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TITLE:

Developing a Virtual Reality Video Game to Simulate Rip Currents

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KEYWORDS:

Virtual Reality, Rip Current, Immersive Media, Risk Communication, Weather Hazards, Beach Safety, Video Games, User Interaction

SUMMARY:

Rip currents are among the deadliest meteorological hazards in the United States. In order to demonstrate the proper actions to take when caught in a rip current in a memorable and engaging way, a virtual reality video game is developed.

ABSTRACT:

Beachgoers in the United States face many different hazards, but rip currents are annually the deadliest for ocean swimmers. Despite the risk presented by rip currents, it is apparent that the public has a limited understanding of their danger and the proper mitigating actions to take when caught in one. A virtual reality (VR) video game placing participants in a simulated rip current was developed to help ameliorate this issue. The VR game was used to survey beachgoers on the Atlantic Coast of Long Island, New York during July and August 2019. The actions participants took when confronted with the rip current were recorded, along with whether they escaped it or drowned. An interview with each player was also conducted after they partook in the game to determine the realism of the rip current simulation and its effectiveness in demonstrating proper actions to take when impacted by one. Analysis of those results indicates that VR has potential to communicate rip current risk and ways to minimize it in a unique and engaging manner. However, further work is needed to improve ease of use of the VR simulation and better understand how factors such as demographics influence perceived rip current risk and behavioral response.

INTRODUCTION:

Rip currents are "strong, narrow flows of water that extend away from the beach[1]." Rip currents can commonly occur on any beach with breaking waves and can transport swimmers quickly away from shore. Hazardous rip currents can occur on seemingly 'safe' beach days with wave heights of only 2 to 3 feet[2], and thus can surprise swimmers as they are carried a considerable distance from shore. This puts swimmers at risk of panic, exhaustion, and even drowning. As a result, rip currents are one of the leading causes of weather fatalities in the United States. For example, in 2018, 71 deaths were attributed to rip currents, and for the 10-year period 2009-2018, an average of 58 individuals perished each year[3]. Rip currents are the leading hazard for beachgoers; in 2018, rip current deaths represented 65% of all 'surf zone' fatalities in the United States. There seems to be some demographic control on rip current vulnerability, as one study found that men are over six times more likely than females to drown from rip currents than females[4]. Moreover, additional research found that infrequent beach users are more likely to make poorer beach safety choices[5] and that non-locals are considerably more likely than locals to sustain injury in the surf zone[6,7].

Nevertheless, despite their place among the deadliest weather hazards in the United States, rip currents are poorly understood by the public. A survey of 392 public beach users in Texas determined that only 13% could correctly identify a rip current from photographs presented to them[8], while similar results were found in studies conducted in Pensacola Beach, Florida[9] (15%) and Miami Beach, Florida[10] (27%). More broadly, Houser et al (2017)[5] performed an Internet-based survey with 1622 respondents across 49 of the 50 US states and found that 54% of the participants correctly reported an action to take when caught in a rip current. However, the self-selected nature of the survey sample dictated that only 10% of the sample was infrequent beach users, who are most vulnerable to rip currents and were shown in the survey to possess less knowledge of what to do in one.

It is clear that rip currents present a unique challenge, given that they are poorly understood by the public, can occur suddenly over small scales with minimal or no prior warning, and may result in death. Thus, new approaches are needed to address this public safety challenge. Immersive technology such as virtual reality (VR) provides an innovative approach to increase rip current literacy and encourage positive behavior upon impact. Prior research has indicated that VR and similar types of immersive media are highly effective at communicating information. VR is generally defined as an interactive experience taking place within a simulated environment that incorporates auditory and visual feedback, usually with the assistance of a headset. One recent study[11] asserted that VR is a mature technology, well-suited to assist in the scientific inquiry process. Moreover, other recent research[12] showed that when individuals read a New York Times story with a VR supplement, they were more likely to perceive the source as being credible, recall the information presented, share it with others, and feel an emotional connection, than those who read the article in traditional media, with just text and graphics. Additional studies[13,14] concluded that immersive media promotes education by increasing engagement and real-world applicability of a topic. Most recently, researchers[15] leveraged VR to simulate a Category 3 hurricane landfall and determined that survey respondents viewing the VR were significantly more likely to consider evacuation than those only viewing traditional text and graphic products. Despite its clear utility, no studies or initiatives have shown comprehensively how VR can be effectively applied to the unique challenge of training beach users to better locate and react to rip currents. The present work fills that research gap by first teaching individuals how to swim and wave in a virtual ocean environment and then evaluating how they react to the sudden and unwarned onset of a rip current. Participants were trained in both swimming and waving for help because each of those actions are regarded as valid responses when caught in a rip current[16,17], with conditions particular to an individual rip often dictating which action might be most effective in facilitating escape[18]. We hypothesize that the realistic and memorable nature of a VR rip current simulation will allow participants to successfully take evasive action in the virtual game and then report that the experience enhanced their knowledge of rip current risk and mitigation.

PROTOCOL:

All methods used were approved by the Hofstra University Institutional Research Board (IRB). The VR video game developed was used to survey 64 individuals.

NOTE: Scripts were written in the C# language, and are available for download at: https://github.com/Jasebern/HofstraVR.

1. Creation of VR rip current video game: Virtual environment and user input/output

1.1. Open VR development platform (e.g., Unity[18]). This procedure was completed in Unity 2018.3.1f1.

1.1.1. Start a new 3D project entitled 'Rip Current.' A 3D project contains one or multiple scenes comprising of 'game objects' that can appear as solid objects[19]. Scripts can be added to game objects allowing for interactivity and real time changes to the environment. This project will contain four scenes and numerous game objects.

1.1.2. Open the **Unity Asset Store** tab. This contains 'prefabs'-- already-created collections of 2D and 3D game objects and audio files -- developed by other users that can be added to the own project[20].

1.1.3. Import the 'Oculus Integration' asset from the Unity Asset Store that provides foundational assets for VR development.

1.2. Create the first new scene: **Main Menu** (**Figure 1**).

1.2.1. Use **Assets | Create | Terrain Layer** and then add appropriate coloring to create a hilly green terrain asset as an appealing background for the main menu scene.

1.2.2. Use **GameObject | UI | Canvas** to add a new canvas, entitled **Main Menu**, with a text box for the title **VR Simulation**. A canvas is a game object that stores text and buttons allowing user interaction and specified events in the simulation based on that input[4].

1.2.3. Attach scripts, written in the C# language, to a game object. Add the script by selecting the desired target game object in the scene hierarchy. Then, in the **Inspector** tab, select **Add Component | New script**, and enter the desired script title.

