing a reason, and all data were collected anonymously.

3.2 Software and Scene Modeling

The virtual environment was implemented in Unity 3D (version 2022.3.18f1) and was based on an existing 3D reconstruction of a Stockholm T-bana subway platform [3]. The original project was obtained from a Git repository and was fine-tuned to suit the requirements of this user study. Adjustments included configuring the scene layout, controlling avatar placement, and enabling experimental manipulation of crowd density, actor type, caregiver presence, and platform safety barriers.

The scenes included platform elements, train tracks, and background passenger avatars. Avatars displayed minimal idle animations to maintain realism while avoiding complex behavior modeling. Participants could freely look around the scene from a fixed position, and the environment was designed to support full immersion in VR.

3.3 Survey

Perceived safety was measured after each scenario using a short Likert-scale questionnaire adapted from previous research [2]. Participants rated how safe they felt in the scene on a numerical scale from 1 (“strongly disagree”) to 5 (“strongly agree”). The statements were:

1. The situation on the platform felt safe.
2. Someone on the platform is in a dangerous position.
3. There are visible factors on the platform that can cause accidents.

These questions targeted the main research aims, focusing on how environmental and social factors influenced participants' perceptions of safety. The survey was designed to be completed without removing the VR headset, preserving immersion.

At the end of the session, participants were invited to provide additional written feedback. They were asked about which factor influenced their sense of safety the most across all scenarios and identifying the scenario they perceived as the least safe. These responses provided qualitative insights that complemented the Likert-scale ratings and helped contextualize participants' perceptions of risk in different experimental conditions.

3.4 Experimental Design and Setup

The study employed a within-subject, repeated-measures factorial design. Each participant experienced all experimental conditions. Four independent variables were manipulated:

1. **Actor type:** child vs. adult near the platform edge
2. **Crowd density:** none vs. high
3. **Caregiver presence:** present vs. absent
4. **Platform safety barrier:** glass doors present vs. absent

All variables were binary, resulting in 16 unique experimental conditions. The order

of scenarios was fully randomized for each participant to minimize order and learning effects.

The experiment was conducted using a Meta Quest 2 virtual reality headset in a mobile testing setup. Rather than testing in a fixed laboratory environment, the equipment was brought to the participants.

Before the experiment, participants received a brief explanation of the study and signed an informed consent form. They then completed a short questionnaire regarding age, gender, and prior VR experience.

The participants were placed at a predefined position on the virtual platform and were instructed to observe a sequence of virtual scenes. In each scene, a target individual (child or adult) stood close to the platform edge. The scenes varied in crowd density, caregiver presence, and the presence or absence of glass platform doors.

Each scenario was shown for approximately 10 seconds. After each scene, participants rated their perceived safety using a short questionnaire, completed without removing the headset, to maintain immersion. This procedure was repeated for all experimental conditions, resulting in 16 scenarios per participant.

The full session lasted approximately 20–30 minutes, after which participants could provide additional written comments via an online form.



Figure 1 - Screenshot of the VR setup, child and a caregiver



Figure 2 - Screenshot of the VR setup, child and a caregiver with glass doors

3.5 Data Analysis

Both quantitative and qualitative data were collected and analysed to examine perceived safety across the experimental conditions.

Quantitative data analysis was based on Likert-scale ratings collected after each VR scenario. Mean perceived safety ratings were calculated for all 16 experimental conditions to examine how perceived safety varied with actor type, crowd density, and the presence of safety doors. Given the limited sample size ($n = 7$), the analysis emphasised descriptive pattern analysis and visual comparison rather than statistical testing.

Qualitative data were obtained from free-text responses collected after the VR session. These responses were analysed using a simple thematic approach. Given

the short and focused nature of the responses, a formal qualitative analysis framework was not applied. Instead, recurring themes related to perceived safety and risk were identified and used to contextualise and support the quantitative findings.

