2025 IEEE World Haptics Conference (WHC)
Suwon Convention Center, Suwon, Korea
July 8 ~ 11, 2025

Pain masking by contextual modification in VR/AR environment

Hibiki ONODA
Department of Informatics
The University of Electro-Communications
Tokyo,Japan
onoda@kaji-lab.jp

Shoha KON
Department of Informatics
The University of Electro-Communications
Tokyo,Japan
shoha.kon@kaji-lab.jp

Keigo USHIYAMA
Department of Informatics
The University of Electro-Communications
Tokyo,Japan
ushiyama@kaji-lab.jp

Izumi MIZOGUCHI
Department of Informatics
The University of Electro-Communications
Tokyo,Japan
mizoguchi@kaji-lab.jp

Hiroyuki KAJIMOTO
Department of Informatics
The University of Electro-Communications
Tokyo,Japan
kajimoto@kaji-lab.jp

***Abstract*— Virtual reality (VR) experiences are increasingly employed as tools for pain management. Conventional VR-based pain reduction strategies rely on distraction of the user's attention from the source of the stimulus. However, these strategies are less effective for individuals with difficulty shifting their attention, highlighting the need for alternative methods. This study introduces a novel approach to pain reduction by modifying the appearance of the stimulus source, altering the context as less unpleasant (contextual modification). This method let users to misinterpret the source of the stimulus. The experiment used an animation of a cat scratching a user as a new context, and investigated whether the discomfort threshold, stimulus interpretation, discomfort level, and intensity of discomfort generated by electrical stimulation could be affected. We conducted this evaluation in both VR and augmented reality (AR) environments. Results indicated that the simultaneous presentation of cat animation synchronized with stimulus increased the discomfort threshold and reduced discomfort and pain compared to the presentation of electrical stimuli alone. The effectiveness of this intervention diminished when a temporal delay was set between the stimulus and the animation.**

Keywords*— *AR, contextual modification, Pain, Stimulus, VR

I. Introduction

Virtual reality (VR) has been established as an effective tool for pain management [1], [2]. Nociceptive stimuli activate cortical and subcortical brain regions collectively termed the "pain matrix" [3]. It is hypothesized that the multisensory signals generated within VR environments consume the neural processing resources of these regions, thereby diminishing the brain's capacity to process pain signals.

Virtual reality (VR)-based methods for pain reduction primarily operate by diverting the subject's attention to mitigate pain and anxiety [4], [5], [6]. These approaches have been extensively studied within the medical field to reduce pain perception and anxiety, particularly during invasive or painful medical procedures [7], [8], [9], [10], [11]. They have also been employed in studies involving pediatric populations [12], [13], [14], [15] as well as patients suffering from chronic pain [16], [17], [18].

Methods to reduce pain and discomfort through the integration of multiple senses with the visual VR experience have been proposed [19], [20]. In a study investigating emotional responses to injections, VR conditions incorporating tactile interactions were found to be preferable to conditions involving mere visual observation of a needle[20]. These results suggest that multisensory stimuli are effective in promoting participants' sense of well-being by offering distraction in stressful or anxiety-inducing scenarios. There is also another method to reduce pain and discomfort by modifying the users' appearance within the VR environment [21].

As previously stated, VR-based pain management techniques have demonstrated varying degrees of success. However, their effectiveness is limited in specific populations. For example, the distraction method has been reported to be ineffective for individuals with heightened fear of pain, as their attention cannot be easily diverted [22]. Therefore, the development of a new pain management approach that does not rely on diverting attention from the source of the stimulus is warranted.

This study aimed to propose and examine the effectiveness of a new pain reduction method using "context modification." The approach is intended for a wider population, including individuals who find it difficult to divert their attention from the source of the pain. The strategy involves mitigating subjective pain by substituting the source of pain with content that is visually non-aversive to the users.

To investigate the effectiveness of this method, the proposed method employs "cat scratching animation" as a visual cue. Cats were selected due to their inclusion in the study that informed the design of this research [23]. We evaluated its effectiveness in managing pain caused by electrical stimulation, in both VR and AR environments. Validation conducted in the VR space examines the method's applicability in environments akin to conventional pain management approaches. Furthermore, validation in the AR space investigates the method's feasibility for use not only in medical settings but also in everyday scenarios, including activities such as shaving or hair removal, highlighting its practical utility.

II. Experiments With VR Environment

A. Setup

Experiments 1 and 2 evaluated the effectiveness of the proposed method in a VR space. In Experiment 1, the threshold of discomfort was measured to determine whether it is influenced by the presentation of the "cat scratching" video. In Experiment 2, the change in sensation was analyzed through a more detailed questionnaire survey.

The experimental setup included a Vive tracker for hand tracking, a head-mounted display (Quest3, Meta) for displaying VR content, a control PC, and an electro-tactile device for delivering electrical stimulation to the subjects. The experimental setup is presented in Fig. 1.

