The Role of Context-Stimulus Congruency in Pain Reduction Through Contextual Modification in Virtual Reality

Hibiki ONODA[1], Izumi MIZOGUCHI[1] and Hiroyuki KAJIMOTO[1]

[1] The University of Electro-Communications , 1-5-1 Chofugaoka, Chofu, Tokyo 182-8585, Japan
{onoda, mizoguchi, kajimoto}@kaji-lab.jp

Abstract. Distraction is a common non-pharmacological method for pain relief, but it has limited efficacy for severe pain and certain individuals. As an alternative, contextual modification—reducing subjective pain by reinterpreting the source of a painful stimulus—has been proposed. This study investigates the influence of congruency between a painful stimulus and a visually presented context on subjective pain perception using a Virtual Reality (VR) environment. Electro-tactile stimuli were delivered to participants' wrists while they viewed a synchronized VR context featuring a computer-generated cat. Three conditions were tested: no context, congruent context, and incongruent context. The congruent condition significantly reduced perceived discomfort and pain intensity compared to the incongruent condition, indicating that stimulus-context congruency is a critical factor for effective pain mitigation via contextual modification.

Keywords: Contextual Congruency, Contextual Modification, Pain Masking, Stimulus Cause, Virtual Reality.

1 Introduction

Drug-based analgesics such as opioids are effective for pain relief but carry well-known side effects including dizziness, nausea, and dependence[1], [2]. Consequently, many people undergoing pain management therapy are hesitant to use such medications due to concerns about side effects and the duration of efficacy. This has led to a demand for non-pharmacological coping strategies to control pain without the use of anesthetics or analgesics.

Distraction is one widely used approach, reducing pain perception by diverting attention [3], [4]. While effective in clinical settings [5], [6], [7] for both acute [8], [9] and chronic pain [10], [11], [12], it fails for intense pain [13] and is difficult to apply to individuals with high fear of pain [14].

To address this issue, Onoda et al. proposed a novel pain-reduction technique called "pain masking using contextual modification" [15], [16]. This method aims to reduce subjective pain by visually replacing the cause of pain with content that is not unpleasant to humans. Their prior work confirmed that temporal synchronization between the visual and pain stimuli is important. However, it remained unclear whether pain reduction resulted from true contextual modification or merely distraction. To resolve this, one must verify content-specific congruence between the pain stimulus and the presented context.

In this study, we prepared multiple stimulus types and visual contexts in VR. By systematically varying congruence between the pain stimulus and the context, we examined how content-specific consistency affects subjective pain. Electrical stimulation was paired with cat animations (scratching and biting) to create congruent and incongruent conditions.

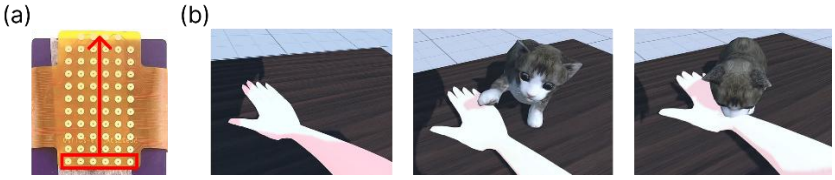

Fig. 1. (a) Stimulus patterns presented. (b) Conditions used in this experiment. From left to right: nothing, scratch, bite.

2 System Overview

The apparatus comprised a Vive Tracker for hand tracking, a Head-Mounted Display (Meta Quest 3) for VR presentation, a control PC, and an electro-tactile device for wrist stimulation(Fig. 2 (b)).

The electrotactile device delivers electrical pain stimuli to the participant's wrist via a 64-electrode array (1 mm diameter, 2.5 mm pitch), mounted beneath the Vive Tracker. Stimulus activates a horizontal electrode row that sweeps upward at 30 ms/row (one "loop" = 300 ms); pulse width was 50 μs at up to 10 mA (Fig. 2 (b) (c)).

Participants were immersed in a Unity 3D environment containing a gender-neutral full-body avatar and a cat (Fig. 2 (d)). Head and hand positions were tracked via the HMD and Vive Trackers. The cat performed either a scratching or biting motion synchronized with the electrical stimulus, aiming to reframe the sensation as a cat interaction rather than an electric shock.

