Doctoral dissertation
博士論文

A Study on Effects of Small FOV Telescope Environment in Virtual Reality Headset
（バーチャルリアリティヘッドセットを用いた視野角縮小による
仮想望遠環境の影響に関する研究）

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学位論文の要旨

近年，バーチャルリアリティ（以下，VR と表記する）デバイスの低価格化，コンテンツ制作環境の整備，VR を扱える人材の増加など様々な要因により，ゲーム・建築・教育・アート・医療など幅広い分野での VR の利用が進んでいる．VR の産業応用として VR の医療分野での利用は注目されている活用方法の一つである．CT スキャンデータなどの 3 次元情報を用いた VR 手術シミュレーション，医療現場や器具等を VR で再現することにより低コスト及び効率的に研修を行う医療教育分野での VR 利用，認知症や統合失調症等の患者に見られる症状を疑似体験することにより病気の正しい理解を促す疾患啓発への VR 利用，VR による暴露療法を用いた恐怖症やトラウマ治療，患者の注意を疼痛からそらすディストラクションと呼ばれる疼痛緩和法への VR 利用，VR デバイスを認知行動療法に用いた摂食障害の改善など多くの領域において VR の医療分野での活用が期待されている．VR を用いた疼痛緩和は近年の VR デバイスの低価格化により実際の医療現場での利用が進みつつある．人間が注意を向けることのできる能力は限られており，VR コンテンツに集中している間は他の外的刺激を処理する能力が減少するため，鎮痛効果があると考えられ VR ディストラクションと呼ばれる．

私は VR ヘッドマウントディスプレイ（以下，VR-HMD と表記する）を用いてコンテンツを表示する際に仮想カメラの視野角を極端に小さくすると，ディストラクションによる鎮痛効果が増進すること，コンテンツが被験者へ及ぼす心理的影響が大きくなることを発見した．VR 内の仮想カメラの視野角を小さくした状態で表示されるコンテンツは，望遠鏡を利用して遠方にあるコンテンツを覗き込んだのと同じように表示される．現実の望遠鏡では望遠鏡自身が少し動くだけで対象物が視野の外に移動してしまう．仮想カメラの視野角を小さくした場合も同様に VR-HMD の少しの動きが対象を視野の外に移動させてしまうため，コンテンツの閲覧には VR-HMD が動かないようする必要がある．私は、本提案手法が被験者に多くの集中力を必要とさせることに注目し，VR を用いた鎮痛効果向上を医療応用することを念頭に研究を行った．本研究で提案する手法は我々の研究以前に先行事例がない。また，VR-HMD にハードウェアの変更を加えることなくソフトウェアだけで環境を構築できること，既に世の中に多く存在する画像や映像など二次元の素材をコンテンツとして提示する手法であることなど，実際の医療現場での利用を想定した場合に非常に革新的な手法であると考えられる．

本学位論文は 6 章からなる．第 1 章では本学位論文の背景と目的について述べるとともに，本研究において提案する仮想カメラの視野角を極端に小さくした環境で VR-HMD を用いてコンテンツを表示する手法（以下，仮想望遠手法と呼ぶ）について述べる．横 8m 縦 6m のスクリーンを 1,200m 先の遠方に設置し視野角 2 度の望遠鏡でスクリーン上に表示されたコンテンツを閲覧する手法である。

第 2 章では，仮想望遠手法を用いた場合の被験者の痛み耐性への影響を調査した．痛み耐性の計測にはコールドプレッサーテストを用いた．コールドプレッサーテストは氷水の中に手を浸し，耐えられなくなり手を氷水から上げるまでの時間を痛み耐性指標として用いる手法である．実験の結果，仮想望遠手法を用いた場合に平均 1.66 倍コールドプレッサーテストの値が高く，t 検定を用いた解析でもより長い時間痛みに耐えることができることが統計的に示された．最も痛み耐性の変化が見られた被験者では仮想望遠手法を用いた場合，用いなかった場合に比べコールドプレッサーテストの値が 5.54 倍であった．仮想望遠手法の影響を顕著に受ける被験者がいる一方，約 3 分の 1 の被験者の痛み耐性に変化を認められなかった．

第 3 章では，被験者ごとの仮想望遠手法の影響差の要因を調べるため，コールドプレッサーテストと催眠感受性の相関を調査した．催眠感受性は催眠誘導への反応性や親和性を示す指標で，その計測には，スタンフォード催眠感受性スケールの日本語版を用いた．日本催眠医学心理学会認定催眠士の有資格者が被験者あたり約 60 分をかけて 1,体位動揺　2,閉眼　3,手の下降(左)　4,腕の運動不能(右)　5,指の組付　6,腕の硬直(左)　7,両手の運動　8,言語抑制(名前)　9,幻覚(蝿)　10,瞼硬直　11,後催眠　12,健忘テストの 12 項目を評価した．コールドプレッサーテストの値と催眠感受性は相関係数 0.344 の弱い相関を示した．被験者が催眠からの覚醒後に一定の行動を取る暗示である後催眠との相関係数は 0.417 と催眠感受性評価項目の中で一番強い相関を示した．