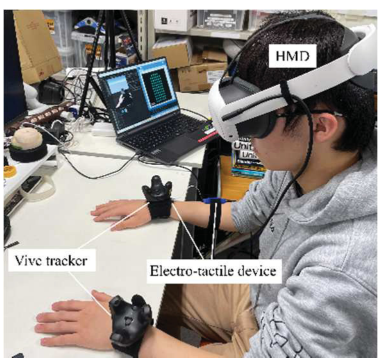

Fig. 1 Setup of experiments 1 and 2.

1) Electro-tactile Device

The electro-tactile device deliver a pain stimulus to the subject through electrical stimulation. The electro-tactile stimulation was selected as the source of pain because it can reliably generate a pain sensation [24], and the intensity of electrical stimulation can be adjusted in real time. The stimulating electrode has a diameter of 1 mm, with a 2.5 mm distance between the centers of the electrodes, and consists of 64 points. As illustrated in Fig. 2, the electrode is positioned directly beneath the Vive tracker, which is mounted on the right wrist.

The stimulation pattern consists of a horizontal row of electrodes that are stimulated nearly simultaneously. Specifically, at one moment only one electrode is selected as the anode, while all other electrodes serve as the cathodes (GND). By rapidly switching this configuration at around 200 μs, a horizontal row pattern is generated. The row of stimuli moves upward incrementally every 30 ms to create the sensation of movement. In this experiment, one “loop” is defined as the movement of the horizontal row of stimuli from bottom to top, and the duration of one loop is 30 ms. The pulse width in this experiment is fixed at 50 μs, with pulse height reaching up to 10 mA. The electro-tactile device is controlled by an ESP32 microcontroller, which communicates with a PC through USB 2.0.

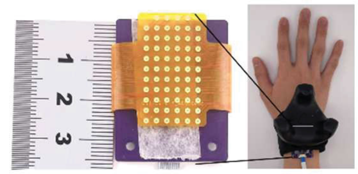

Fig. 2 Left: Stimulation electrodes. Right: Placement of the electrodes.

2) VR Space

Using the head-mounted display (HMD), subjects are immersed in a virtual reality (VR) environment featuring a full-body avatar and a cat (Fig. 3). The VR space was developed using the Unity 3D game engine and displays only the avatar, cat, chair, and desk. Subjects can interact with the VR space by moving their heads and hands.

The 3D avatar was tracked at three points: the hands and head. The lower half of the body was fixed in a seated position on a chair in the VR space to align the posture with that of the real space. The head was tracked using the positional data from the head-mounted display (HMD), and the hands were tracked using the positional data from the Vive trackers attached to the wrists. Due to limitations in tracking the fingers, they were instructed to align the avatar's hand shape in the VR space with their own hand shape in real space as closely as possible. The avatar was designed to be simple and neutral to minimize the effect of gender differences among subjects.

A cat is placed in the 3D space, where it can scratch the subject with its right paw. In response to this motion, an electrical stimulus is presented.

3) Subjects

Thirteen subjects (2 females and 11 males), aged 21 to 24 years, participated in the experiment. The Ethical Review Committee of the University of Electro-Communications(No.H24013) approved the study. Prior to participation, all subjects provided informed consent. All experiments in this study were conducted with the same subjects.

Fig. 3 VR Space.

B. Experiment 1: Method

The purpose of Experiment 1 was to test whether the threshold of stimuli that produce discomfort is influenced by “scratching by the cat.” Prior to the main conditions, several preparatory tasks were performed. The subjects were instructed to sit on a chair in real space while wearing the HMD, the Vive tracker, and the electro-tactile device, as shown in Fig. 1. A reaching task in VR space, in which the subject repeatedly touched a floating cube with the hand closer to the cube, was conducted for 1 minute. This was to ensure the sense of subjectivity in VR space [25]. They were then instructed to adjust their hand position so that the paw of the scratching cat would contact the right wrist, where the stimulating electrode was attached.

The experiment included three conditions. In each condition, a loop of electrical stimulation was applied to the subjects' right wrist every 3 seconds. The electrical stimulation began at 0 mA and increased to a maximum of 10 mA. The output was raised by 0.1 mA with each loop of stimulation. The amount of electrical stimulation was recorded at the point when the subjects verbally reported discomfort under each condition. In this experiment, the level of stimulus applied was defined as the threshold for discomfort. They were instructed to focus on the right wrist, where the electrodes were located, throughout the experiment.

The three conditions were as follows.

- Condition 1: No cat was displayed in the VR space, and only the electrical stimulation was applied.
- Condition 2: A cat was displayed on the desk in the VR space, and the cat made a scratching motion against the subjects' right wrist during the electrical stimulation. Each cat animation lasted 0.25 seconds and synchronized with the electrical stimulation.
- Condition 3: Similar to Condition 2, but the cat's scratching behavior occurred 1 second before the electrical stimulation, indicating a lack of temporal synchronization.

