KEY:
Experimental Group = VR Treatment
Control Group = No VR, Audio-Only

Methodology

Note: the method described below can be delivered in-person or online. The team will prepare two versions of the latter: one delivered synchronously (where everyone attends the same zoom meeting simultaneously) and another version asynchronously (with canned presentations that any individual can view at their leisure). Surveys will be administered using google forms.

The experimental design is a case-control study, with an administered pre-survey prior to each group receiving either audio data interpretations or virtual reality (VR) scenarios. The goal, as stated in the hypothesis section, is to determine whether visualizations allowed by VR created more flood risk awareness and greater perception of vulnerability to flood risk in users than audio alone. Both textual and VR representations describe the southwest corner of Washington Square Park, near the NYU campus and Bobst Library. This area was chosen because of the presumed familiarity all on-campus students have with it, in order for them to have an informed opinion on the zone's potential for flood risk during an extreme weather event.

To conduct the experiment, both the Experimental Group (those individuals who receive the VR demonstration prior to taking the post-survey) and the Control Group (individuals who receive only the audio interpretation prior to taking the post-survey) are gathered in a conference room (virtual or actual) together, where all participants receive the pre-survey. This includes a mix of demographic information, as well as questions assessing their flood risk perception of the given area.

The demographic questions solicit personal information (i.e. preferred gender identity, age), as well as information that might contribute to a greater knowledge of flood risk to the area (i.e. amount of time living in New York City, whether they were residents in the areas impacted by Hurricane Sandy). The section, in full, includes:

Gender: _______(M/F/Other/Prefer Not to Answer)
Age: _______ or prefer not to answer
Role at NYU:______ (student,grad, faculty, staff, etc./prefer not to answer)
How long have you been at NYU (years, round up):_____
Ethnicity:______(Latinx, African American, Asian, Native American, White, Other)
Do you live/ work /study near WSP?
What is your zip code?_______
If you live in New York City, for how many years (including time at NYU): ______
What is your professional background and/or area of study?:
____

How do you get information on extreme weather?_______________(Social Media, Word of Mouth, TV or Radio, NYC Gov bulletins, etc.)
Were you impacted by Hurricane Sandy?________
Were you impacted by another hurricane / flooding event?______________

Following collection of the pre-survey, all participants are given a series of seven questions, answered on a 7-point likert scale. These are also given during the post-survey, once participants receive either Experimental or Control instruction:

1. **Washington Square Park is near a coastal area.**

Strongly Disagree 0 1 2 3 4 5 6 7 Strongly Agree

2. **If a weather event that included coastal flooding affected New York City, I would feel safe travelling to NYU's WSP campus.**

Strongly Disagree 0 1 2 3 4 5 6 7 Strongly Agree

3. **The WSP campus would operate normally following a coastal flooding event that affected New York City.**

Strongly Disagree 0 1 2 3 4 5 6 7 Strongly Agree

4. **Washington Square Park will experience serious flooding following an extreme weather event.**

Strongly Disagree 0 1 2 3 4 5 6 7 Strongly Agree

5. **Evacuating NYU during an extreme weather event would be extremely difficult.**

Strongly Disagree 0 1 2 3 4 5 6 7 Strongly Agree

6. **I will likely start emergency planning --i.e., what to do and how to evacuate during an extreme weather event.**

Strongly Disagree 0 1 2 3 4 5 6 7 Strongly Agree

7. **I know what NYU/WSP would look like during an extreme weather event.**

Strongly Disagree 0 1 2 3 4 5 6 7 Strongly Agree

These questions were designed to indicate whether a participant was aware of both Washington Square Park as a part of a coastal city, as well as the individual's overall concern with flood events.

The participants are then broken into the Experimental and Control groups at random, where the Experimental group receives the VR comfort questions and then a VR demonstration that shows the flood risk to the area during a series of extreme weather events, as well as a vocal description of the visuals. The Control group is given only the vocal/audio description of the area's susceptibility to flood risk during extreme weather events.

The individuals from each group are then asked to complete the post-survey, which contains only the seven likert-scale questions from the pre-survey. Upon collection of the surveys, the groups are brought back together and quickly debriefed. Those in the Control group are given the opportunity to view the VR demonstration if they wish, so that all participants still leave the experiment with the same knowledge of flood vulnerability.

