The Effect of Multimodal Virtual Reality Experience on the Emotional Responses Related to Injections

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Abstract: The objective of this study is to determine if using a multimodal experience, haptics and audio in a virtual environment, can change the emotional responses related to injections. Participants were poked with a blunt end needle in three conditions, where they were asked to look away from the needle, look at the needle directly, or interact haptically with bubbles in a virtual environment. Participants were asked to rate the arousal (calm-fear), valence (happy-unhappy), and pressure felt (no pressure-high pressure) for each trial. Our results showed that participants preferred the haptics-VR condition as indicated by their comments and significant valence scores. They described the simulation as relaxing, fun, and pleasant. The results support the idea that multisensory simulation can be effective in increasing participants' happiness through distraction in stressful or fearful situations.

1 INTRODUCTION

In the current work, we investigated whether distraction using a multimodal experience of mid-air haptics in a virtual environment can reduce the anxiety and stress related to needles as opposed to an experience without multimodal stimulation. Furthermore, conditions of looking directly at the injection site or looking away from it were tested. We relied on a tactile phenomenon known as tactile suppression (Ziat et al., 2010) where a tactile stimulation is suppressed by another tactile stimulus. Because our central nervous system receives a vast amount of sensorimotor information, the brain has developed a mechanism to suppress some incoming information. Putting this into application, using tactile feedback can help suppress the tactile sensation coming from the needle. While we did not directly address a sensory suppression in this study; which can be visual, auditory, or haptic, the phenomenon has been studied in multiple sensory modalities (Porcu et al., 2014).

Several studies have already explored the influence of haptics on emotions in a multimodal context (Eid and Al Osman, 2015) (Tsalamlal et al., 2018) (Ziat and Raisamo, 2017) and the effectiveness of haptics for pain treatment. One study reported significant results of tactile feedback reducing deafferentation pain through a multimodal experience using a VR headset and vibrotactile motors on the hand (Sano et al., 2016). Another notable study tested ultrasound tactile stimulation with virtual reality for pain distraction. Authors found a pain tolerance increase and higher-than-midpoint values for valence and arousal, indicating more positive emotions associated with the multimodal experience (Karafotias et al., 2017).

2 RELATED WORK

Virtual reality has been proven to effectively reduce perceived pain. For burn patients undergoing painful treatments while using virtual reality, a reduction of activity in the pain-related areas in the brain has been observed in the insula, the thalamus, and the primary and secondary somatosensory cortex (Hoffman, 2004) (Das et al., 2005). Another study showed that haptic feedback can enhance the realism of a virtual reality experience (Krogmeier et al., 2019).

The healthcare industry is always looking for means to help individuals overcome fear and pain. Injections, magnetic resonance imaging scans, pre-operative and post-operative care, blood draws, blood donations, and waiting rooms are situations where people experience high anxiety or pain. (Canbulat et al., 2014) (Ditto and France, 2006) (Hamilton, 1995) (Kain et al., 2006) (Karanci and Dirik, 2003) (Munn and Jordan, 2013) (Pineault, 2007).

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When it comes to injections, up to two thirds of children and one fourth of parents are afraid of needles (Taddio et al., 2012). It is more common for children than adults to suffer from needle-related or injection phobia/fear, known as Belonephobia or Trypanophobia (Doctor et al., 2008) (Orenius et al., 2018), and the need for distraction in younger children may be greater than in older children. In a study on how children perceive pain, children reported needle related procedures as very painful (Kortesluoma and Nikkonen, 2004). Treating children who have a fear of needles can also be a stressful and difficult experience for nurses (Ives and Melrose, 2010).

When administering immunizations, a study has shown that distraction can be a more effective means to help children cope with pain and fear than parental comfort (Manimala et al., 2000). In another study where children were distracted by an iPad during immunizations, parents reported that the children experienced less distress, crying, and need for being held (Shahid et al., 2015).

3 PRE-STUDY SURVEY

As children are a demographic that displays high anxiety during injections (Taddio et al., 2012), we, first, conducted interviews with three parents to get a better understanding of the immunization process for children. We wanted to learn about the feelings experienced by patients during injections and the strategies used by parents and practitioners to help children cope with the fear and pain.