These conditions are referred to as "nothing," "cat," and "lag," respectively. Each condition was performed once with randomized order to minimize discomfort for the subjects during the experiment.

C. *Experiment2: Method*

The purpose of Experiment 2 was to clarify the differences in sensation between conditions using a more detailed questionnaire. In Experiment 1, a gradually increasing stimulus was employed to determine the threshold of discomfort, while in this experiment, participants were asked to provide feedback on the quality of sensation in response to a constant stimulus.

In this experiment, the amount of electrical stimulation was determined before the main procedure. After performing the reaching task as in Experiment 1, the subjects were asked to rate their preference for the cat using a 7-point Likert scale (1: not at all, 7: favorable). The discomfort threshold was determined with the same procedure in the "nothing" condition of Experiment 1, where the cat was not displayed in the VR space. The recorded electrical stimulation level served as the fixed value of electrical stimulation in this experiment.

The experiment involved the same three conditions as in Experiment 1. In the "nothing" condition, the cat was not displayed. In the cat condition, the cat was displayed on the desk, and its scratching behavior coincided with the electrical stimulation. In the lag condition, a time lag was introduced between the electrical stimulus and the cat's movements. Unlike Experiment 1, the amount of electrical stimulation was fixed at the previously described standard. In each condition, electrical stimulation was administered for five loops, with one loop occurring every three seconds. The stimulation location was consistent with that of Experiment 1.

In each condition, the following perception and hand ownership [26] questionnaires were administered after the electrical stimulation. A 7-point Likert scale was used for all responses.

Q1: Did the stimulus feel like an electric stimulus? (1: don't feel it at all, 7: feel it very much)

Q2: Did the stimulus feel like a cat scratch? (1: don't feel it at all, 7: feel it very much)

Q3: How uncomfortable was the stimulus? (1: not uncomfortable; 7: extremely uncomfortable)

Q4: Intensity of the pain (1: weak; 7: strong)

Q5: Did you feel the presence of the cat? (1: no; 7: yes)

Q6: Did the stimulus correspond to the scratching of the cat? (1: no correspondence; 7: correspondence)

Q7: Did the virtual hand feel like a real hand? (1: no; 7: yes)

In the present study, the electrical stimuli that the subjects reported as unpleasant in the "nothing" condition served as the reference. Therefore, for Q3, the subjects were asked to regard the response value for the "nothing" condition as 4, and relatively rate the other conditions.

While Experiment 1 assessed discomfort, Experiment 2 examined both discomfort (Q3) and pain (Q4) separately. This distinction was made to explore whether the subjects considered pain and discomfort as separate experiences. The rationale for treating the perception of the stimulus as a cat scratch (Q2) and the correspondence between the stimulus and the cat's scratch (Q6) as separate questions was to investigate whether the two aspects of perception were viewed as distinct, specifically in terms of the quality of the stimuli and their perceived correspondence.

D. *Result*

1) *Experiment 1*

A Shapiro-Wilk test was conducted on the data from Experiment 1. The results revealed a significant difference ($p<0.05$, $W = 0.92365$), indicating that the data deviated from a normal distribution. A nonparametric Friedman test was performed to assess differences between conditions, and significant differences were confirmed ($p<0.05$, X square = 7.9565). Multiple comparisons were performed using a two-sided Wilcoxon signed rank test for each condition, with Bonferroni corrections applied.

The amount of electrical stimulation that caused discomfort was compared across conditions (Fig. 4). Response of one subject whose responses were affected by image disturbances during the experiment were excluded from the data. A significant difference was observed between the "nothing" and "cat" conditions ($p<0.05$, W: nothing-cat = 54, nothing-lag = 32, cat-lag = 12.5), while no significant difference was found between the "nothing" and "lag" conditions. These findings suggest that the presentation of a cat scratching video synchronized with the timing of the electrical stimulus raised the threshold of discomfort, while a distinct time delay between the stimulus and video diminished this effect.

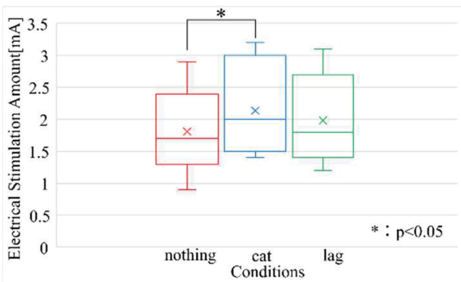

Fig. 4 Results of Experiment 1.

2) Experiment 2

The data collected in Experiment 2 were based on a Likert scale, which is an ordinal scale. A nonparametric Friedman test was performed to confirm significant differences ($p<0.05$, X square: Q1 = 12.286, Q2 = 22.533, Q3 = 11.15, Q4 = 14.389, Q5 = 22.545, Q6 = 23.532, Q7 = 8). Multiple comparisons between conditions were conducted using a two-sided Wilcoxon signed-rank test, and the Bonferroni method was applied to adjust for multiple comparisons.

