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Research Article

Does Immersive Virtual Reality Using Aquarium Exposure Reduce Pain Perception? A Pilot Study in Normal Healthy Volunteers

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Abstract

Background: There are multiple distraction strategies suggested to reduce anxiety and pain among children. Interactions with swimming fish in aquariums may have the possibility to reduce both pain and anxiety, according to some previous studies. However, cost and bacteria may reduce the possibility of using natural aquariums in hospitals. Interacting with immersive Virtual Reality (VR) may be able to divert attention and slow response to incoming pain signals. The present study will investigate the anti-nociceptive effect of exposure to a VR aquarium in a normal adult cohort.

Materials and methods: Forty-one (41) healthy subjects (mean age 25.2 years) were exposed to a VR aquarium system (eSea system by Sky Factory) depicting a coral reef in the Philippines with 500 species of coral and 2,000 species of fish. Pain perception levels were assessed using an electrical stimulation device, the Pain Matcher (Cefar Medical AB, Sweden), after 5 minutes, 10 minutes, 20 minutes, and 30 minutes of continuous VR aquarium exposure. A final measurement was taken 10 minutes after the aquarium exposure ended.

Results: A statistically relevant increase in pain level was noted after 5 minutes of VR aquarium contemplation. We also noticed a threshold increase after 10 minutes, 20 minutes, and 30 minutes of VR aquarium exposure. A residual effect was noted 10 minutes after exposure.

Conclusion: VR aquarium protocol is now used in our department as a non-pharmacological anti-nociceptive technique. The residual effect 10 minutes after VR aquarium exposure is helpful in clinical practice for performing painful procedures in children, such as those involving needles, immediately after 10 minutes-20 minutes of virtual aquarium exposure.

Keywords: Distraction technique; Fish aquarium; Virtual reality; Pain; Pain matcher; Pain threshold

Introduction

Multimodal analgesia may include pharmacology (e.g., basic analgesics, opioids, and adjuvant analgesia), regional anesthesia, rehabilitation, psychological approaches, spirituality, and integrative modalities, which act synergistically for more effective acute pain control with fewer side effects than any single analgesic or modality [1-10]. A wave of new research methods explores Animal-Assisted Therapy (AAT), more specifically, this complementary and Alternative Medicine (CAM) intervention known as Animal-Assisted Therapy (AAT) or "pet therapy". Most research into the health benefits of human-animal interaction has focused on species that interact physically with humans, such as dogs. Such interaction may be unsuitable for certain populations for various reasons, including accessibility and risk of adverse consequences to both the person and the animal.

In 2015, we conducted a pilot study to determine the effect of Fish Aquarium Animal-Assisted Therapy (FA-AAT) on pain perception in a cohort of healthy volunteers. This study showed a statistically significant increase in pain perception threshold after 5 minutes of aquarium viewing. This augmentation in threshold also increased after 10 minutes, 20 minutes, and 30 minutes of FA-AAT. A residual effect was noted up to 10 minutes after exposure. It may be helpful for painful procedures in children, such as needle placement or blood tests, improving conditions if performed immediately after aquarium exposure. However, technical, financial, and bacteriological constraints can make it near impossible to build and use freshwater or marine aquariums in clinical departments. In such situations, a compromise may be found, using Virtual Reality (VR) aquariums instead of real fish tanks. Such immersive VR consists of exposure to a marine aquarium through real-time rendering technologies and latest-generation devices. Users can be immersed as if they were in a real-life situation, and we postulate that this virtual experience appears to have therapeutic potential. Using the same protocol as in our first study, this study evaluated the benefit of VR-FA-AAT as a non-pharmacological anti-nociceptive technique on pain threshold.

Methods

Population studied

Forty-one (41) healthy subjects, 25 women (mean age 23.3 years) and 16 men (mean age 25.5 years), were selected from medical

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students and residents in our department. Of these, 22 were medical students, and 19 were residents. Exclusion criteria included allergy, skin disease, asthma, pregnancy, diabetes, or chronic pain. None had taken pain-modifying or antihistamine drugs.

Our Institutional Review Board (IRB #2020-1-124) approved this study and written informed consent was obtained from all subjects participating in the trial.

We decided to use the same control group as the first study, which comprised 12 healthy subjects (4 men, 8 women; mean age 27.4 years) randomly assigned from the cohort of 41 volunteers.