1.2.4. Follow the above procedure to add the script entitled **MainMenu** to the **Main Menu** canvas.

NOTE: Please see **Table 1** for title and function of all scripts used.

1.2.5. Use **GameObject | UI | Button** to add four text buttons to the canvas: **Start**, **Options**, **About**, and **Quit**. Call appropriate function from **MainMenu** and **MouseHover** scripts when a button is selected.

1.3. Create the second new scene: **Buoy Test** (**Figure 2**).

1.3.1 Download the **Realistic Water** asset from the Unity Asset Store and add the **Sea** prefab to the scene.

1.3.1.1 Add an audio file of ocean waves to the **Sea** prefab on loop. Add from the **Inspector** tab by selecting **Add Component | Audio Source**.

1.3.1. Use the terrain layer tool as above to create a Game Object named **Beach**. In the **Terrain** options in the **Inspector** tab, use the **Paint Terrain** and **Terrain Settings** tool to style and color as sand.

1.3.2. Download the **Standard Assets** package from the Unity Asset Store and add the **Player** prefab to the scene. The **Player** prefab includes a Camera that is embedded within the Player, thus following its movements to create the sensation that the game participant is controlling the Player.

1.3.2.1. As performed above, add the **PlayerController, PlayerMotor, PlayerMotor2,** and **FloatObject** scripts to the **Player** prefab. Those scripts allow the game participant to control the Player prefab by using Oculus VR Controllers.

1.3.2.2. Add an animation to the Camera by selecting **Assets | Create | Animator Controller**. Use the **Animator Window** to record an animation of the Camera bobbing up and down and set it to loop continuously. This simulates a person keeping afloat in the ocean.

1.3.2.3. As performed above, add a Canvas entitled **TextCanvas**. Child **TextCanvas** to the Player by dragging it into **Player** in the hierarchy. A child game object inherits the movement and rotation properties of the parent game object. Add the text “Swim through the buoys” to **TextCanvas**. Record an audio file reading that text, add it to **TextCanvas** as performed above, and set it to play at the start of the scene.

1.3.2.4. Set the player location by navigating to the inspector tab and adjusting the **Position** in the **Transform** options. Set player location to X=-23.44, Y=1, and Z=5.97.

1.3.3. Download the **VR Hands and FP Arms Pack** from the Unity Asset Store and as above child the ‘FP_Character’ prefab to the **Player**. This will allow the arms to move with the **Player** and also bob up and down with the Player Camera.

1.3.3.1. Choose the desired prefab by selecting it in the hierarchy and checking the box next to its name. The FP_Character prefab contains both male and female prefabs, each containing two arms, left and right.

1.3.4. Add a new Game Object by right clicking in the Hierarchy and selecting **Create Empty**. Name the Game Object **Checkpoint**.

1.3.5. Download the **Simple Buoy** asset from Unity Asset Store and add the **Buoy** prefab to the scene as a child of the Checkpoint. Duplicate the **Buoy** prefab by right clicking on it and selecting **Duplicate**. Name one ‘buoy L’ and the other ‘buoy R,’ and place them 4 units part in the X axis by adjusting the transform position of each as above. Set the location for buoy L at X=-2, Y=0, and Z=0, and location for buoy R at X=2, Y=0, Z=0.

1.3.5.1. In the **Inspector** tab for the **Checkpoint** Game Object, select **Add Component | Physics | Box Collidor**. Then, select **Edit Collider** and draw the collider between the two buoys.

1.3.5.2. As above, add the **Checkmark** script to the **Checkpoint** Game Object. The script exits the scene once the Player enters it (i.e., swims through the buoys) and transitions to the next scene.

1.4. Create the third new scene: **Wave Test** (**Figure 3**) by selecting **File | Save As** while still in the Buoy Test scene and renaming it.

1.4.1 Delete the **Checkpoint Game Object** by right clicking on it in the **Hierarchy** and selecting **Delete**.

1.4.2 Add a simple wooden boat to the scene by downloading the **Old Wooden Row Boat v2** asset from the Unity Asset Store and add the **Boat** prefab to the scene. Adjust the Transform position of the boat as above to X=-12, Y=-0.16, and Z=14.66.

1.4.3 Download the **Low Poly Animated People** asset from the Unity Asset Store and add the **Kid** prefab to the scene. Duplicate the **Kid** prefab as above and child both to the **Boat** prefab, renaming the **Game Object** to **Boat with kids**, and locating the two kids on top of the two seats in the boat.

1.4.4 As above, add an **Animator** to the **Boat with kids** Game Object, and record an animation of the boat slowly circling around the water, emulating a rowboat slowly moving around.

1.4.5 Navigate to the **Player** prefab and its children in the **Hierarchy** window and rename the left female hand to ‘wave hand.’

1.4.5.1 As above, add an **Animator** to the wave hand and record an animation of the arm and hand moving up and down simulating a hand wave.

1.4.5.2 As above, in the **Inspector** tab for the **Player Game Object**, add an Audio Source with an audio clip of a hand splashing in water, distinct from the clip of two arms splashing in the water added earlier.

1.4.5.3 As above, add the **FemaleAnimate** script to the wave hand, to allow the game participant to control the hand wave using the Oculus Controllers.

1.4.6 Adjust the text in **TextCanvas** to read 'Wave to the people on the boat!,' record an audio file reading that text, and set it to play at the start of the scene.

1.4.7 Based on the **PlayerMotor2** script, as soon as the participant sees the boat and waves, Unity transitions to the Rip Current scene.

1.5 Create the fourth new scene: **Rip Current** (**Figure 4**).

1.5.1 Adjust the text in **TextCanvas** to read 'You are being pulled from shore!' and as above, record an audio file reading that text, add it to **TextCanvas**, and set it to play at the start of the scene.

NOTE: Do not explicitly state that the participant is experiencing a rip current, in order to most accurately simulate being unexpectedly caught in a rip current.

1.5.2 As above, create a new **Game Object** in the hierarchy named **rip_collider** and add a **Box Collider**. To use **rip_collider** to emulate a rip current as a narrow channel of flow extending from the beach into the ocean, use transform to set the position to X, =251, Y=1, Z=251, and change the scale to X=8.2 and Z=35.7 to create appropriate dimensions. The **PlayerMotor2** script also simulates a rip current by constantly pulling the Player perpendicular (away) from shore (i.e., beach terrain). This rip current is a constant force 1.25 times stronger than the normal player swimming motions.

1.5.2.1 Select **GameObject | Effects | Particle System** to add a new particle system, entitled 'Rain Basic,' and child it to **rip_collider**. A particle system emulates liquid entities in 3D such as rain and clouds. The particle system is used to simulate foamy water, which helps demarcate a rip current in ocean water. To do so, in the **Inspector** tab set the transform position to X=0, Y=3, and Z=0.97, and scale X=0.1 and Z=0.1, in order to embed the particles within the rip current channel.