3.6 Limitations and Delimitations

The study focuses exclusively on perceived safety and does not simulate actual accidents or physical harm. Avatars were static with minimal idle animations, and scenarios lasted only 10 seconds, limiting the ability to capture extended interactions. Audio cues were not implemented, and participants observed from a fixed position in the VR environment. Additionally, the sample size was small ($n = 7$), which emphasizes perception trends rather than generalizable conclusions. These constraints should be considered when interpreting the results. Future studies could address them by incorporating dynamic avatars, longer scenarios, and allowing participants to move freely within the virtual environment, as well as including larger participant groups.

4. RESULTS

This section presents the results from the VR experiment, combining quantitative Likert-scale ratings with qualitative feedback from participants. The findings describe how various social and environmental factors influenced perceptions of safety across the simulated subway platform scenarios.

4.1. Quantitative Results

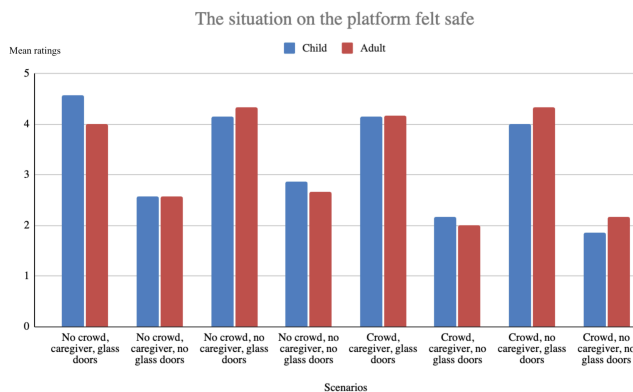


Figure 3 - The mean of the ratings (1-5) of the statement “The situation on the platform felt safe”

Perceived safety was measured using Likert-scale ratings ranging from 1 (“strongly disagree”) to 5 (“strongly agree”). Mean safety ratings were calculated for each of the 16 scenarios. Figure 3 presents these results, showing the mean perceived safety for all combinations of crowd density, caregiver presence, and platform safety barriers, separately for scenarios involving a child (blue bars) and an adult (red bars) near the platform edge.

Overall, clear patterns emerged across participants regarding the influence of environmental safety features, social context, and crowd conditions.

Across all scenarios, the presence of glass platform doors was associated with the highest perceived safety ratings. Participants tended to rate scenes with platform doors as safer than otherwise similar scenes without barriers, independent of variations in crowd density and actor type.

Actor type also influenced perceived safety. Across nearly all conditions, scenarios involving a child near the platform edge

were rated as less safe than those involving an adult. For instance, in crowded, no-caregiver, no-doors scenarios, child ratings were almost 2, while adult ratings were slightly higher, around 2-2.3. This pattern suggests that participants perceived children as more vulnerable, consistent with previous research.

Higher crowd density was associated with lower perceived safety, with safety ratings tending to decrease across conditions, particularly in scenarios without glass platform doors. The combination of high crowd density and the absence of safety barriers resulted in some of the lowest safety ratings overall.

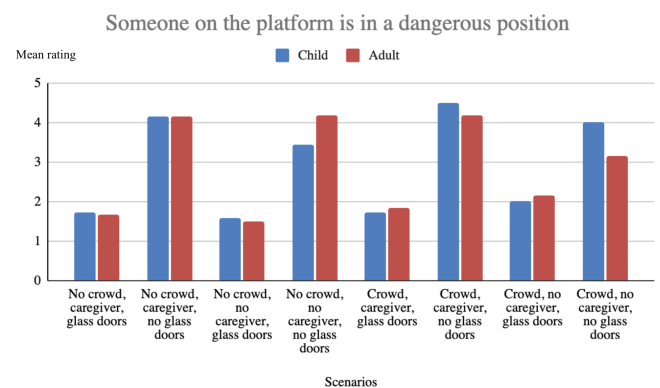


Figure 4 - The mean of the ratings (1-5) of the statement “Someone on the platform is in a dangerous position.”