VR-FA-AAT device

The protocol used a Sky Factory eSea digital cinema window (Figure 1). This eSea screen was installed in the main waiting room of the department. An aluminum frame surrounds the screen to create the illusion of a window into a much larger underwater opening. Screen size was 47" × 26".

The study used a 51-minute Ultra-HD underwater video called "Anemone and Coral". This video is a scene from the Philippine Coral Reef Tank at the California Academy of Sciences, which is home to a variety of softly textured anemones, colorful coral, and several species of coral fishes (https://www.skyfactory.com/products/underwater/).

Figure 1: Pictures of the Sea display system by Sky Factory used for subjects' distraction.

Experimental pain threshold assessment device

The Pain Matcher [11,12] is an electrical stimulation device used to assess pain perception thresholds. It provides constant current stimulation despite variable skin resistance. A microprocessor controls it, providing rectangular pulses at a frequency of 10 Hz and amplitude of 10 mA. The stimulus intensity increases from zero to a maximum of 396 (in increments of four) over 99 steps. The electrical charge per second is exceedingly low and does not cause any damage to the tissue. The value of intensity (0 to 99) is linked directly to the pulse width and is presented on a liquid crystal display screen (Figure 2). We asked the subjects to hold the Pain Matcher electrodes between their left hand's thumb and index finger. Electrical stimulation was initiated by the subjects who were asked to press a device button at the first perceptible sensation (the sensation threshold). After this, the device was turned back on, and subjects were instructed to press the button when the perceived signal became painful (pain threshold). This is a highly reliable method for patients, simple to use, well tolerated, and helpful in assessing pain threshold in patients and control subjects [11,12].

Figure 2: The Pain Matcher (Cefar Medical AB, Sweden) is an instrument for electrical stimulation that provides constant current stimulation despite variable skin resistance. The electrical charge per second is extremely low and causes no tissue damage. The intensity value (0 to 99) is directly related to the pulse width and is displayed on a liquid crystal screen.

Study procedure

The 41 subjects had measures collected to assess sensation and pain thresholds. These measurements were taken before exposure to the eSea screen and repeated after 5 minutes, 10 minutes, 20 minutes, and 30 minutes of continuous contemplation. Subjects sat comfortably between 0.5 meter and 1.5 meter in front of the screen. We asked them to observe the marine fauna (i.e., corals and fish) on the eSea screen in a continuous manner. Further distractions, such as oral communication and cell phones, were not allowed during the observation phases. The same measurements were repeated at T40, in front of a white wall, 10 minutes after the VR aquarium exposure ended.

For the control group, 12 healthy subjects (of which four were male, eight female, mean age 27.4 years), picked randomly from the cohort of 41 volunteers, were again tested for the same thresholds while looking at a white wall without any distractions.

Statistical method

We collected all data in a computer database and then analyzed them using SPSS version 16 (IBM Corp. USA). The normality of quantitative variables was assessed before testing by using multivariate skewness and kurtosis tests. For normally distributed data, the statistical analysis was conducted through paired and unpaired t-tests. A statistical difference in pain thresholds was evaluated according to gender and different durations of exposure to the aquarium.

For the control group, because of a non-normal distribution of data, non-parametric tests were conducted by using the Wilcoxon signed rank test; $P<0.05$ was judged statistically relevant.

Results

Table 1 shows the minimum and maximum pain threshold values in both the virtual aquarium and control groups based on the duration of exposure to the eSea screen and the average of these values and their standard deviation. Our results show a trend toward increasing pain thresholds with the time of exposure to the virtual aquarium.

Table 2 presents the results of statistical analysis (paired analysis) comparing the Pain Matcher's threshold values at different times of eSea screen contemplation. Pain thresholds were significantly increased after 5 minutes, 10 minutes, 20 minutes, and 30 minutes of virtual aquarium contemplation compared to the initial threshold values before exposure. They remained significantly higher 10 minutes after the aquarium contemplation stopped (Figure 3).

Table 1: Results of Pain Matcher* thresholds values among the population according to the different exposure durations.

	n	Minimum	Maximum	Mean	Standard Deviation
T0	41	4	43	18.78	8.96
T5	41	6	72	22.46	12.806
T10	41	6	83	24.32	14.623
T20	41	9	102	29.02	19.714
T30	41	12	102	32.22	20.572
T40	41	12	95	28	19.719

*Cefar Medical AB, Sweden

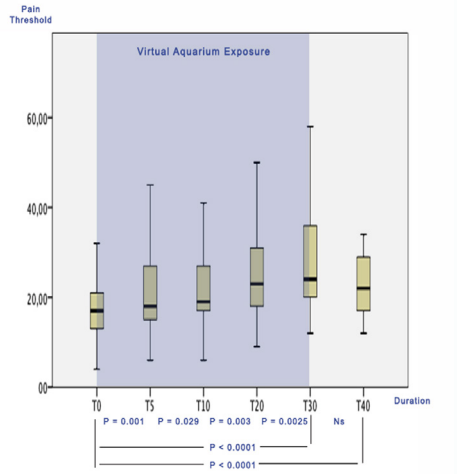

Figure 3: Comparison of means (Paired T-test) Pain Matcher* threshold values according to the different exposure durations.