Fig. 5 presents the response values for each condition and question. The average score for liking the cat before the experiment was 5.75, and no subject provided a response lower than 4. Therefore, the subjects appeared to interpret the presence of the cat as a positive influence.

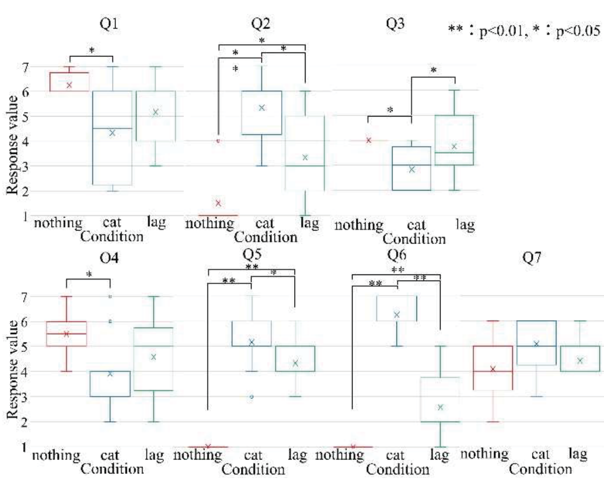

Fig. 5 Results of Experiment 2.

A significant difference was found only between "nothing" and "cat" in whether the stimulus was perceived as an electrical stimulus (Q1) ($p<0.05$, W: nothing-cat = 0, nothing-lag = 0, cat-lag = 19). The results suggest that presenting the cat scratching video synchronized with the timing of the electrical stimulus made it more challenging for participants to identify the cause of the stimulus as electrical.

Significant differences were found between "nothing" and "cat," "nothing" and "lag," and "cat" and "lag" ($p<0.01$, $p<0.05$, and $p<0.05$, respectively, W: nothing-cat = 78, nothing-lag =66, cat-lag = 0) in the perception of the stimuli as cat scratches (Q2). The results suggest that presenting a cat scratching video synchronized with the electrical stimulation led subjects to interpret the stimulus as caused by cat scratching. The strength of this effect decreased when a time lag was introduced between the electrical stimulation and the cat scratching video.

Significant differences were found between "nothing" and "cat," and between "cat" and "lag," in the discomfort level of the stimuli (Q3) ($p<0.05$, $p<0.05$, respectively, W: nothing-cat = 0, nothing-lag = 21, cat-lag = 51). The results suggest that presenting a cat scratching video synchronized with the electrical stimulation reduced discomfort, while a time lag between the video and stimulation diminished this effect.

A significant difference in pain intensity (Q4) was found between "nothing" and "cat" ($p<0.05$, W: nothing-cat = 0, nothing-lag = 0, cat-lag = 37). The results suggest that presenting the cat scratching video synchronized with the electrical stimulation reduced pain perception.

Significant differences were found between "nothing" and "cat," "nothing" and "lag," and "cat" and "lag" ($p<0.01$, $p<0.01$, and $p<0.05$, respectively, W: nothing-cat = 78, nothing-lag = 78, cat-lag = 0) regarding the presence of the cat (Q5). The results suggest that synchronization of the cat scratching video and the electrical stimulation enhanced the realism of the experience.

Significant differences were found between "nothing" and "cat," "nothing" and "lag," and "cat" and "lag" ($p<0.01$, $p<0.01$, $p<0.01$, respectively, W: nothing-cat = 78, nothing-lag = 66, cat-lag = 0) regarding the statement, "the stimulus was felt like it corresponded to a cat scratch" (Q6). The results suggest that the subjects understood the time difference between the "cat" and "lag" conditions. Although similar to Q2, clearer distinctions were observed between the conditions.

No significant difference was found among the conditions in the feeling that the virtual hand had become a real hand (Q7).

III. Experiments With AR Environment

A. Setup

Experiments 3 and 4 were conducted in an AR space (Fig. 6). The head-mounted display used to present AR content, the electro-tactile device for providing electric stimulation, and the PC were identical to those used in Experiments 1 and 2, with the key difference being that the subject could view their arm through the video see-through function of the HMD. The goal of these experiments is to assess the effectiveness of the proposed method in an AR environment where the subject can observe their own arm, to determine its potential for application in daily life, and to compare any differences between the proposed method and a VR environment.

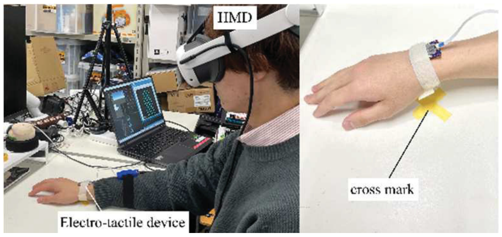

Fig. 6 left: setup of experiments 3 and 4, right: standard for hand placement.