1.5.3 As above, use the **Inspector** tab to add the **RipExit** script to the **rip_collider** Game Object. The script records whether the Player escapes the Rip Current (i.e., exits the **rip_collider** collider).

NOTE: As described in **Table 1**, the **PlayerMotor2** script controls most aspects of the Rip Current scene, by exiting the scene and returning back to the Main Menu scene once any of the following

conditions is met:
-- Player waves
-- Player exits rip_collider
-- Stamina reaches zero
The script also writes out the results of player interaction in the scene to a file, used for later data analysis on overall participant interactions with the rip current.

1.6 To build the final project, select **File | Build Settings** and ensure all four scenes created are checked off and in the proper order. Then, select the platform **PC, Mac & Linux Standalone** and select **Build**. This will prompt a selection window for a build output folder. Select a suitable folder (i.e., 'Desktop') and then build. This will create an executable file shortcut in the desired folder entitled 'Rip Current.'

2. Survey individuals with the VR rip current video game

2.1 Open up the 'Oculus' software using the desktop shortcut, and then set up the hardware through the program. Ensure that the headset, two sensors, and two controllers are all showing as green (**Figure 5**).

2.1.1 Determine a survey location and recruitment method. In this study, convenience sampling was employed. The researchers visited a public beach two times per week for eight weeks during July and August and solicited potential participants while they walked along the beach promenade. Besides being at least 16 years of age, there was no other requirement besides willingness to participate.

2.2 Administer survey part one (consent form and demographic questions) on a separate iPad.

2.3 Hand the VR controllers to the participant and make sure they are holding them properly in the correct hands, and are familiar/comfortable with the controls, and then fit the headset on the participant.

2.4 Select and run the **Rip Current** shortcut from the Desktop.

2.5 Allow the participant to proceed through the simulation, providing coaching/advice only when necessary. They should complete the main rip scene on their own.

2.6 Once they finish, remove the headset and begin part two of the survey, the interview portion.

2.7 Plug a microphone into a tablet and begin recording. Ask questions regarding prior knowledge and experience with rip currents and the efficacy of the rip current simulation at demonstrating the proper actions to take, as well rating of its realism and immersive nature.

2.8 Once the interview is complete, stop recording, thank the participant, and provide compensation as desired. Save the interview file with name corresponding to date and player number as recorded in the Rip Current scene.

REPRESENTATIVE RESULTS:

The VR rip current video game survey was conducted in July and August 2019 on Long Island at the Town of Hempstead Beach in Point Lookout, New York (detailed results can be found in **Supplementary Table 1-3**). 64 individuals played the game and responded to the survey, with 60 escaping the rip current and 4 drowning (i.e., stamina reached zero). Among the 60 who escaped, 51 exited by waving for help, and 9 did so by physically swimming out of the rip. Given that most participants waved for help as a means of escape, the amount of time taken in the simulation was skewed towards higher values, with a mean of 11.1 s, median of 9.5 s, and standard deviation of 6.2 s (**Figure 6a**). Conversely, the ending stamina was skewed towards lower values, with a mean of 36.8, median of 41.3, and standard deviation of 15.3 (**Figure 6b**). Most participants were able to accurately assess the situation and determine an appropriate course of action to escape the rip current relatively quickly. However, there was a slight uptick in ending stamina closer to zero (i.e., between 0 and 12). That finding may have been caused by the heavy breathing (which began playing when stamina fell below 20) helping individuals realize they were in more imminent danger, and as a result, they changed their strategy and were able to escape before stamina reached zero.

After completing the video game, participants were asked a series of dichotomous, Likert, and open-ended questions regarding the VR and its effectiveness. There were 51 respondents to the Likert-scale question (scale of 1 to 5 with 5 being highest) asking if they felt better prepared for a rip current after interacting with the VR. The average response was 3.81, with a minimum of 1, maximum of 5, and standard deviation of 1.01. Moreover, 61 individuals responded to a similar Likert-scale question asking about how immersive the VR experience was, with an average of 3.96, minimum of 2, maximum of 5, and standard deviation of 0.79. Participants were also asked if they had been caught in a rip current prior to playing the game, and if so, how the VR compared to real life. 17 individuals responded to the latter question, with 7 stating that the simulation bore at least some resemblance to real life. 7 of the respondents found that the VR was not as realistic or scary as real life, while 4 asserted that it was not at all similar.

In addition, participants were provided with a set of six brief statements meant to capture their opinion of the VR experience and asked which they most agreed with (**Table 2**). Of the 58 respondents to that question, 53 selected statements stating that the VR helped them feel better prepared for a rip current, with only 5 selecting ones saying it did not help. 30 of the 58 chose the statement that said the VR helped them feel better prepared because it was realistic, and 19 chose the one stating it helped because it was scary or made them felt worried. Last, users were asked to identify the most and least useful aspects of the VR, along with any suggestions for improvement. 19 individuals provided useful aspects of the simulation, with the most common being its realism (6), the inclusion of VR (3), instruction provided (3), and ability to wave (3). Conversely, 6 respondents reported the least useful aspects, with 3 of the 6 mentioning the short duration of the game as a negative. Accordingly, regarding the improvements, there were 19 responses, with 13 suggesting an expansion of the simulation such as more scenarios, additional training, or more options.

FIGURE AND TABLE LEGENDS:

Figure 1. Main Menu scene. Opening scene of the VR experience.

Figure 2. Buoy test scene. First training scene in the VR experience.

Figure 3. Wave test scene. Second training scene in the VR experience.

Figure 4. Rip current scene. User evaluation scene in the VR experience.

Figure 5. VR hardware setup screen. Demonstrates proper configuration for connecting virtual reality equipment to a computer.

Figure 6. Results of rip current virtual reality video game (A) Bar chart showing ending stamina of all participants (**B**) Bar chart showing time taken for all participants.

Table 1. Scripts developed for project. Scripts were written in the C# language.

Table 2. Brief statements regarding rip current virtual reality experience. Participants were asked to select which one they most agreed with.

Supplementary Table 1. Individual VR simulation results.

Supplementary Table 2. Aggregated survey demographic results.

Supplementary Table 3. Selected post-VR interview results.

DISCUSSION:

Preliminary analysis of the results from the follow-up survey demonstrates the VR rip current video game was generally effective in accurately portraying risk and demonstrating proper actions to take in an engaging and memorable way. Respondents to the Likert-scale questions indicated the VR simulation resulted in them feeling more prepared than not for a rip current and also that it was fairly immersive. Moreover, the results of choosing one of six brief statements clearly showed the video game was helpful given that over 90% of the selections were positive. Similarly, in free response questions, numerous participants lauded the VR for characteristics such as its realism and interactivity. The overall player outcomes of the video game also underscored the efficacy of the experience at conveying proper actions to take in a rip current. 60 of the 64 participants successfully escaped the rip, most of them by waving for help, and the majority also took an evasive action quickly.