This system was implemented on a cloud platform using the Python Flask web application API as the backend. The survey was generated and captured using SurveyJS and stored with the user identification number and the responses to the surveys in the server database. The virtual reality simulation with the flood inundation modelling was created using the Potree and Three.js libraries to visualize the water levels in the 3D model. This system allows the participants to roam around the environment on a laptop/pc machine remotely, feeding back the information for the results.

Assessment of Perceived Risk

Prior to the VR demonstration, in which each individual in the Experimental group is given the opportunity to view the VR model of Washington Square Park during flood events, the project coordinators read the following script:

"Despite feeling like the middle of a city, the Washington Square Park campus is less than a mile from the Hudson River. This makes the likelihood of flooding during high-impact storms a likelihood, with inundation models showing flooding as near to the NYU campus as the southwest corner of WSP. The risk is not from rainfall but, as a result of the campus's proximity to the coast, from storm surge. Storm surge is defined by NOAA as the "abnormal rise in seawater level during a storm." It is the combination of off-shore rainfall, storm winds, and tide that can cause flooding in coastal cities. It's important to note that while the models we are

going to discuss are the worst-case scenario models, the amount of category 3 and 4 hurricanes have doubled globally over the past 35 years, according to a 2005 article from the National Science Foundation. Other factors, like climate change, increasing populations, and urbanization may also make predictability of storm severity and frequency more difficult.

Models from FEMA predict worst-case scenarios for storm surge that take into account sea level rise and worsening storms as a result of climate change. In the coming decades, we could see category 3 storm surge inundating the western part of the park up to Sullivan Street, with 2-3 feet of water, including storm surge flooding between here (Bobst) and the Hudson River. For a category 4, storm surge could reach LaGuardia Place and Bobst Library with 2-3 feet of water, with water levels at least 8 feet at the western border of the park

Now, each of you will have the opportunity to view our model of Washington Square Park (WSP). You will not be moving around in the simulation, but instead will have a 360-degree static viewpoint. The first iteration will be at the corner of WSP South and MacDougal, next flood levels will be superimposed showing Category 3 and Category 4 projections. These projections are derived from FEMA models that were translated into GIS maps to get heights for certain areas."

For the Control group, the project coordinator reads the following script:

"Despite feeling like the middle of a city, the Washington Square Park campus is less than a mile from the Hudson River. This makes the likelihood of flooding during high-impact storms a likelihood, with inundation models showing flooding as near to the NYU campus as the southwest corner of WSP. The risk is not from rainfall but, as a result of the campus's proximity to the coast, from storm surge. Storm surge is defined by NOAA as the "abnormal rise in seawater level during a storm." It is the combination of off-shore rainfall, storm winds, and tide that can cause flooding in coastal cities. It's important to note that while the models we are going to discuss are the worst-case scenario models, the amount of category 3 and 4 hurricanes have doubled globally over the past 35 years, according to a 2005 article from the National Science Foundation. Other factors, like climate change, increasing populations, and urbanization may also make predictability of storm severity and frequency more difficult.

Models from FEMA predict worst-case scenarios for storm surge that take into account sea level rise and worsening storms as a result of climate change. In the coming decades, we could see category 3 storm surge inundating the western part of the park up to Sullivan Street, with 2-3 feet of water, including storm surge flooding between here (Bobst) and the Hudson River. For a category 4, storm surge could reach LaGuardia Place and Bobst Library with 2-3 feet of water, with water levels at least 8 feet at the western border of the park."

VR Component

The study of virtual reality (VR) has found it is a useful pedagogical tool for recognizing and understanding environmental risk compared to more traditional methods (Hu, et al., 2018). It provides a more immersive experience and therefore promotes a deeper first-person understanding of a spatial area than merely audio or static visual representations. Our experiment hypothesizes that the use of VR will prove more effective at promoting risk awareness and the vulnerability of our chosen Washington Square Park location for the Experimental Group than what the Control Group receives through merely verbal explanation.

In order to ensure that any risks associated with VR (which may include dizziness, eye fatigue, and nausea), the Experimental Group (and, later, any participants from the Control group interested in viewing the VR data) are given a warning and then asked a series of questions to assess their well-being prior to experiencing the VR scenario. This reads:

> *"As a warning, there is a potential for motion sickness with all VR devices. We will be asking each user a set of questions throughout the demonstration to monitor for discomfort. Another symptom of VR use is blurred or distorted vision. Prolonged use of VR will cause the eyes to relax as they don't have to constantly refocus on objects in front of them—due to the nature of the VR screen, every item will be centimeters from your face. In time, your brain adjusts, and upon exiting VR you may notice slight and temporary changes in your vision. For anyone who may be driving, it is recommended to wait at least 1-2 hours before doing so as a safety precaution. This will be a short demonstration with minimal likelihood of symptoms.*
>
> *"For your preparedness, note that common first signs of nausea on VR include:*
>
> - *General discomfort*
> - *headache*
> - *Sudden awareness of the stomach area*
> - *pallor (whitening of the face)*
> - *sweating*
> - *drowsiness*
> - *disorientation*
> - *Apathy."*

Any participants using the VR are also seated, to prevent potential injury from any of the above risks. We recommend the use of a swiveling chair, so that the participant may still view and experience the three dimensions of the simulation.

The view on-screen is of the southwest corner of Washington Square Park, first as it appears under normal weather conditions (no flooding). Then, throughout the 15-second simulation series, the view changes to the same corner, under the conditions of Category 2, 3, and 4 storm models, which utilize worst-case scenario SLOSH projections from NOAA's National Surge Database. The third view shows the participant the conditions under a Category 3 weather event, with heavy flooding. Finally, the last view shows Category 4 conditions. In this view, the blue water line that represents the floodwater goes above the participant's head. After a few seconds at each view, the simulation moves on to the next, and then eventually resets to the original normal conditions. Each participant should view at least one full cycle of the simulation, but is welcome to do more if they are comfortable and interested in doing so.

Following the simulation, the participant is asked to remove the headset and hand it to a project coordinator. They are then told to collect their bearings while remaining seated for a few moments, and then to stand up when they are ready and allow another participant to experience the simulation. It is recommended to have at least four VR headsets and compatible devices for the experiment, so that more than one participant can experience it at a time and therefore there is less waiting time by those not using the device, in order to minimize the time between the simulation and receiving the post-survey.

Participants

Students enrolled in undergraduate or graduate courses were the target demographic for this study group. Members of the research team contacted professors to potentially recruit students from their classes to volunteer for the study. This was the most efficient method of recruitment at the time of the COVID-19 pandemic, as truly random collection on campus was not possible. By doing this we were able to compile a list of potential participants and distribute a recruitment statement to them stating what we would require from them.

Measuring efficacy

Each participant received a pre- and post-survey consisting of seven questions. These questions were the same for all treatments and a likert scale of 0 to 7 was used to assess how the communication method, either VR or non-VR, worked in increasing risk literacy specific to flooding events near Washington Square Park.

We assume non-normality of the data --this will be verified later on. A Mann-Whitney U test will be used to compare post-minus-pre survey responses in the experimental group versus the control (samples are independent of each other).

How significantly did the responses improve from pre- to post- for the control, and then for the Experimental VR group? Next we had to assess if the efficacy of VR between the pre- and post-survey was significantly better compared to the control. By doing so, we can confirm if the

VR module was effective in communicating the risk that flooding events can have on this part of NYU's campus near Washington Square Park.

Educational equality

Ultimately, after recording post-survey results, we allow Control participants to view VR to ensure equal information distribution on flood risk. The current literature on VR efficacy shows that as an alternative to static imagery or verbal instruction, VR is able to produce better results in many different applications. VR can serve as a learning tool around risk preparedness by providing safe immersion in disaster scenarios (Hu et al., 2018), adding a layer of immersion for handicap participants that other methods do not facilitate (Rossol et al., 2011), and effectively displaying local geography in a way that connects participants meaningfully with the visualization (Evans et al., 2014). The mission surrounding UrbanARK's research is to educate the public and improve risk literacy, so it was important to allow the control group access to these visualizations after the post surveys were concluded.

Evans, S. Y., Todd, M., Baines, I., Hunt, T., & Morrison, G. (2014). Communicating flood risk through three-dimensional visualization. *Proceedings of the Institution of Civil Engineers,*(167), 48-55.

Hu, Y., Zhu, J., Li, W., Zhang, Y., Zhu, Q., Qi, H., . . . Zhang, P. (2018). Construction and Optimization of Three-Dimensional Disaster Scenes within Mobile Virtual Reality. *ISPRS International Journal of Geo-Information,7*(6), 215. doi:10.3390/ijgi7060215

Rossol, N., Cheng, I., Bischof, W. F., & Basu, A. (2011). A framework for adaptive training and games in virtual reality rehabilitation environments. *Proceedings of the 10th International Conference on Virtual Reality Continuum and Its Applications in Industry - VRCAI 11*. doi:10.1145/2087756.2087810