The statistical analysis showed no significant difference between pain threshold measurements after 30 minutes of aquarium exposure and 10 minutes after exposure ended (T40). Such results would suggest a residual effect of aquarium exposure on healthy subjects. Analysis of control group data found no statistically significant differences in pain threshold measurements at any time.

The difference between men and women was significant in pain threshold values. The men showed significantly higher pain threshold values before aquarium exposure (P-0.022). Following aquarium exposure, pain thresholds increased similarly in men and women. Although, pain thresholds in men remained significantly higher than those in women, particularly at T30 (P-0.010) and T40 (P-0.008) (Table 3 and Figure 4).

The results also reveal no significant difference in pain thresholds between medical students and residents.

Discussion

Non-pharmacological intervention is a critical component of stress, anxiety, and pain management protocols and is used as an adjunct to pharmacological treatments [1,13]. Other objective data,

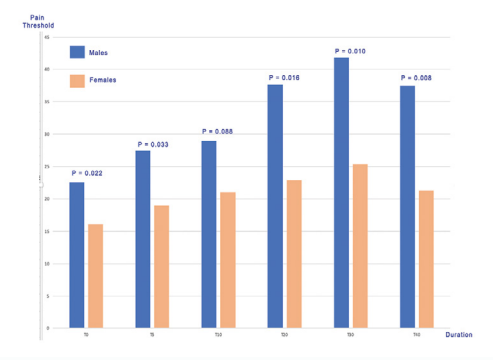

Figure 4: Comparison of means (unpaired T-test) Pain Matcher* threshold values according to the different exposure durations and gender.

such as levels of anxiety, depression, and hostility, could have been tested in our cohort, as in the study by Cole and Gawlinski [14]. That study was conducted on patients awaiting heart transplantation. A saltwater fish tank containing multicolored coral, stones, and colorful fishes was installed in patients' rooms. Patients expressed delight at having fish aquariums in their rooms, which humanized the environment. The aquarium provided cognitive stimulation and became a bridge for communication among patients, family, and staff.

In pediatric practice, non-pharmacological interventions are becoming increasingly essential to pain management. Numerous studies suggest that interventions such as distraction, positioning, and cold application may help reduce patients' pain perception [1-10]. Nurses can also implement these methods independently, enhancing their ability to care for children and their families. In addition, non-pharmacological methods are relatively inexpensive [1]. To reduce the perception of pain in children, several prevention strategies have been proposed, including sedative premedication [2], behavioral preparation programs, music therapy [3], animated cartoon visualization [4-7] hypnosis [8], acupuncture [9] and, most recently, virtual reality [10,15]. Some of these interventions, such as cartoon visualization and musical distraction, are used relatively frequently. In contrast, others including hypnosis and acupuncture are used less frequently because of undesirable side effects, time constraints, or increased healthcare costs [16].

As discussed in our first study in 2015 and data, using animals in health care as a therapeutic healing modality has recently gained popularity [17] and has proven its efficacy (anonymized reference). Animal-Assisted Therapy (AAT) is a goal-directed intervention in which an animal that meets specific criteria is an integral part of a treatment process. AAT is designed to improve human physical, social, spiritual, emotional, and/or cognitive functioning [18-20]. This therapy is acknowledged and used across the health care continuum (in outpatient care and acute care) [21] and extended care facilities

Table 2: Comparison of means (Paired T-test) Pain Matcher* threshold values according to the different exposure durations.

Pair	Mean	Standard Deviation	Standard Error	t	P
T0 *vs.* T5	-3.683	6.732	1.051	-3.5	0.001
T5 *vs.* T10	-1.854	5.237	0.818	-2.27	0.029
T10 *vs.* T20	-4.707	9.373	1.464	-3.22	0.003
T20 *vs.* T30	-3.195	8.815	1.377	-2.32	0.025
T30 *vs.* T40	4.22	13.566	2.119	1.992	0.053
T0 *vs.* T40	-9.22	15.363	2.399	-3.84	<0.0001
T0 *vs.* T30	-13.44	16.765	2.618	-5.13	<0.0001

*Cefar Medical AB, Sweden

Table 3: Comparison of means (unpaired T-test) Pain Matcher* threshold values according to the different exposure durations and gender.