Some feedback also indicates that improvements can be made to this and future VR simulations developed. Indeed, more instruction might be necessary, especially for individuals with less experiencing playing video games and using VR. Additional optional training scenes are one possibility for allaying those concerns. Further, realism can always be improved to make the VR experience more relatable and meaningful for participants. To do so, enhancements such as physically moving one's arms to swim (instead of using a joystick controller) and further distinguishing the rip current from the surrounding ocean water can be incorporated.

The results of the survey also provide unique insight into individual behavioral responses to a rip current scenario. For example, 51 of the 64 participants were able to escape the rip current by waving for help. However, in the follow-up survey, only 20 of those participants stated that waving or calling for help was the preferred action to take in the rip current. It is possible some of the inconsistency in knowledge versus action can be explained by the survey order, as the instructions for waving always occurred just before the rip current simulation, which may have predisposed some individuals to wave for help in escaping the rip. Thus, randomizing the order of the training scenes could allow for even more realistic results in the future. It is also possible, however, that the intensity (i.e., feeling of being quickly pulled from shore) and rapid onset of the simulated rip current caused individuals to either forget, or be deterred from attempting, a more complicated, riskier evasive action: swimming parallel to shore. This is further confirmed by the fact that 20 respondents mentioned swimming parallel (or 'sideways') to shore was a proper action to take, but only 9 participants escaped the rip current in that manner.

Moreover, the gap between rip current knowledge and action, and resultant personal risk, was demonstrated by individuals believing they knew the proper response, but then performing an incorrect one. Four participants drowned (i.e., stamina reached zero) in the simulation, despite all four of them stating afterwards that they knew want to do in a rip current. Three of the four, however, reported an incorrect evasive action, with the fourth also showing a limited understanding of what to do, mentioning that they should swim 'away out of it,' but not specifying a direction to swim. Similarly, 45 of the 64 survey respondents affirmed they would know if they were caught in a rip current. Of those 45, however, 10 clearly demonstrated in their responses that they did not actually know what a rip current was, confusing it with a phenomenon such as an 'undertow' that pulls individuals underwater and may involve large waves. Thus, the combined results of the VR simulation and survey indicate two primary obstacles in rip current risk communication: 1) Some individuals do not know what a rip current is, or have incorrect knowledge of a rip current, and therefore may not take the proper mitigating action, and 2) When caught suddenly in a rip current, even individuals who know what to do in one may forget or disregard those actions, potentially exposing themselves to risk.

Future research can expand upon this work in order to better understand how sociodemographic factors influence personal mitigation of rip current risk. For instance, 57 of the 64 participants in the present survey reported living within 30 minutes of the beach, while 54 stated they visited at least 'occasionally.' However, many rip current fatalities involve individuals residing far from the beach who may only visit once a year or less for vacation. Future surveys can be conducted at more neutral locations or online to gain a broader sample and understand behavioral differences in rip current reaction between those who visit the beach more and less frequently.

Undoubtedly, VR has the unique ability to allow users to conceptualize risk and learn proper mitigating actions in a memorable way. Improved understanding of its current shortcomings, especially as they pertain to certain demographic characteristics, will allow researchers and emergency managers to capitalize on immersive technology in a nuanced way and develop the next generation of effective warning products.

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DISCLOSURES:
The authors have nothing to disclose.

REFERENCES:
1. National Weather Service, Rip Current Science. https://www.weather.gov/safety/ripcurrent-science (2020).
2. Moulton, M., Dusek, G., Elgar, S., Raubenheimer, B. Comparison of rip current hazard likelihood forecasts with observed rip current speeds. *Weather and Forecasting*. **32** (4), 1659-1666 (2017).
3. National Weather Service, Weather Related Fatality and Injury Statistics. https://www.weather.gov/hazstat/ (2020).
4. Gensini, V. A., Ashley, W. S. An examination of rip current fatalities in the United States. *Natural Hazards*. **54** (1), 159-175 (2010).
5. Houser, C. et al. Public perceptions of a rip current hazard education program:"Break the Grip of the Rip!". *Natural Hazards and Earth System Sciences*. **17** (7), 1003 (2017).
6. Doelp, M. B., Puleo, J. A., Cowan, P., Arford-Granholm, M. Delaware coast Delaware surf zone injury demographics. *The American Journal of Emergency Medicine*. **36** (8), 1372-1379 (2018).
7. Castelle, B. et al. Surf zone hazards and injuries on beaches in SW France. *Natural Hazards*. **93** (3), 1317-1335 (2018).
8. Brannstrom, C., Trimble, S., Santos, A., Brown, H. L., Houser, C. Perception of the rip current hazard on Galveston Island and North Padre Island, Texas, USA. *Natural Hazards*. **72** (2), 1123-1138 (2014).
9. Caldwell, N., Houser, C., Meyer-Arendt, K. Ability of beach users to identify rip currents at Pensacola Beach, Florida. *Natural Hazards*. **68** (20), 1041-1056 (2013).
10. Fallon, K., Lai, Q., Leatherman, S. Rip current literacy of beachgoers at Miami Beach, Florida. *Natural Hazards*. **90** (2), 601-621 (2018).
11. Berg, L. P., Vance, J. M. Industry use of virtual reality in product design and manufacturing: a survey. *Virtual Reality*. **21** (1), 1-17 (2017).

12. Sundar, S. S., Kang, J., Oprean, D. Being there in the midst of the story: how immersive journalism affects our perceptions and cognitions. *Cyberpsychology, Behavior, and Social Networking*. **20** (11), 672-682 (2017).
13. Dede, C. Immersive interfaces for engagement and learning. *Science*. **323** (5910), 66-69 (2009).
14. Klippel, A. et al. The value of being there: toward a science of immersive virtual field trips. *Virtual Reality*. 1-18 (2019).
15. Bernhardt, J. et al. Communicating Hurricane Risk with Virtual Reality: A Pilot Project. *Bulletin of the American Meteorological Society*. **100** (10), 1897-1902 (2019).
16. National Weather Service, "Break the Grip of the Rip" brochure, https://www.weather.gov/media/safety/rip/rip_brochure_51419b.pdf (2019).
17. National Oceanic and Atmospheric Administration, Rip Current Survival Guide transcript, https://oceantoday.noaa.gov/ripcurrentfeature/ (2016).
18. McCarroll, R. J. et al. Evaluation of swimmer-based rip current escape strategies. *Natural Hazards*. **71** (3), 1821-1846 (2014).
19. Unity User Manual (2019.2). https://docs.unity3d.com/Manual/2Dor3D.html (2019).
20. Unity Asset Store. https://assetstore.unity.com/ (2020).