Parents were asked to walk through their children's experiences while getting an injection and discuss the most difficult aspects of this experience. They rated their perception of children's valence on a scale from 1 to 5 (extremely unhappy-extremely happy). They were also asked what comforting strategies they try on their children before and during injections, how receptive the children were to toys when stressed, and what were the most effective methods for calming the children. Parents were asked how important they felt it was that hospitals would ease the tension during injections on a scale of 1 to 5 not important -very important) and what they believe would be an ideal injection process.

Parents reported that their children were less happy before and during injections, and the children were usually scared when seeing a doctor or nurse. Easing the tension during an injection was very important for parents as they can become stressed from the non-cooperation of their children. They usually bring toys, and often pat their children to calm them down. Overall, this short survey shows that injections are negative experiences for children and parents, with parents believing that positive injection experiences are important, and touch brings comfort to their children. These preliminary interviews were used for collecting additional qualitative findings to inform the direction of the study; this data had less bearing on the results.

4 PRELIMINARY STUDY

In the current work, we wanted to test the effect of multimodal experiences beyond visual and auditory sensations on fear and pain. Our hypothesis was participants would rate arousal, valence, and pressure lower when they were poked with the needle during the tactile-VR simulation. The null hypothesis is that there would be no difference in ratings between participants' experience when using the virtual simulation and when not using the virtual simulation. Our objective is to discover if multimodal experiences reduce fear and pain as well as increase happiness during injections. During and after ratings were collected for a VR experience that lasts over time. For this study, each trial was short in requesting before and during the rating experience.

4.1 Participants

5 adult participants between the ages of 24 and 64 were recruited, including 2 males and 3 females. Due to the COVID-19 lockdown which mandated limited contact with others, participants were volunteers from the entourage of the authors themselves. It was not possible to recruit participants in-person at this time. Nevertheless, the requirement for a minimum number of participants for a formative study was met (Nielsen, 2000). They were provided with a consent form to agree to their voluntary participation to the experiment. Some participants may have an emotional reaction to seeing a nurse or doctor. For this reason, we chose to minimize the injector's visual presence and dialogue to isolate the condition most suitable for this experiment, the needle itself.

Figure 1: A syringe with a blunt needle tip was used for the mock injections.

Figure 2: The mock injection was administered two inches below the wrist.

4.2 Apparatus

A syringe with a blunt needle tip was used (Fig. 1) for ethical and safety consideration during the experiment. The syringe resembles an injection needle, which provides a more realistic experience of an actual injection. In Fig. 2, the needle tip was applied to the same area, two inches below from the wrist, on the ventral side participants' left forearms for each trial. Although there may be multiple injection sites, we chose to use the site most common for IVs. It is important to note that the injection site was consistent for all the participants.

For tactile feedback, an Ultraleap STRATOS Explore development kit was used. It consists of an ultrasound mid-air haptics array and a hand tracking sensor. The 192-transducer array emits ultrasound into the user's hand to create tactile sensations. Additionally, the sensor's camera tracks the spatial orientation of the user's hand in real time. The virtual hand, which is displayed over a virtual array that represents the Ultraleap device, can interact with virtual bubbles and feel tactile sensations concurrently. The Oculus Rift CV1. was used during the virtual interaction to view and hear the virtual environment. Although VR headsets are recommended for those 13 and older, the concerns involving younger children are mainly for long-term usage. Younger children can still use a VR headset, but for a limited time, which is relatively short when a nurse is providing a shot.

4.3 Stimuli

In this test, three visual conditions were compared: "Look Away" where participants are looking away from the injection arm, "Look At" where participants are asked to look directly at the injection arm, and "Simulation," where participants are exploring a virtual environment and feeling tactile feedback when they interact with objects. Both Look Away and Look At conditions were included to mimic common injection scenarios yet separate biasness of seeing the injection or anticipating the shot.

Figure 3: Multimodal VR experience of nature environment visuals, popping bubbles tactile feedback, and waterfall audio.

For the Simulation condition, a nature virtual reality environment was built using Unity (Unity, n.d.) as shown in Fig. 3. A nature setting was used to induce the biophilia effect (Kellert, 1995) (Lidwell et al., 2010) (Wells, 2000), also known as healing through nature, which helps participants feel more relaxed and less stressed when presented with a real or artificial visual depiction of nature. In this environment, the viewer stood on a boulder surrounded by a pool of water and cliffs. They could also view a pink willow tree to their left and a waterfall to their right. Waterfall ambient noise, which resembles the sound of a high waterfall with a substantial volume of water crashing into a pool of water, was added to enhance the realism of the setting.