B. Experiment 3: Method

This experiment is a variation of Experiment 1 conducted in an AR environment. The subjects were asked to sit on a chair in real space while wearing the HMD and the electro-tactile device, as shown on the left side of Fig. 6. They were then instructed to place their right wrist at the crossed-out position on the desk, as indicated on the right side of Fig. 6. The same cat scratching video from Experiment 1 was presented to the subject at this position.

The experimental conditions were consistent with those in Experiment 1: “nothing,” “cat,” and “lag” in the AR space. Subjects verbally indicated when they perceived the electrical stimulation as unpleasant, and the corresponding amount of stimulation was recorded. The AR space was as shown in Fig. 7.

C. Experiment 4: Method

This experiment represents an AR-based version of Experiment 2. The experimental procedure and conditions were consistent with those of Experiment 2. However, as we observe our own arms, Q7 was omitted, and participants were instructed to answer questions Q1 through Q6.

Fig. 7 AR Space

D. Result

1) Experiment 3

A Shapiro-Wilk test was applied to the data from Experiment 3. The results revealed a significant difference ($p<0.05$, $W = 0.79435$), leading to the rejection of normality. To assess differences between conditions, a nonparametric Friedman test was performed, confirming significant differences ($p<0.05$, X square = 7.0909). Multiple comparisons were conducted using a two-sided Wilcoxon signed-rank test for each condition, with Bonferroni corrections applied.

As shown in Fig. 8, a statistically significant difference was observed in the amount of electrical stimulation between the "nothing" and "cat" conditions ($p<0.05$, W: nothing-cat = 70, nothing-lag = 49, cat-lag = 3). No significant difference was found between the "nothing" and "lag" conditions. These findings suggest that the presentation of a cat scratching video synchronized with the timing of the electrical stimulus raised the threshold of discomfort, while a distinct time delay diminished this effect.

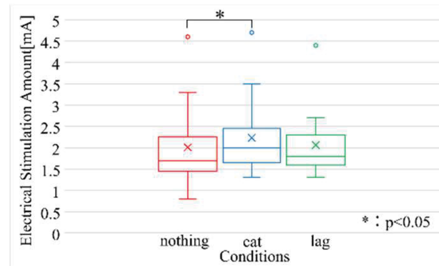

Fig. 8 Results of Experiment 3.

2) Experiment 4

The data collected in Experiment 4 consisted of Likert scale responses, which are ordinal in nature. The Friedman test, a nonparametric test, was performed to assess significant differences ($p<0.05$, X square: Q1 = 16.217, Q2 = 25.529, Q3 = 17.745, Q4 = 11.405, Q5 = 23.244, Q6 = 23.13). A two-sided Wilcoxon signed rank test was subsequently used for multiple comparisons between the conditions, with the Bonferroni correction applied.

Fig. 9 illustrates the response values for each condition and question. A significant difference was observed between “nothing” and “cat,” and between “nothing” and “lag,” for the question of whether the stimulus felt like an electrical stimulus (Q1) ($p<0.01$, $p<0.05$, W: nothing-cat = 3, nothing-lag =0, cat-lag = 47). Thus, the presence of the cat in the AR space decreased the likelihood of interpreting the stimulus as an electrical stimulus, regardless of the synchronization between the electrical stimulus and the cat's scratching video.

Significant differences were found between "nothing" and "cat," "nothing" and "lag," and "cat" and "lag" ($p<0.005$, $p<0.005$, $p<0.01$, W: nothing-cat = 91, nothing-lag =91, cat-lag = 0) in whether the stimuli felt like cat scratches (Q2). Therefore, presenting a cat scratching video synchronized with the electrical stimulation can be seen as the cause of the stimulus, while a lag between the electrical stimulation and the cat scratching video weakens this interpretation.

Significant differences were observed between “nothing” and “cat” and between “cat” and “lag” in the discomfort level (Q3) of the stimuli ($p<0.005$, $p<0.05$, W: nothing-cat = 0, nothing-lag =27.5, cat-lag = 55). Therefore, as in Experiment 2 in the VR environment, the discomfort level decreased when the cat scratching video was synchronized with the electrical stimulation, while this effect was diminished when a time lag was introduced.

Unlike the experimental results in the VR environment, no significant differences were found in pain intensity (Q4) between the conditions. However, significant trends were observed between “nothing” and “cat” and between “cat” and “lag” ($p<0.08$, $p<0.08$, W: nothing-cat = 6, nothing-lag =8, cat-lag = 41).

Significant differences were observed between “nothing” and “cat” and “nothing” and “lag” in whether the cat felt as though it were present (Q5) ($p<0.005$, $p<0.005$, W: nothing-cat = 91, nothing-lag =91, cat-lag = 2.5). Therefore, it is suggested that placing the cat in the AR space may create the sensation that the cat is present, regardless of the timing of the electric stimulus and the cat's scratching video.