Figure 1

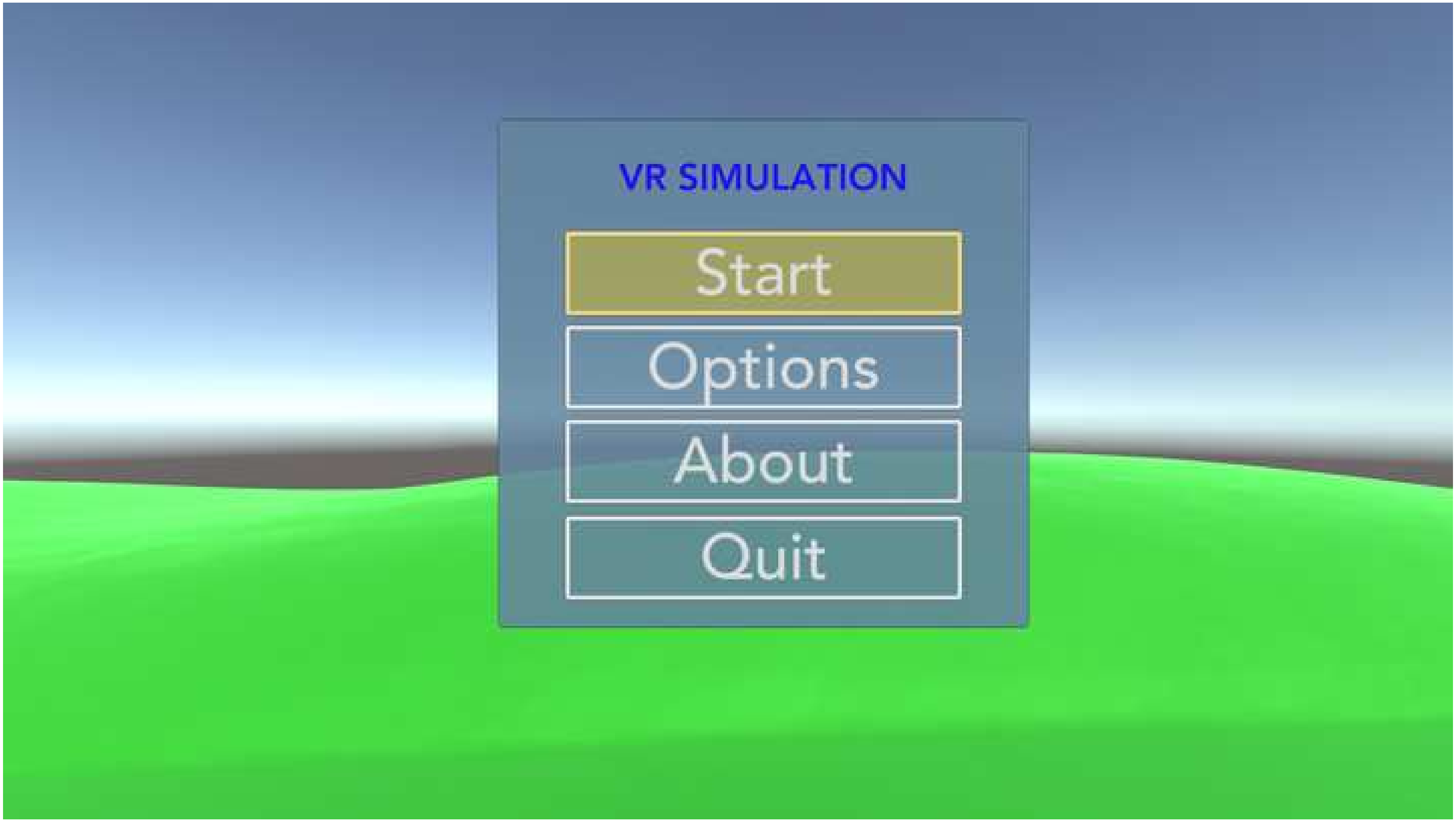

Figure 2

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Figure 3

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Figure 4

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Figure 5 Click here to access/download;Figure;fig_5.jpg