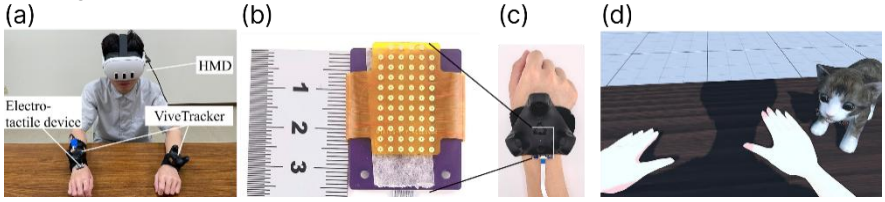

Fig. 2. (a) Experimental setup. (b) Stimulation electrode placement. (c) Location of stimulation electrodes. (d) VR space.

3 Method

This experiment investigated the effect of visual-context congruence on pain reduction. It used an instantaneous pain stimulus. This experiment was approved by the Ethics Committee of the University of Electro-Communications (H24013), and all participants provided informed consent prior to their participation.

This experiment enrolled 18 participants (5F, 13M; aged 21–31). This session began with a one-minute reaching task to enhance the sense of agency, followed by individual stimulus calibration: intensity was increased in 0.1 mA steps until the participant reported discomfort, and that threshold was used throughout.

Three conditions were presented in randomized order (Fig. 1 (b)): (1) "Nothing"—no cat displayed; (2) "Scratch"—cat performs a scratching motion synchronized with the stimulus

(congruent for instantaneous, incongruent for continuous); (3) "Bite"—cat performs a continuous biting motion (congruent for continuous, incongruent for instantaneous). In Experiment 1, the instantaneous stimulus was delivered five times (one loop each, every 3 s) per condition.

After each condition, participants completed a 7-point Likert questionnaire (Q1–Q7) assessing: felt as electrical stimulus (Q1), felt as caused by the cat (Q2), unpleasantness (Q3), pain intensity (Q4), cat's sense of presence (Q5), correspondence between stimulus and animation (Q6), and sense of virtual hand ownership (Q7). For Q3, ratings were anchored relative to the "nothing" baseline (= 4).

4 Result

Data were analyzed using the Friedman test followed by Wilcoxon signed-rank post-hoc tests with Bonferroni correction. Results for experiment is shown in Fig. 3.

Significant differences between scratch and bite conditions were found for Q1 (felt as electrical: $p < 0.05$), Q2 (caused by cat: $p < 0.05$), Q3 (unpleasantness: $p < 0.05$), and Q4 (pain intensity: $p < 0.05$). Presenting the congruent scratching animation reduced unpleasantness and pain relative to the nothing condition, while the incongruent biting animation paradoxically increased them. Participants also correctly discriminated congruence levels (Q6, $p < 0.01$).

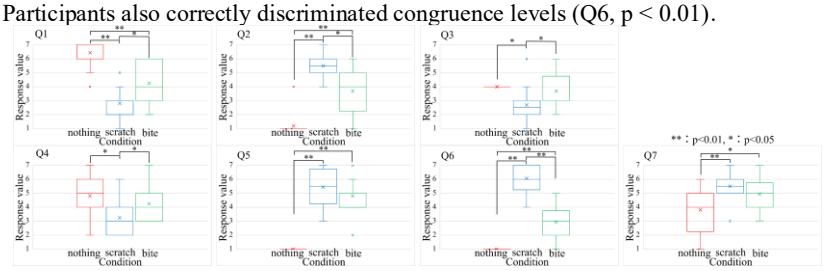

Fig. 3. Results of Experiment.

5 Discussion

Congruent stimulus-context pairings consistently outperformed incongruent pairings in reducing pain and discomfort, supporting the importance of content-specific consistency in contextual modification. Ten participants found the scratching animation convincing for the instantaneous stimulus. Some participants reported no incongruence in the mismatched conditions, possibly due to the periodic stimulus presentation structure.

6 Open Research Questions and Interdisciplinary Exchange

Our VR-based pain study suggests that congruency between stimulation and presentation context is important for cognitive pain relief. However, evaluation was limited to questionnaires. We invite cognitive psychologists to discuss additional assessment measures beyond self-report. Furthermore, we are actively seeking collaborators with a neuroscience background to establish more comprehensive cognitive indices.

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