For the tactile feedback, participants placed their hand on the virtual array (Gray block under the virtual hand in Fig. 4) and began popping bubbles. The ultrasound array created tactile waves on the skin when bubbles popped or collided with the virtual hand. An auditory feedback of the popping bubble was heard each time a bubble was popped by the participant to reinforce the tactile sensation.

5 PROCEDURE

The environment setup was similar to an injection chair that is commonly used in a doctor's office. Participants sat in a chair with each of their forearms resting on elevated platforms (small tables and boxes) as shown in Fig. 4a. The ergonomics of this layout also ensures that neither arm will experience fatigue. The ultrasound array was placed approximately 20 centimeters below the participants' right hand for optimal accuracy in hand detection, as demonstrated in Fig. 4b.

Additionally to the three visual conditions (Look

Figure 4: (a) Ergonomics were considered to prevent arm fatigue by utilizing a table and boxes as armrests. (b) Ultrasound array is placed approximately 20 centimeters under the right hand.

at, Look Away, Simulation), there was a contact condition where a pressure was applied on the skin with the cannula, and a no-contact condition where the needle hovered over the area without touching the skin. These two injection types prevent participants from becoming accustomed with the needle stimulus and to avoid any anticipation about the contact with the needle. A total of 18 trials (3 visual x 2 injection x 3 repetitions) were run for each participant with a randomized order.

For each trial, participants were asked to report whether they felt a sensation of pressure on their skin. If participants' answer was affirmative, additional questions related to valence, arousal, and pressure were asked. More specifically, on a 10 point scale, participants were asked to provide a score for the arousal dimension, with one representing calm and a score of ten representing fear. For valence, a score of one represented happy and a score of ten represented unhappy. Finally, for pressure, a score of one represented feeling no pressure and a score of ten represented feeling high pressure.

After the experiment, there was a verbal follow-up with the participants where they reported any phobia of needles and ranked the three conditions and modalities (visual, auditory, tactile) by preference.

6 RESULTS

Fig. 5 displays the grand mean ratings of valence, arousal, and pressure for the three conditions (Look Away, Look At, Simulation). Because of a small sample and the nature of the data (ordinal), the difference in arousal, valence, and pressure ratings were analysed using the non-parametric Friedman test. Our hypothesis is participants will have lower ratings for arousal, valence, and pressure in the simulation condition than the other two conditions.

For valence, Friedman test was significant (χ^2 = 5.65, p <0.05). In the simulation condition, the majority of participants felt calmer as the mean valence rating was the lowest for participants. The test was not significant for both arousal (χ^2 = 3.44, p >0.05) and pressure (χ^2 = 2.21, p >0.05).

Although the data for arousal and pressure did not show a statistically significant difference, the ratings for the Simulation condition were lower than the Look At or Look Away conditions. The means for the Look Away and Look At conditions were closer to each other (see Fig. 5).

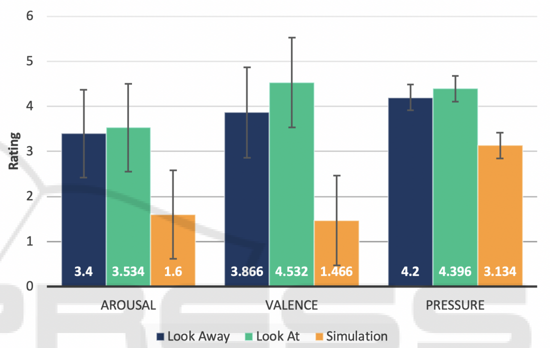

Figure 5: Grand mean for the "Look Away," "Look At," and "Pressure" conditions among the participants. From left to right: Arousal, Valence, and Pressure ratings.

6.1 Post-survey

Participants were asked to rank the conditions from highest preference to lowest preference. They all chose the Simulation condition first, the Look At condition second, and the Look Away condition third. One of the participants reported Trypanophobia but her responses were not different from the other participants.