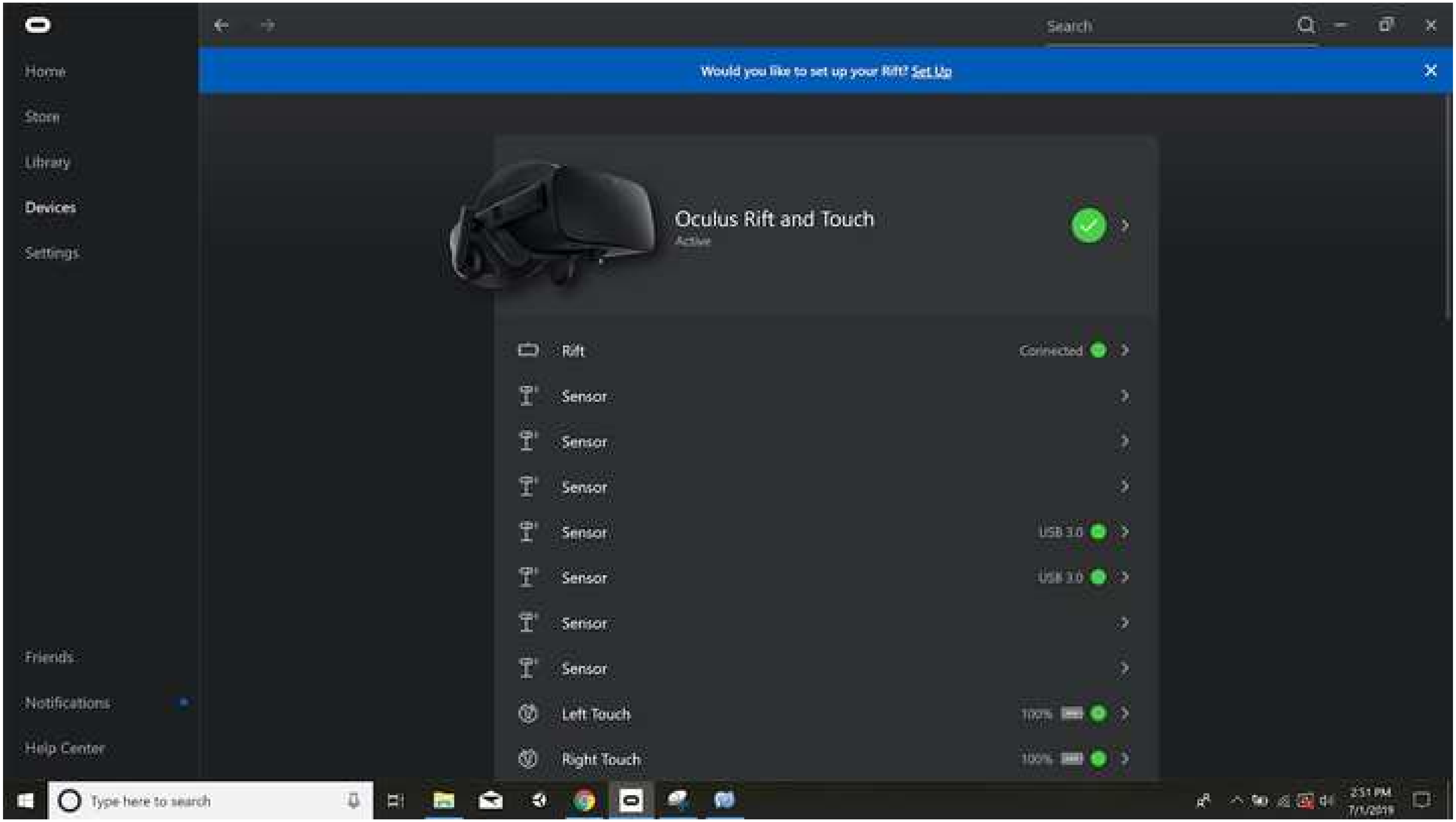
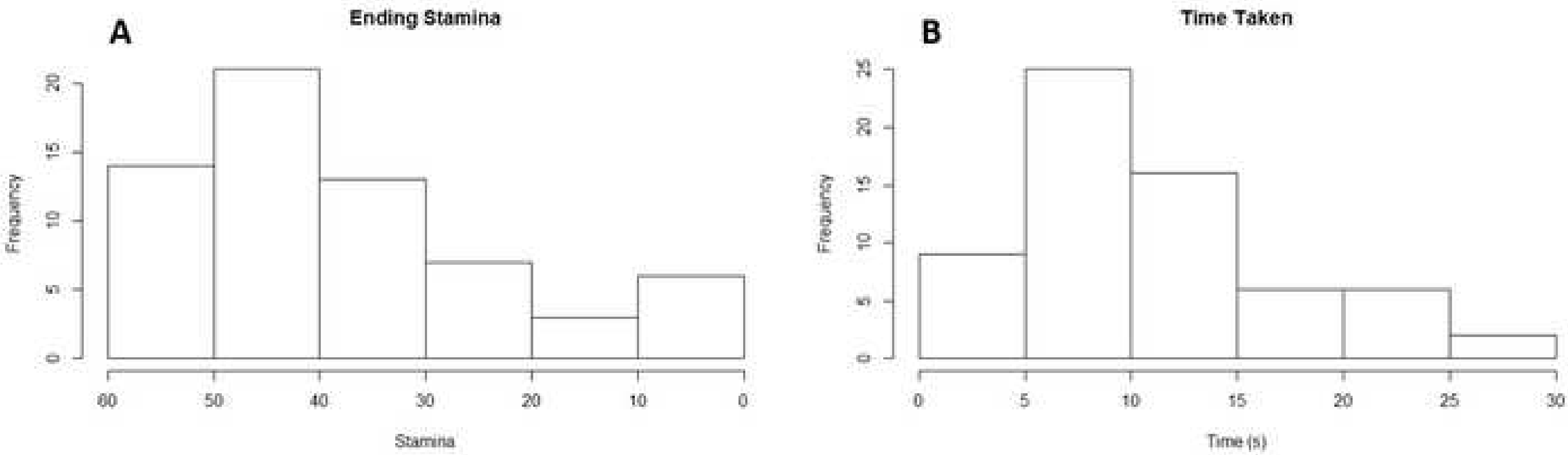


Figure 6


A
Ending Stamina
Frequency
0
5
10
15
20
60
50
40
30
20
10
0
Stamina
B
Time Taken
Frequency
0
5
10
15
20
25
0
5
10
15
20
25
30
Time (s)

Script Name	Script Function	Scenes Used
MainMenu	Controls menu buttons	Main Menu
MouseHover	Controls highlighting of menu buttons	Main Menu
PlayerController	1) Stores user input from Oculus controller joystick 2) Stores user input from head movements in Oculus headset	Main Menu, Buoy Test, Wave Test, Rip Current
PlayerMotor	1) Physically move the player in the environment (i.e., swim) based on input from PlayerController script 2) Rotates the camera view based on input from PlayerController script	Buoy Test, Wave Test, Rip Current
PlayerMotor2	1) Inherits and extends functionality of PlayerMotor 2) If player is swimming, plays a sound of arms splashing in water *For Rip Current Scene Only:* 3) Applies a constant drifting motion to player away from the beach to simulate being pulled away from shore in a rip current 4) Creates and tracks 'Stamina' variable based on a timer and user input; Stamina begins at 60 decreases by 1*second if player is stationary and by 3*second if player is swimming 5) Creates a timer variable which tracks time elapsed in Rip Current Scene 6) Assigns each user a unique player number based on date and sequential player of that day 7) If player waves, print player number, current Stamina, time elapsed, and player condition ('Waved') in a text document; transition to Main Menu (also transitions from Wave Test scene to Rip Current scene) 8) If player escapes rip current, print player number, current Stamina, time elapsed, and player condition ('Escaped') in a text document; transition to Main Menu	Buoy Test, Wave Test, Rip Current

	9) If player stamina reaches zero, print player number, current Stamina [0], time elapsed, and player condition (‘Drowned’) in a text document; transition to Main Menu	
Checkmark	If player swims between buoys, entering the collider box, transition to next training scene (Wave Test)	Buoy Test
FloatObject	The water has no collider, meaning the player should fall straight through the water due to gravity. This script simulates floating to keep the player at the level of the water.	Buoy Test, Wave Test, Rip Current
FemaleAnimate	If player presses the ‘A’ or ‘X’ button on the Oculus controller, initiates a hand waving animation in the left player arm, and plays an audio clip of a hand splashing water	Wave Test, Rip Current
Buyoancy2	Records whether or not the hand is waved in a scene and if in Rip Current scene, record in PlayerMotor2 script that player waved	Wave Test, Rip Current
RipExit	1) If player exits rip current collider box, record in PlayerMotor2 script that player escaped the rip current 2) If stamina is below 20, start playing heavy breathing audio emanating from the player	Rip Current

Positive Statements

i) The VR experience helped me feel be better prepared because it was realistic.

ii) The VR experience helped me feel be better prepared because it was scary/or made me feel worried.

iii) The VR experience helped me feel be better prepared because it taught me what to do.