Significant differences were observed between “nothing” and “cat,” “nothing” and “lag,” and “cat” and “lag” ($p<0.005$, $p<0.05$, $p<0.05$, W: nothing-cat = 91, nothing-lag =45, cat-lag = 0) for whether the stimuli corresponded to cat scratches (Q6). Therefore, as in Experiment 2, it can be confirmed that the subjects understood the time difference between the “cat” and “lag” conditions.

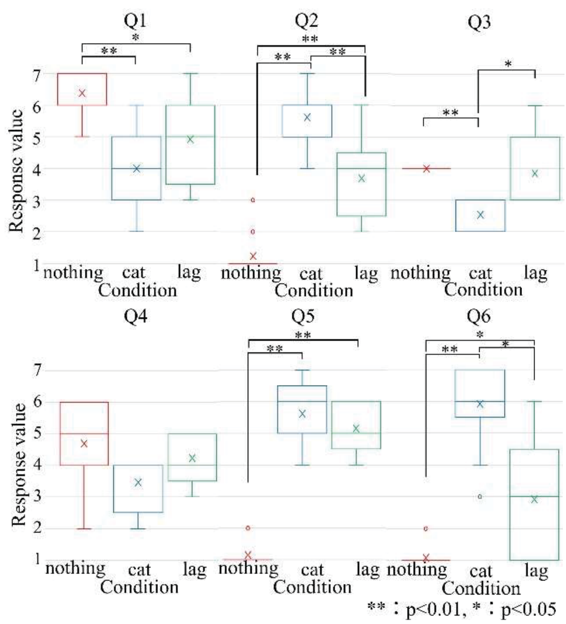

Fig. 9 Results of Experiment 4.

IV. Discussion

The results of Experiments 1 and 2 indicate that the effect of context modification was most noticeable in the "cat" condition, where the stimulus and the video were presented simultaneously. Five participants indicated that the cat-scratching video, presented in response to the electrical stimulus, was more convincing. In contrast, some participants reported that the time delay between the video and the stimulus created discomfort, making it difficult to perceive the scratching. Several participants found the "nothing" condition to be the most unpleasant. This may be attributed to the presence or absence of the cat, or perhaps to the lack of timing prediction due to the absence of the cat. Although the cat's presence may have reduced pain by diverting attention, the comments noted above and the unchanged threshold in the condition lag suggest that the pain reduction in the condition cat resulted not from simple distraction, but from the effect of the proposed “context modification.”

The results of Experiment 2 support the interpretation that the stimulus was caused by a cat scratch in the "cat" condition (Q1, 2, 6). Comparison with the "lag" condition further emphasizes the importance of temporal synchrony. Previous studies have consistently shown that synchronized visual and tactile presentations significantly enhance the sense of presence [27], [28], [29].

The difference in discomfort and pain reduction appeared to be larger in the “nothing-cat” group when subjects were categorized based on their responses to the cat liking questionnaire before the experiment: those who answered “4 or 5” and those who answered “6 or 7.” However, the small sample size precluded statistical analysis in this case. This represents a potential area for further research.

The results of Experiment 2 also indicated that participants had differing interpretations of the “lag” condition. Some participants reported that the “lag” condition enabled them to anticipate the stimulus based on the cat's actions, which reduced pain, while others indicated that they experienced more pain because the stimulus did not occur at the expected time in the video. In the former group, the response values for condition “lag” were similar to those for condition “cat”, whereas in the latter group, the response values for condition “nothing” resembled those for condition “cat”. This may account for the larger variance observed in condition “lag” compared to the other conditions.

Experiments 3 and 4 conducted in the AR environment yielded results similar to those of Experiments 1 and 2 conducted in the VR environment, although certain factors were found to be more pronounced in the AR environment. One participant reported that the AR condition was more realistic and less unpleasant than the VR condition. Another participant noted that the onset of the electrical stimulus in Experiment 3 was perceived slower than in Experiment 1 in the VR condition, although we did not change the setup. These observations were attributed to the shift in the experimental environment from VR to AR, in which the surrounding environment and the hand receiving the stimuli became physical. This change likely enhanced the sense of realism and improved subjects' understanding of the modified context. It is possible that the increased realism contributed to a significant difference in discomfort levels (Q3) between the “cat” and “lag” conditions in Experiment 4, which was larger than the difference observed in Experiment 2. In the “cat” condition, the factors involved heightened the sense of presence and certainty of the stimuli, which reduced discomfort. However, in the “lag” condition, the discomfort caused by the temporal discrepancy between stimuli diverged from the certainty provided by the surrounding environment, potentially diminishing the sense of presence and certainty of the stimuli, thus increasing discomfort levels.