They described the Simulation condition as "relaxing," "calming," "peaceful," and "immersive." They also mentioned that the simulation disengaged attention away from injections. The popping bubbles were often labelled as "pleasant," "fun," and "realistic," while the haptic feedback made the simulation more effective in distracting them from the needle. One participant explained that if the bubbles were not included in the environment, it would have been less effective. Additionally, participants mentioned that both visual and auditory effects of the waterfall were realistic and relaxing. Finally, seeing the virtual hand interact with the haptic bubbles enhanced the realism of the simulation.

Participants least favoured the Look Away condition. They all preferred to see the needle than wait for the action to happen. Participants disliked the anticipation factor of the Look Away condition because they were waiting anxiously for the needle to make contact with their skin as opposed to knowing when the needle would poke the skin. They stated that the visual feedback made them feel "calmer," "at ease," and "in control" since they felt there was a sense of comfort to see what the needle would do to the skin. Moreover, for the Look Away and Look At conditions, participants had found the room environment "more boring" and "less interesting" than the virtual environment. For the ranking of the modalities, the visual and tactile conditions were ranked first by two participants each, while one participant ranked the auditory condition first. The second most favourite modalities were tactile and auditory by two participants each.

7 DISCUSSION AND CONCLUSION

Our study shows that multimodal immersive experiences can increase happiness, reduce anxiety and boredom, and potentially reduce fear for adults receiving injections. Although the participants were only adults, it can be inferred that the responses would be stronger in children since findings from a previous study showed a greater percentage of children than adults experienced trypanophobia (Taddio et al., 2012). Multimodal experiences are also highly preferred as a distraction tool for unpleasant experiences. Participants favoured and expressed positive sentiments about the simulation. They described the simulation as relaxing, fun, and enjoyable. The data revealed that arousal and pressure ratings were not significant, but the data for the valence rating was significant. This indicates that participants felt significantly happier during the virtual simulation than when they looked away or looked at the injection site.

In addition, all participants correctly identified if stimuli had made contact or no contact to their arms. The fact that participants reported that the multimodal condition was an effective distraction from the syringe suggests that sensory suppression occurred. Similar studies have examined the effect of virtual reality and haptic sensation for pain distraction. One study showed that when there is physical interaction in a virtual reality experience, tactile feedback can increase pain tolerance (Karafotias et al., 2017). Our study differs by focusing on the multimodal experience without isolating the VR, haptic, or auditory conditions separately. The study was designed to more closely simulate conditions that may occur in a healthcare facility by isolating the look at, look away, or multimodal experience conditions.

In the future, we would like to further investigate the timing and location of the injection, the devices and visualizations used, the age and number of participants, and how closely the experiment would match an actual doctors office. Since suppression phenomena are very complex and ill understood, investigating the timing and location of the mock injection's tactile stimulation (same arm vs different arm) emitted from the haptic array would allow a better understanding of how different locations and timing influence suppression.

As we had tested virtual reality and tactile concurrently, it would be beneficial to test the tactile, visual, and auditory sensations separately to compare unimodal versus multimodal effectiveness. This could help determine which sensations are the most effective in unimodal and multimodal situations. Additionally, non-contract mid-air haptics and contact tactile feedback, such as surface touch (Meyer et al., 2014) or vibrotactile haptics (Ziat et al., 2006) (Ziat et al., 2005), could be compared to investigate how the nature of the haptic stimulation affects the level of immersion. Furthermore, many participants preferred to look at the injection site, so a possible visualization could be a nurse's hand holding a syringe as a future investigation.

Because of the COVID-19 lockdown, number of participants were limited to five. When deemed safe and possible, we plan to expand the number of participants and conduct a summative study on a younger demographic, potentially adolescent patients between the ages of 13 and 18. Additionally, a study could be done with children under 13. Because virtual reality devices recommend users to be 13 years or older, the study could be modified for children under 13 years of age by using a monitor display with speakers instead.

Patients could experience anxiety in real-life situations induced by an unsettling and unfamiliar hospital environment as well as the administration of the injection by a staff member. This was not tested in our current experiment as participants came from the immediate environment of the authors. For this reason, we would like to extend our experiment to include a more realistic scenario allowing us to analyze the effectiveness in real life application.

Finally, the implementation of a similar system is cost-effective (around $150 USD) using NVIDIA Jetson Nano Developer Kit, a Google Cardboard VR headset, a 5-inch cell phone, and a 48-transducer ultrasonic directive speaker kit. This would allow practical application in hospitals without significantly increasing cost.

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