There are visible factors on the platform that can cause accidents

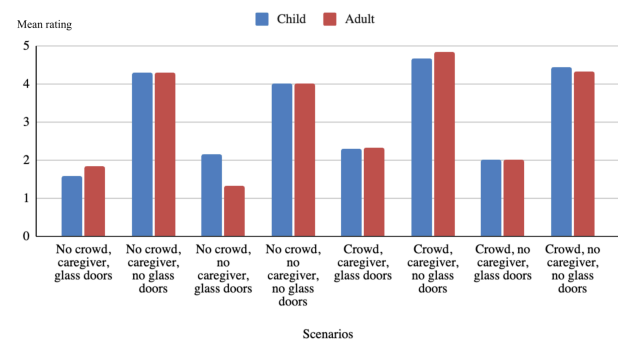


Figure 5 - The mean of the ratings (1-5) of the statement “There are visible factors on the platform that can cause accidents”

4.2. Qualitative Results

Participants' written feedback collected after the VR session provided additional insights into the factors shaping perceived safety. Many participants explicitly identified glass platform doors as the most important element contributing to a sense of safety on the platform.

Several participants reported higher concern when children were positioned near the platform edge, particularly when no caregiver was present. These situations were frequently described as uncomfortable or risky, even in the absence of other danger. High crowd density was also commonly mentioned as a source of anxiety, with participants noting reduced personal space and increased unpredictability of other passengers' movements.

Some participants referred to specific scenarios as particularly unsafe, such as those involving unsupervised children or crowded platforms where people stood close to the edge. These comments align closely with the patterns observed in the quantitative ratings.

4.3. Patterns Across Scenarios

Taken together, the quantitative and qualitative results indicate that perceived safety on subway platforms is shaped by both environmental and social factors. From an environmental perspective, the presence of glass platform doors increased perceived safety across all conditions. From a social perspective, actor type, caregiver

presence, and crowd density mutually influenced participants' safety judgements.

The lowest perceived safety ratings occurred in scenarios where a child stood near the platform edge on a crowded platform without glass barriers and without caregiver supervision.

5. DISCUSSION

This section interprets the experimental results in relation to the research questions, hypotheses, and previous literature on perceived safety in subway environments. Key trends are analyzed, limitations are acknowledged, and implications for future research are outlined.

5.1 Analysis of Quantitative Results

The quantitative results show that platform safety barriers had the strongest influence on perceived safety. Scenarios with glass platform doors were consistently rated as safer than those without, regardless of crowd density or actor type. This indicates that visible physical separation from the train tracks plays a central role in shaping safety perception, supporting earlier findings that environmental design can reduce perceived risk by limiting exposure to hazards [5],[6].

Actor type also significantly affected perceived safety. Scenarios involving a child near the platform edge were rated as less safe than those involving an adult, reflecting established findings that children are perceived as more vulnerable in potentially hazardous environments [1],[2].

High crowd density further reduced the participants' perceived safety, particularly in scenarios without platform barriers. This may be explained by reduced personal space, limited situational awareness, and increased unpredictability in crowded environments. These trends are consistent with prior research linking crowd density to lower perceived safety on subway platforms [5].

Caregiver presence partially mitigated safety concerns in child scenarios. When a caregiver was present, perceived safety increased compared to unsupervised child scenarios. Although ratings remained lower than those for adult scenarios. This suggests that supervision reduces, but does not eliminate, concerns related to child vulnerability.

The lowest safety ratings occurred when multiple risk factors were combined: a child near the platform edge, high crowd density, absence of a caregiver, and absence of safety barriers. This aligns with the hypothesis that perceived safety is shaped by the interaction of social and environmental cues rather than by individual factors in isolation.

5.2 Analysis of Qualitative Results

The qualitative responses largely supported the quantitative findings. Participants frequently identified glass platform doors as the most important factor contributing to a sense of safety, describing them as reassuring and protective. Many participants also reported discomfort when children were positioned close to the platform edge, particularly in the absence of

a caregiver, reinforcing the role of perceived vulnerability.

High crowd density was commonly mentioned as a source of stress, with participants expressing concern about people standing close to the edge or being pushed unintentionally. Several participants explicitly identified unsupervised children in crowded conditions as the least safe scenarios, closely mirroring the lowest-rated conditions in the quantitative data. Overall, the qualitative feedback helped explain the numerical patterns by providing insight into participants' reasoning and emotional responses.