V. Future Work

Future research will clarify the relationship between content preference and pain reduction. The effects will be further examined in various body areas, and the differences in responses based on the type of pain (Sharp pain, dull pain, invasive pain, heat-induced pain) will be investigated. In addition, the present experiment was limited by gender and age bias, a small sample size, and the absence of a control experiment using a model other than cats. These issues will be addressed in future research. This study included a broader range of participants and was not limited to those who had difficulty diverting their attention from the cause of the stimulus. Future research will recruit participants suitable for this type of test and evaluate the effectiveness of the method.

REFERENCES

[1] A. S. Won, J. Bailey, J. Bailenson, C. Tataru, I. A. Yoon, and B. Golianu, "Immersive Virtual Reality for Pediatric Pain," *Children*, vol. 4, no. 7, Art. no. 7, Jul. 2017, doi: 10.3390/children4070052.

[2] A. Gupta, K. Scott, and M. Dukewich, "Innovative Technology Using Virtual Reality in the Treatment of Pain: Does It Reduce Pain via Distraction, or Is There More to It?," *Pain Medicine*, vol. 19, no. 1, pp. 151–159, Jan. 2018, doi: 10.1093/pm/pnx109.

[3] A. Mouraux, A. Diukova, M. C. Lee, R. G. Wise, and G. D. Iannetti, "A multisensory investigation of the functional significance of the 'pain matrix,'" *NeuroImage*, vol. 54, no. 3, pp. 2237–2249, Feb. 2011, doi: 10.1016/j.neuroimage.2010.09.084.

[4] V. Smith *et al.*, "The Effectiveness of Virtual Reality in Managing Acute Pain and Anxiety for Medical Inpatients: Systematic Review," *Journal of Medical Internet Research*, vol. 22, no. 11, p. e17980, Nov. 2020, doi: 10.2196/17980.

[5] A. Li, Z. Montaño, V. J. Chen, and J. I. Gold, "Virtual reality and pain management: current trends and future directions," *Pain Management*, vol. 1, no. 2, pp. 147–157, Mar. 2011, doi: 10.2217/pmt.10.15.

[6] K. M. Malloy and L. S. Milling, "The effectiveness of virtual reality distraction for pain reduction: A systematic review," *Clinical Psychology Review*, vol. 30, no. 8, pp. 1011–1018, Dec. 2010, doi: 10.1016/j.cpr.2010.07.001.

[7] L. D. Morris, Q. A. Louw, and K. Grimmer-Somers, "The Effectiveness of Virtual Reality on Reducing Pain and Anxiety in Burn Injury Patients: A Systematic Review," *The Clinical Journal of Pain*, vol. 25, no. 9, p. 815, Dec. 2009, doi: 10.1097/AJP.0b013e3181aaa909.

[8] S. M. Schneider, C. K. Kisby, and E. P. Flint, "Effect of virtual reality on time perception in patients receiving chemotherapy," *Support Care Cancer*, vol. 19, no. 4, pp. 555–564, Apr. 2011, doi: 10.1007/s00520-010-0852-7.

[9] E. Furman, T. R. Jasinevicius, N. F. Bissada, K. Z. Victoroff, R. Skillicorn, and M. Buchner, "Virtual Reality Distraction for Pain Control During Periodontal Scaling and Root Planing Procedures," *The Journal of the American Dental Association*, vol. 140, no. 12, pp. 1508–1516, Dec. 2009, doi: 10.14219/jada.archive.2009.0102.

[10] H. G. Hoffman *et al.*, "Virtual Reality as an Adjunctive Non-pharmacologic Analgesic for Acute Burn Pain During Medical Procedures," *Annals of Behavioral Medicine*, vol. 41, no. 2, pp. 183–191, Apr. 2011, doi: 10.1007/s12160-010-9248-7.

[11] J. I. Gold, A. J. Kant, S. H. Kim, and A. "Skip" Rizzo, "Virtual anesthesia: The use of virtual reality for pain distraction during acute medical interventions," *Seminars in Anesthesia, Perioperative Medicine and Pain*, vol. 24, no. 4, pp. 203–210, Dec. 2005, doi: 10.1053/j.sane.2005.10.005.

[12] D. G. Rao *et al.*, "Assessment of Efficacy of Virtual Reality Distraction in Reducing Pain Perception and Anxiety in Children Aged 6–10 Years: A Behavioral Interventional Study," *Int J Clin Pediatr Dent*, vol. 12, no. 6, pp. 510–513, 2019, doi: 10.5005/jp-journals-10005-1694.

[13] J. I. Gold and N. E. Mahrer, "Is Virtual Reality Ready for Prime Time in the Medical Space? A Randomized Control Trial of Pediatric Virtual Reality for Acute Procedural Pain Management," *Journal of Pediatric Psychology*, vol. 43, no. 3, pp. 266–275, Apr. 2018, doi: 10.1093/jpepsy/jsx129.

[14] S. M. Alshatrat, J. M. Sabarini, H. M. Hammouri, I. A. Al-Bakri, and W. M. Al-Omari, "Effect of immersive virtual reality on pain in different dental procedures in children: A pilot study," *International Journal of Paediatric Dentistry*, vol. 32, no. 2, pp. 264–272, 2022, doi: 10.1111/ipd.12851.