	Gender	n	Mean	Standard deviation	Standard error	t	P
Global	Male	17,000	22,529	10,678	2,590	2,383	0,022
	Female	24,000	16,125	6,523	1,331		
T0	Male	17,000	22,530	10,678	2,590	2,383	0,022
	Female	24,000	16,130	6,523	1,331		
T5	Male	17,000	27,470	16,760	4,065	2,207	0,033
	Female	24,000	18,920	7,627	1,557		
T10	Male	17,000	28,940	19,354	4,694	1,747	0,088
	Female	24,000	21,040	9,182	1,874		
T20	Male	17,000	37,650	26,391	6,401	2,508	0,016
	Female	24,000	22,920	9,873	2,015		
T30	Male	17,000	41,820	27,144	6,583	2,708	0,010
	Female	24,000	25,420	10,346	2,112		
T40	Male	17,000	37,470	27,505	6,671	2,801	0,008
	Female	24,000	21,290	6,061	1,237		

*Cefar Medical AB, Sweden.

[22] as adjunctive therapy for use by nurses and across all patient populations, from pediatrics [19,23,24] to geriatrics [18,20,22,25].

Because surgery and various invasive procedures generate substantial pain, varying resources and staff trained in caring for pediatric patients make a pediatric surgery department a unique place to care for children in pain. Many recent studies were conducted regarding individual (sex, age) differences in pain perception [26-28]. Because of the relaxation effects observed in elderly patients and patients with Alzheimer's disease [21,22,25] we aimed to evaluate the effects of virtual aquarium therapy.

Because of ethics rules and constraints, mainly due to an experimental-based pain protocol, our two studies were conducted in a cohort of healthy adult volunteers. The initial study aimed to determine the effect of fish aquarium AAT on volunteers' pain perception, as assessed using a specific testing device (the Pain Matcher; Cefar Medical AB, Sweden). At that time, the aquarium was located in our department.

This new study, related to the first, aims to evaluate the effectiveness of viewing a virtual aquarium on a high-definition screen dedicated to this type of video (https://www.skyfactory.com/products/underwater/) [29]. Several arguments justify the use of digital videos rather than a natural aquarium. First, the maintenance cost of a 250-gallon fish tank is about 2,000 euros per month. Using a VR aquarium is less cumbersome and much more affordable. In addition, hygiene measures using a natural aquarium must be carefully followed, including cleaning the aquarium and windows (algae, waste), draining used water, caring for fish and corals, and storing animal feed. Also, the bacterial risk from a fish aquarium in a hospital clinical department must be considered [30,31].

Using a VR aquarium device such as the eSea high-definition screen was considered very comforting by children, parents, and caregivers. Numerous videos perfectly reproduce aquatic life within an underwater ecosystem, have an aesthetic purpose, and soothe spectators who view them. This screen costs about 30,000 euros and does not require special care, except for regular maintenance included in after-sales services. The financial investment of this screen is therefore depreciated in less than two years, compared to the use and maintenance of a natural aquarium. Installing such a video projection system does not require any hygiene precautions. In addition, the playful aspect of the screen and the various videos available (e.g., seabed, fresh water, jellyfish, etc.) make it a more interesting system that offers greater diversity. Finally, the aesthetic quality of the videos (e.g., colors, resolution, etc.) is undeniable and almost makes the screen even more attractive and pleasant than a natural aquarium.

The main reason for the original installation of a VR aquarium in our surgery department was the calming and relaxing effects of fish aquarium, as reported in a literature review [25].

Our 2015 pilot study has confirmed that assisted animal therapy provided by a 250-gallon marine fish aquarium will objectively increase the nociceptive threshold, which allows moderate invasive and painful medical procedures, like vein puncture, to be carried out with more comfort in our pediatric population.

Compared to this first study, the present protocol shows the same benefits of using a VR aquarium system. Regarding individual differences in pain perception, the literature strongly suggests that males and females differ in their pain responses, with increased pain sensitivity and clinical pain risk most commonly noticed in female subjects [26,28]. We also found this difference in our study, in which pain thresholds were higher in men than women. Some recent studies have demonstrated that anxiety and gender may affect the effectiveness of attentional strategies for pain management [28].