5.3 Comparison to Previous Research

The findings align well with previous research on perceived safety in public transport environments. The heightened concern associated with children near hazards reflects earlier work on vulnerability and risk perception [1, 8], while the negative impact of crowd density is consistent with studies of subway platform safety [5, 6]. Moreover, recent research highlights that both environmental and situational cues can elevate passenger anxiety and affect safety perception in urban rail contexts, emphasizing the importance of considering these factors in design [9].

The results correspond with prior research indicating that VR can evoke meaningful and realistic safety judgements despite the absence of real-world risk [7]. Overall, the findings are in line with the study's hypotheses and underline the importance of considering both physical infrastructure and

social context in the design of safe subway environments.

5.4 Methodology Critique and Limitations

Several limitations should be considered when interpreting these results. The small sample size ($n = 7$) limits generalizability, and the short duration of each scenario may not fully capture extended interactions or evolving perceptions. Avatars were static, with minimal animations, and audio cues were not included, which may reduce ecological validity. Participants were also fixed in position on the platform, limiting perspective and movement compared to real-world subway experiences. These factors should be taken into account when interpreting the findings.

5.5 Future Research

The study highlights the importance of both social and environmental factors in subway safety design. Glass barriers, caregiver presence, and managing crowd density can enhance passengers' sense of safety. Future research could address the current study's limitations by incorporating dynamic avatars, ambient sound, longer scenarios, and a larger participant pool. Additionally, exploring interactions between multiple passengers and extended VR exposures may provide more realistic insights into perceived safety and inform safer subway design and policy, particularly in crowded urban transit systems.

An important direction for future research concerns the spatial configuration of actors on the platform. In the present study, distances between the actor and the

platform edge, as well as between a child and a caregiver, were kept constant. However, perceived safety is likely sensitive to these spatial relationships. Future studies could systematically vary these distances to identify thresholds at which situations begin to be perceived as dangerous. Similarly, manipulating the distance between a child and a caregiver could clarify how close supervision needs to be for a situation to be perceived as safe, and when increasing distance leads to heightened perception of risk.

5.6 Project Assessment

This project followed a clear overall plan, but its execution was affected by several practical challenges. While responsibilities were divided across group members, coordinating meetings proved difficult due to differing schedules, which limited opportunities for joint discussion and slowed parts of the workflow. Although a detailed time plan was established early on, many tasks, particularly VR development, technical troubleshooting, and testing, took longer than expected, leaving less time for iteration than initially planned.

Technical constraints in Unity and with the VR headset required more effort than anticipated, especially when adapting the existing project repository to suit the experimental design. These delays made extensive pilot testing difficult, which may have affected the refinement of the scenarios. In retrospect, some experimental conditions were quite similar, and the study could have benefited from fewer, more clearly differentiated scenarios.

Participant recruitment also posed challenges, resulting in a small sample size. Despite these limitations, the project produced coherent and meaningful results that aligned with existing literature. Overall, the study highlights the importance of allocating sufficient time for technical development, pilot testing, and coordination when conducting VR-based research, and demonstrates that valuable insights can still be obtained under constrained conditions.

6. CONCLUSIONS

This study investigated how social and environmental factors influence perceived safety on subway platforms using a VR-based experimental approach. The results indicate that both platform infrastructure and social context play significant roles in shaping safety perception: glass platform doors consistently increased perceived safety, while the presence of children near the platform edge, high crowd density, and the absence of caregivers reduced it. These findings support the use of VR as a safe and effective tool for studying human perception in controlled yet realistic settings. The study highlights the importance of considering both physical safety measures and social cues in the design of public transport environments, and provides a foundation for future research exploring more dynamic scenarios, larger participant samples, and additional sensory inputs.