[15] K. Arane, A. Behboudi, and R. D. Goldman, "Virtual reality for pain and anxiety management in children," *Canadian Family Physician*, vol. 63, no. 12, pp. 932–934, Dec. 2017.

[16] K. P. Wong, M. M. Y. Tse, and J. Qin, "Effectiveness of Virtual Reality-Based Interventions for Managing Chronic Pain on Pain Reduction, Anxiety," *Healthcare*, vol. 10, no. 10, Art. no. 10, Oct. 2022, doi: 10.3390/healthcare10102047.

[17] P. D. Austin *et al.*, "The short-term effects of head-mounted virtual-reality on neuropathic pain intensity in people with spinal cord injury pain: a randomised cross-over pilot study," *Spinal Cord*, vol. 59, no. 7, pp. 738–746, Jul. 2021, doi: 10.1038/s41393-020-00569-2.

[18] T. Jones, T. Moore, and J. Choo, "The Impact of Virtual Reality on Chronic Pain," *PLOS ONE*, vol. 11, no. 12, p. e0167523, Dec. 2016, doi: 10.1371/journal.pone.0167523.

[19] G. Karafotias, G. Korres, A. Teranishi, W. Park, and M. Eid, "Mid-Air Tactile Stimulation for Pain Distraction," *IEEE Transactions on Haptics*, vol. 11, no. 2, pp. 185–191, Apr. 2018, doi: 10.1109/TOH.2017.2781693.

[20] K. Chin, M. Thompson, and M. Ziat, "The Effect of Multimodal Virtual Reality Experience on the Emotional Responses Related to Injections," in *Proceedings of the 16th International Joint Conference on Computer Vision, Imaging and Computer Graphics Theory and Applications*, Online Streaming, --- Select a Country ---: SCITEPRESS - Science and Technology Publications, 2021, pp. 128–134. doi: 10.5220/0010195601280134.

[21] M. Matamala-Gomez, B. Nierula, T. Donegan, M. Slater, and M. V. Sanchez-Vives, "Manipulating the Perceived Shape and Color of a Virtual Limb Can Modulate Pain Responses," *Journal of Clinical Medicine*, vol. 9, no. 2, Art. no. 2, Feb. 2020, doi: 10.3390/jcm9020291.

[22] M. H. Johnson, "How Does Distraction Work in the Management of Pain?," *Current Science Inc*, vol. 9, no. 2, pp. 90–95, Mar. 2005, doi: 10.1007/s11916-005-0044-1.

[23] T. Takami, T. Saito, T. Kameoka, and H. Kajimoto, "ExtEdge: Haptic Augmentation of Visual Experiences of a Smartphone by Electro-Tactile Sensation Through the Edges," in *Proceedings of the 2023 ACM Symposium on Spatial User Interaction*, in SUI '23. New York, NY, USA: Association for Computing Machinery, Oct. 2023, pp. 1–8. doi: 10.1145/3607822.3614543.

[24] Z. Zhou, Y. Yang, J. Liu, J. Zeng, X. Wang, and H. Liu, "Electrotactile Perception Properties and Its Applications: A Review," *IEEE Transactions on Haptics*, vol. 15, no. 3, pp. 464–478, Jul. 2022, doi: 10.1109/TOH.2022.3170723.

[25] J. Piccione, J. Collett, and A. De Foe, "Virtual skills training: the role of presence and agency," *Heliyon*, vol. 5, no. 11, p. e02583, Nov. 2019, doi: 10.1016/j.heliyon.2019.e02583.

[26] M. Pyasik, G. Tieri, and L. Pia, "Visual appearance of the virtual hand affects embodiment in the virtual hand illusion," *Sci Rep*, vol. 10, no. 1, p. 5412, Mar. 2020, doi: 10.1038/s41598-020-62394-0.

[27] P.-H. Han *et al.*, "Haptic Around: Multiple Tactile Sensations for Immersive Environment and Interaction in Virtual Reality," in *Proceedings of the 24th ACM Symposium on Virtual Reality Software and Technology*, in VRST '18. New York, NY, USA: Association for Computing Machinery, Nov. 2018, pp. 1–10. doi: 10.1145/3281505.3281507.

[28] J. K. Gibbs, M. Gillies, and X. Pan, "A comparison of the effects of haptic and visual feedback on presence in virtual reality," *International Journal of Human-Computer Studies*, vol. 157, p. 102717, Jan. 2022, doi: 10.1016/j.ijhcs.2021.102717.

[29] I. Hwang, H. Son, and J. R. Kim, "AirPiano: Enhancing Music Playing Experience in Virtual Reality with Mid-Air Haptic Feedback," in *2017 IEEE World Haptics Conference (WHC)*, Jun. 2017, pp. 213–218. doi: 10.1109/WHC.2017.7989903.