Negative Statements

i) The VR experience did not help me feel be better prepared because it was not realistic.

ii) The VR experience did not help me feel be better prepared because it was scary and/or made me feel worried.

iii) The VR experience did not help me feel be better prepared because it did not teach me what to do.

Name of Material/ Equipment	Company	Catalog Number	Comments/Description
Dell 17.3" Alienware 17 R5 Laptop	Dell		PC for virtual reality development
Oculus Rift S	Oculus		Virtual reality headset

Response to Reviewers Document for Bernhardt et al. JoVE61296

Changes to be made by the Author(s):

1. Please take this opportunity to thoroughly proofread the manuscript to ensure that there are no spelling or grammar issues. The JoVE editor will not copy-edit your manuscript and any errors in the submitted revision may be present in the published version.

We have carefully proofread the manuscript to ensure it is free of spelling and grammar issues.

2. Unfortunately, there are a few sections of the manuscript that show overlap with previously published work. Though there may be a limited number of ways to describe a technique, please use original language throughout the manuscript. Please see lines: 30-46

A new abstract has been written to deal with this concern.

3. Figure 3 can be removed and the Oculus system can be cited in the Table of Materials instead.

Figure 3 has been removed as advised and the Oculus system is already included in the Table of Materials, so that remains unchanged.

4. Are all the files needed for the game provided or the details provided to obtain/download the files?

A GitHub repository has been created to provide access to the necessary script files, with URL added to Table 1.

5. Is the filming of the survey (Step 2) required?

We prefer to briefly film dissemination of the survey in order to demonstrate how we applied the VR simulation developed. However, if the filming seems to be running too long, we can remove this portion from the script.

6. Figure 8 can be revised for better presentation.

This figure has been changed to a table to allow for better presentation.

Reviewer #1:

Manuscript Summary:

It is an interesting application for VR in rip current simulation use case. I think the application will be useful for educational purposed and awareness for the topic. I have minor suggestion to improve the structure of the paper.

Thank you!

Major Concerns:

None

Minor Concerns:

-More supporting references can be added on VR and its use in environmental context.

An additional relevant citation has been added to the VR discussion in the Introduction section.

-Discussions section can be divided into 2 sections to share the "Results and Discussions" and "Conclusion" of the study.

We have followed the JoVE formatting guidelines to construct the manuscript in this way.

-Project files and assets can be shared on an open code repository to replicate the study along the procedure.

A GitHub repository has been created to house all the script files for this project with URL added to Table 1. The project assets, which were created by third parties, are available from the Unity Asset Store.

-Survey results can be share as a table to further see the details of each survey.

We have added Supplementary Tables 1-3 with more detailed survey results, and reference them at the end of the first sentence of the Representative Results section.

-Oculus photo might need a reference or copyright information.

This photo has been removed in accordance with the Editor's guidance above

Reviewer #2:

Manuscript Summary:

The authors develop a VR training game to train and improve the users' survival skills in swimming and rip currents.

Major Concerns:

Too many detail in the creating process.

We take this comment into consideration and edit to remove extraneous details in the following portions of the Protocol:

-- Editing sentences for length and clarity in 1.1.2 and 1.23.2

-- Removing a sentence from 1.3.3.4

-- Making the wording in 1.3.4.1, 1.4.6, and 1.5 more concise

-- Removing Figure 3

However, we were careful not to remove details deemed important for the experiment to be replicated

I would like to see some formulations of how to generate the rip current, such as strength and frequency.

We added a sentence to 1.5.2 to clarify the strength of the rip current

The analysis is quite limited. Should extend it a little bit.

We have expanded the analysis by adding three new paragraphs to the Discussion section.

Reviewer #3:

Manuscript Summary:

The manuscript summarizes the development and testing of a VR rip current simulation. The goal of the presented VR video game was to improve public understanding of the rip currents and to assess their knowledge and abilities to take protective actions. The development protocol and the results of the survey are interesting, informative and could be used to inform future studies. A few minor comments for the authors to consider:

Thank you for the positive feedback!

Summary, abstract and introduction:

While rip currents are undoubtedly dangerous phenomena, stating that rip currents are among the deadliest natural hazards in the US may not be accurate. While rip currents is a major coastal (surf zone) hazard, the fatalities from weather hazards such as tropical cyclones, floods, heat waves and tornadoes are much higher. Please revise the text (lines 25, 30, 54, 59) so not to overstate the fatality rate of rip currents compared to other weather-related and natural hazards.

We cited statistics directly from the National Weather Service (footnote #3). Indeed, in 2018 (and many other years), rip current deaths in the U.S. were greater than those from hurricanes (7), tornadoes (10) and lightning (20) combined and trailed only heat (108) and flooding (80) as the deadliest weather related hazards.

Introduction:

If the authors have these data, it would be interesting to provide statistics on the fatalities as well as knowledge of rip currents / rip currents safety among costal residents vs tourists. Information on geographic distribution the fatalities would be helpful. The NWS data show that Florida has the highest rip current fatalities compared to other coastal states. Were these mostly visitors or locals? This may be useful information for future considerations in training and education efforts using the VR video game.

We agree these are important points and added this additional context and citations about gender breakdown, infrequent beach users, and non-locals to the end of the first paragraph in the Introduction section.

Protocol:

Please provide details on how individuals were recruited and, if available, the participants' demographic characteristics and prior experience with rip currents.

Section 2.1.1 was added to discuss survey recruitment.

Demographics and previous rip current experience as determined from the survey can also now be found in the new Supplementary Tables 1-3. Possible important of past experience with rip currents is also described in the new paragraphs added to the Discussion section.

Reviewer #4:

Manuscript Summary:

This article presents the results of a study of a VR interface that displays rip current-like conditions, and measures the potential effect of experiencing a virtual rip current on rip current learning.

The article is generally well-written, and the concept is an important contribution to VR hazard preparedness studies generally. My concerns and questions with the paper are primarily methodological in nature.

Thank you!

Major Concerns:

(1) Were participants trained that waving is the proper response to a rip current, should they encounter one? Or were they simply trained to wave and were then exposed to a rip current? Early in the article, I had been under the (potentially mistaken) impression that the VR was intended to train people to respond appropriately to a rip current. There are a few issues embedded in this. First, according to the NWS, the first actions individuals should take are to (a) not panic, (b) follow the current, and then (c) swim parallel to shore to get out of the current. The NWS only lists waving as an appropriate action to take after these other actions have been taken. The article does not mention this, but it seems a critical omission. The proper actions to

be taken, and the potential connection between the VR and any improved action, should be explicit.