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Appendix

GitHub repo: <https://github.com/sassner33/Crowd-Simulator-and-Tbana-Reconstruction-CP3.git>



Figure 1: Screenshot of the VR setup, child, without caregiver, without glass doors, no crowd



Figure 2: Screenshot of the VR setup, child with a caregiver, with glass doors, no crowd

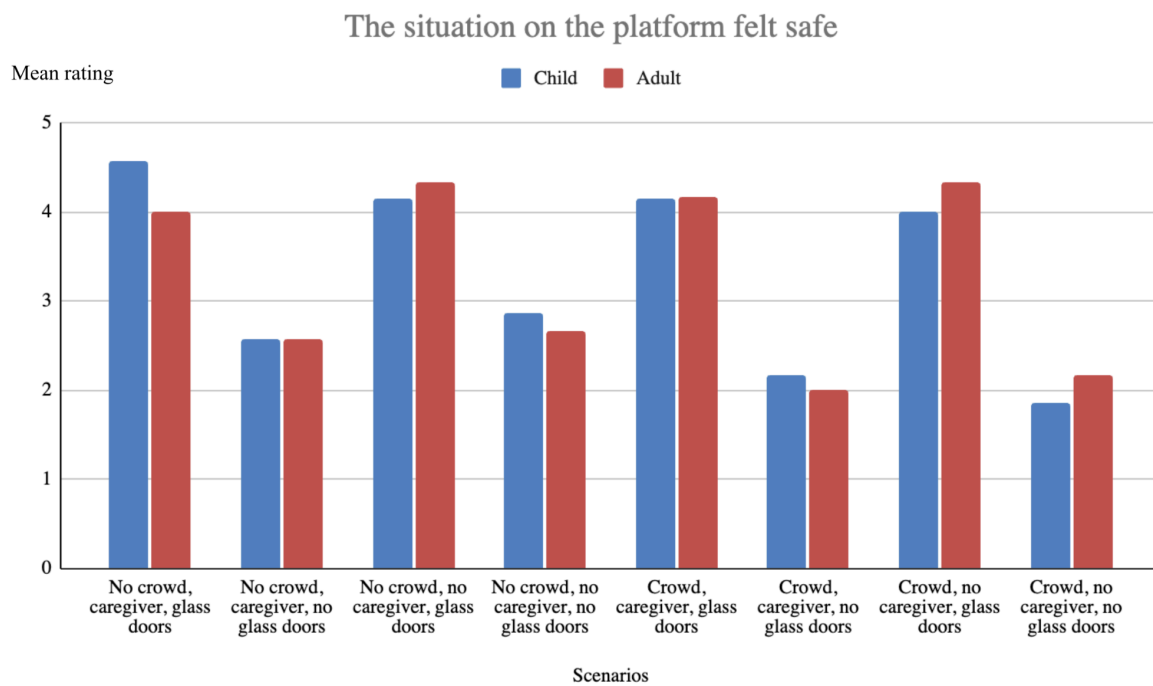


Figure 3: The mean of the ratings (1-5) of the statement “The situation on the platform felt safe”