The eSea display is developed to offer the relaxing and therapeutic benefits of watching living underwater environments. Research has determined that watching such environments helps restore emotional balance, reduce anxiety, and even decrease blood pressure. Conceived as a portal to large underwater environments, eSea features marine life's smooth, fluid movements. This movement activates an automatic relaxation response in the observer.

Our study found a statistically significant increase in pain perception threshold after five minutes of exposure to aquarium viewing from an eSea digital cinema window. Again, this threshold increased after 10 minutes, 20 minutes, and 30 minutes of viewing compared to baseline levels. A persistent effect was noticed up to 10 minutes after exposure. We used the pilot study control group to strengthen our results. This brief time after the observation may be useful in clinical practice to conduct certain painful procedures in children, such as ones involving needles, in better conditions right after exposure to the eSea screen. As a standard practice in our department, children and parents are asked to watch the eSea for 10 minutes-20 minutes before venous punctures.

VR aquariums are particularly well suited for use in regulated healthcare environments that cannot maintain live aquariums, such as clinical wards, operating rooms, intensive care units, etc., which

require very high hygiene standards. The live aquarium needs high maintenance of the equipment and marine animals. Hygiene control is also a significant concern, mainly in pediatric hospitals. For example, Mycobacterium marinum is a common pathogen known as the tuberculosis of fish. It is found in fresh and saltwater and can contaminate aquariums, fish farms, and non-chlorinated pools. Infections are related to water contamination in aquaria or injuries to fishers. The germ is often spread through the blood or lymphomatous route, leading to tenosynovitis, arthritis, or osteitis. These infections with Mycobacterium marinum are severe and have a high rate of complications [31].

The VR-FA-AAT offers us an optimal solution to reduce the expenses and risks associated with waterborne pathogens [12]. The importance of animal protection, bacterial risk, and the annual cost of a natural fish aquarium are arguments that make an alternative such as a VR aquarium very attractive.

In addition, in 2016, we conceived an original project with a therapeutic, playful, and educational focus, designing a digital virtual aquarium composed by patients (http://illuminartaquariumvirtuel.blogspot.com/) [32]. Built on the use of the "Illuminart" device, the virtual aquarium was a pleasant immersive experience for patients. This interactive digital aquarium was created by two young artists who create animated movies. They conducted workshops where the long-stay patients made their personal sea animals, which were integrated into the virtual aquarium. Afterward, with the help of a stop-motion film, the sea creatures could move at variable speeds, blow bubbles, play, etc. Calm and soothing water sounds complemented these animations. Also, in October 2019, we presented the "Illuminart Virtual Museum" to hospitalized patients, exhibiting more innovative artworks (http://artdanslacite.eu/illuminart-museum/) [33]. This project is a multicultural place open to the world, allowing patients to experience artworks from all over the world. They have access to a multicultural, multidisciplinary, and international artistic and cultural program from their hospital room. The programming can change, including special exhibitions dedicated to children, entertainment content, audio, videos, books, and musical instruments. It is a bacterial-free museum with only artistic contents. In the future, the sensory challenge will be an additional asset for hypnosis and pain management in patients. Music headphones for hearing, the addition of fragrances for olfaction, and compression by external devices for epicritic tact all contribute to the development of multisensory distraction processes.

Because of ethical rules and limitations, especially with the use of electrical stimulation by the Pain Matcher, we did not conduct this study in a cohort of preoperative children. Still, we suggest that the distraction effect should be the same, or perhaps higher, in children than in our cohort of healthy adult volunteers. In addition, since our study population knew the purpose of the research, this may have influenced the outcome. We fully acknowledge the potential bias of the present study and the necessity of studying a sample of children to generalize the impact of such distraction therapy on procedural pain in children. Although the findings from our population of healthy adults may not apply to children, we expect that eSea's on-screen distraction-similar to that of cartoons or games on digital screens-will have highly beneficial impacts on preoperative anxiety, particularly in children aged three to seven years [4-7]. It is unclear, however, whether new generations of children will be more easily distracted by a virtual fishbowl or, on the contrary, due to their earlier access to digital screens, whether these children will be less receptive as they are too familiar with these new technologies.

These virtual digital innovations encouraged us to work with alternative strategies and to develop a pain management plan that would provide the most significant benefit. Children at our institution will benefit from the latest medical approaches and proven effective alternative therapies.

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