Thank you for the constructive feedback. The participants were trained to both swim and wave in a virtual ocean environment and then exposed to the rip current without any warning. Those results were intended to provide insight into how people react to rip currents and (in the realistic scenario of no advance warning) and if they take one of the proper actions (swimming parallel to shore or waving). We have added a sentence clarifying this to the end of the Introduction section.

Regarding the proper actions to take if caught in a rip current, the literature from the NWS emphasizes that there is no prescribed order of operations, as both swimming parallel to shore and waving for help are valid responses, as mentioned in this brochure: https://www.weather.gov/media/safety/rip/rip_brochure_51419b.pdf

Moreover, the NOAA 'Rip Current Survival Guide' also states that calling and waving for help can be a preferred option when caught in a rip current:

https://oceantoday.noaa.gov/ripcurrentfeature/

Further, McCarroll et al. (2014) demonstrated that either swimming parallel to shore or waving for help may be preferable action depending on the conditions accompanying on a particular rip current.

Thus, we add a sentence to the end of the Introduction sentence, with those citations, to justify why both escape options were added to the VR.

(2) Relatedly, then, the authors should clarify that the increased propensity to wave may be helpful, but it is also not the first recommended response. This is simply a limitation of this VR setup for improving responses to rip currents.

As above, we posit that waving is just as valid a response as swimming parallel to shore. However, we agree that there is limitation in the VR in the sense that more people may have waved because that training came after the swimming training and right before the rip current simulation. Thus, we have added this idea as a limitation of the study to the new paragraphs in the Discussion section.

(3) It would help if the authors clarified the purpose of the VR experience briefly in the abstract or introduction, for example, by stating a hypothesis about how their VR stimulus was hypothesized to relate to the outcome.

We add a hypothesis to then end of the introduction section as suggested to further clarify the intentions of this study

Minor Concerns:

Lines 59-63: This is interesting background, but given the particular nature of this study, are there any studies regarding the fraction of people who know what to do in a rip current? This would serve as a more helpful baseline for this study.

We have added additional context with a citation to incorporate this baseline information. (now Lines 83-88).

Lines 70-71: The mention of "communicating risk and information" - do the authors simply mean risk information? Communicating risk implicitly involves communicating a lot of information.

We have modified this passage (now starting in Line 94) to just include the broader context of communication of information, which then matches the findings in the literature reviewed in the rest of that introductory paragraph.

Representative results section: How were the 64 participants approached/recruited?

Section 2.1.1 was added to discuss survey recruitment.

Line 308: Instead of "skewed right," recommend saying "skewed toward higher values" (if that's what you mean)

Lines 309-310: Instead of "skewed left," recommend saying "skewed toward lower values" (again, if that's a correct interpretation of what you mean)

We have changed the wording as advised.

Supplemental Table 1

Record Number	**VR Simulation Results**		
#	Stamina	Time	Condition
1	31.29934	11.38007	waved
2	0	28.50046	drowned
3	40.79956	11.44007	waved
4	49.89977	4.019997	waved
5	35.97945	12.5801	waved
6	8.198939	24.56037	waved
7	41.33957	10.66005	waved
8	55.01989	4.979996	waved
9	42.6596	7.419994	waved
10	4.158941	26.76042	escaped
11	49.11975	5.959995	waved
12	53.51985	4.919996	waved
13	53.53985	3.819997	waved
14	54.51987	2.439998	waved
15	37.61949	7.459994	waved
16	37.01947	12.34009	waved
17	24.21918	13.70012	escaped
18	0	24.38037	drowned
19	52.89984	7.099994	waved
20	33.8394	16.12018	waved
21	14.95897	22.04031	waved
22	31.49935	13.18011	waved
23	55.21989	4.779996	waved
24	33.6594	18.30023	waved
25	41.41957	7.939993	waved
26	23.25916	16.22018	escaped
27	50.37978	8.380002	waved
28	46.33969	10.18004	waved
29	40.67956	6.439995	waved
30	51.3398	5.619996	waved
31	48.21973	6.499995	waved
32	41.31957	9.560029	waved
33	31.93936	10.42005	waved
34	27.87926	12.44009	waved
35	44.73965	6.659995	waved
36	53.47985	5.519996	waved
37	41.79958	9.200021	waved
38	42.83961	5.719995	waved
39	25.81922	18.94024	escaped
40	41.29957	12.5401	waved
41	51.75981	5.759995	waved
42	39.47953	8.320001	waved
43	51.73981	8.259999	waved
44	55.6199	4.379997	waved
45	33.31939	10.84006	waved

46	34.23941	8.680009	escaped
47	29.6193	10.82006	waved
48	0	23.18034	drowned
49	47.13971	7.579994	waved
50	45.01966	9.020017	waved
51	51.0998	4.219997	waved
52	29.81931	10.30005	waved
53	0	22.34032	drowned
54	31.25934	10.22004	escaped
55	51.67981	6.839994	waved
56	43.35962	8.360002	waved
57	12.55897	19.32025	escaped
58	44.21964	8.620008	waved
59	35.83945	9.720033	escaped
60	46.47969	4.519997	waved
61	44.29964	15.70017	waved
62	43.49962	9.500028	waved
63	16.099	20.94029	waved
64	25.41921	13.22011	escaped

Gender		**Race/Ethnicity**	
Male	**40**	American Indian or Alaskan Native	**2**
Female	**23**	Asian	**5**
Other	**1**	Black or African American	**1**
		Hispanic, Latino, or Spanish Origin	**3**
		White	**53**
Distance from beach		**Beach visit frequency**	
0-10 minutes	**8**	Rarely (1-3 times a year)	**10**
10-30 minutes	**49**	Occasionally (every few weeks)	**22**
30-60 minutes	**5**	Often (once a week)	**23**
> 60 minutes	**2**	Very Often (more than twice a week)	**9**

Highest level of education		**Age range**		**Children**	
Some high school	**12**	15-17	**19**	Yes	**17**
High school diploma	**11**	18-25	**21**	No	**47**
Some College	**17**	25-39	**12**		
2- or 4-year college degree	**10**	40-60	**9**		
Graduate Student	**4**	Over 60	**3**		
Post-graduate degree	**10**				
How often go into ocean		**Swimming ability**			
Never	**1**	Can't swim	**2**		
Rarely (1-3 times a year)	**23**	Weak	**9**		
Occasionally (every few weeks)	**21**	Average	**36**		
Often (once a week)	**13**	Strong	**17**		
Very Often (more than twice a week)	**6**				

Heard of a rip current		Know if caught in a rip current	
Yes	56	Yes	45
No	8	No	11
Not Sure	0	Not Sure	8

Been caught in a rip current before

Yes	21
No	39
Not Sure	4