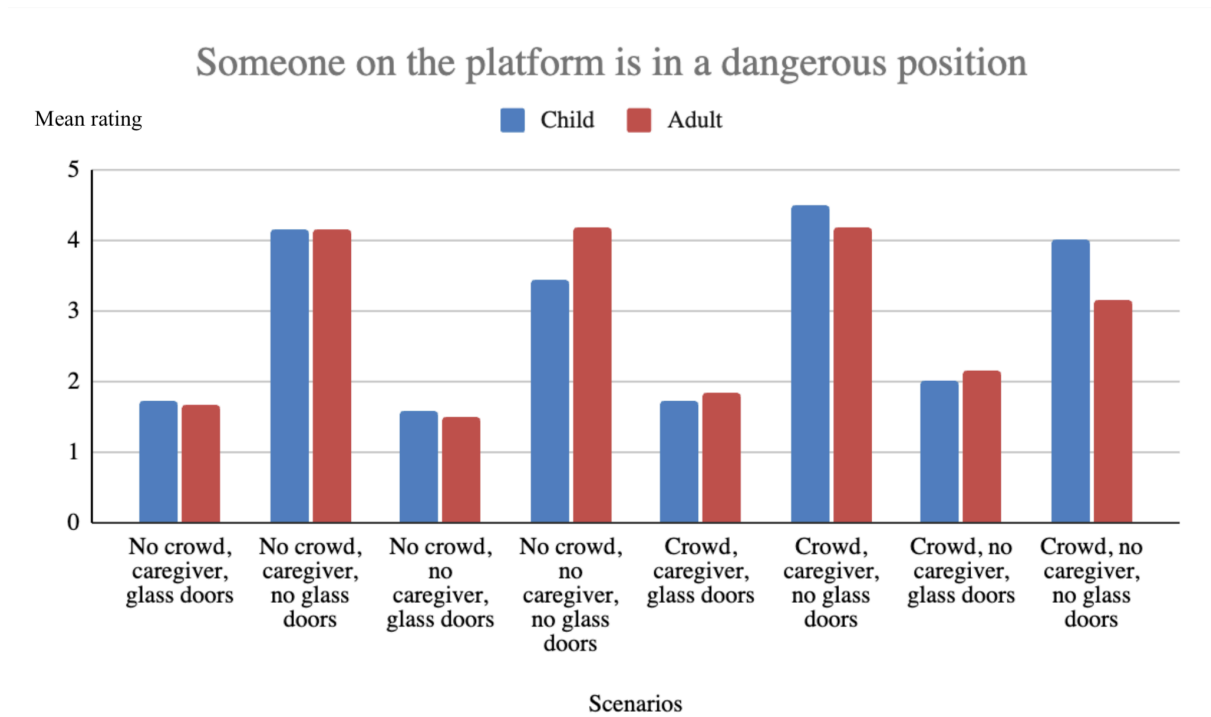


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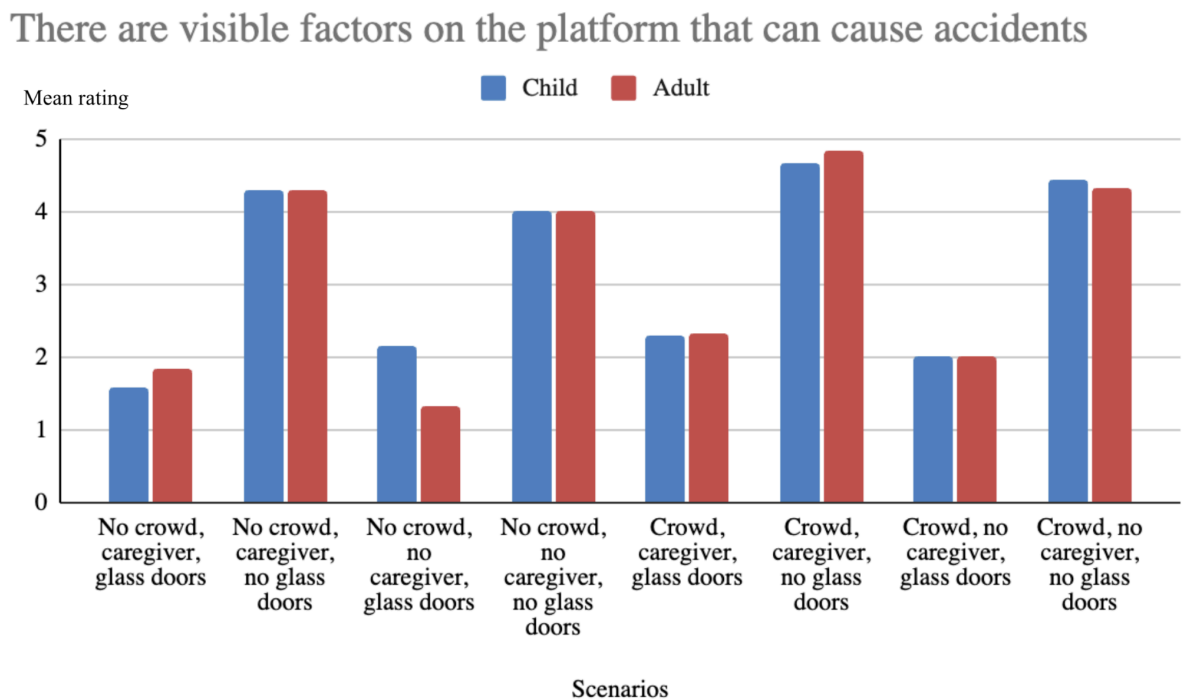


Figure 5: The mean of the ratings (1-5) of the statement “There are visible factors on the platform that can cause accidents”