第 4 章では，仮想望遠手法の心理影響を評価した．仮想望遠手法を用いた場合と用いない場合の刺激画像に対する心理影響を比較した．表示するコンテンツは心理実験で広く使われる画像セットである International Affective Picture System (以下，IAPS と表記する)を用いた．IAPS は感情喚起刺激として画像ごとに感情価 (pleasure)，覚醒 (arousal)，支配性 (dominance)の 3 つの尺度で評価されている画像セットであるが，その中から覚醒度合いの最も高いものから 20 枚と低いものから 20 枚の計 40 枚の画像を実験に用いた．心理影響の評価手法として Self-Assessment Manikin を用い，画像提示による心理変化を 12 名の被験者が主観的に 9 段階で評価した．実験の結果，仮想望遠手法を用いたコンテンツ提示が被験者の覚醒度合いをより強まることが確認された．

第 5 章では，仮想望遠手法が心理影響を強めている原因を探るため，仮想望遠手法を用いた際にどれだけ VR-HMD が安定した状態で固定されて利用されているかを調査した．仮想望遠手法を用いてコンテンツを提示している 100 秒間の間に，VR-HMD がどれだけ動いたかを記録し解析を行った．本実験では 100 秒の間継続してコンテンツを提示するため動画を用いた実験を行った．VR-HMD の動きは縦方向及び横方向の回転角度を記録し，仮想望遠手法を用いた場合とそうでない場合を比較した．実験の結果，仮想望遠手法を用いた場合の方が中心点からの回転角度合計は 0.50 倍と小さく t 検定においても有意差が得られ，被験者は VR-HMD を動かさずより安定した状態で利用していることが示された．被験者は

VR-HMD 固定のためにより多くの集中力を要していると考えられ，そのことが被験者の心理状態に影響を及ぼしていると考えられる．

第 6 章では，本研究を総括し結論を述べた．本提案手法の有効性を明らかにするだけでなく，研究成果の医療現場での臨床応用に関してなど今後の展望を述べるとともに，残された課題について議論する．実験によって得られた結果から，本研究で提案する仮想望遠手法はコンテンツの被験者への心理影響を強めること及び被験者の痛み耐性を高めることが示された．我々の考案した本提案手法は過去に先行研究事例がないため，引き続き研究を重ねることで VR の鎮痛作用や心理影響を効果的に高める手法を確立するとともにその有効活用を推し進める予定である．

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Chapter 1.
Introduction

1.1. Background

Low cost and high-quality Virtual Reality Head Mounted Displays (VR-HMDs) are getting popular and used for various applications in these days. As more people use VR-HMDs for longer time, psychological impacts are considered as one of important factor for healthy growth of VR industry. Side effects of VR such as nausea, oculomotor and disorientation symptoms are one of concerns for long period of usage of VR. Sharples et al. shows induced more symptoms and effects comparing to other displaying devices such as desktop, projection and theatre screen [1].

On the other side, VR is used in medical treatment with its positive psychological effect as well as in surgery training and simulation field[2]. Exposure therapy is used for panic disorder[3], arachnephobia[4], acrophobia[5] as well as claustrophobia[6][5] with VR and shows its effectiveness[7]. The mechanism of exposure therapy was explained with emotional processing which is modification of memory structure of the characteristic of the fear situation, the individual's response and aspects of its meaning. In order to change the structure of the fear, fear-relevant information needs to activate the fear memory and new incompatible memory must be integrated[8]. Virtual environment needs to be realistic to activate fear memory for exposure therapy.

Cognitive behavioral therapy is another approach of the usage of VR for medical treatment. In the allocentric lock theory, negative body image is thought to cause obesity and eating disorders, and it is suggested that VR can be used to induce a controlled sensory arrangement that facilitates an update of the locked allocentric negative body Image. Experiencing body with third person view in VR is used to induce the update in the therapy[9].

VR is also widely studied for pain reduction. Impact of psychological factors on the effectiveness of VR-based analgesia to distract from pain was analyzed and concluded that presence, fun, and anxiety influence VR efficacy [10]. Hunter G et al. applied VR as analgesic for burn injured patients to reduce procedural pain. Interactive immersive VR contents was used and reported significant reductions in procedural pain [11][12]. The mechanism of pain reduction was discussed that pain requires cognitive attention[13] and humans have limited attentional capacity[14] and patients have less attention available to process incoming signals from pain receptors while in VR [15]. The method of directing attentions to others to distract pain is called distraction and used as a psychological pain intervention. It has been shown considerable efficacy[16]. Deep breathing, music, video and games etc. are being used as typical distraction interventions[17], and VR as a method of pain reduction have now growing interests.

Effectiveness of VR distraction for reducing pain has been studied with various conditions to obtain strong analgesic effect. Comparative experiments with interactive and passive distraction using VR shows that interactive distraction condition was significantly more effective although both distractions were effective. Video game was used as an interactive distraction and pre-recorded game play was used as a passive distraction material in the study[18]. Influences of display quality of VR-HMD was compared with thermal pain stimulus by Hoffman et al., and it is shown that High-Tech-VR helmet reduces pain more effectively. It hypothesized that high quality equipment makes greater presence by greater VR immersion and produce more pain reduction[19]. Hoffman et al. reported that pain reduction was correlated presence in VR[20]. However, pain tolerant study with avatar point of view shows no pain-tolerance score difference even though subjects feel more presence with first person view[21]. The result indicates that high presence is not a necessary factor for VR distraction. As the previous studies have shown, interactive VR contents and high-quality VR-HMD induce greater pain reduction, however the cost demanding environment may matter in the actual clinical sites.

Although passive contents work less effective in pain distraction comparing to interactive contents, it reduces pain significantly, however, subject group with passive contents show habituation to the analgesic effect. The effect of distraction attenuates over several sessions[22]. Even current interactive VR-based treatments use pre-defined scenarios that are fixed for all patients, so treatments have limited possibilities for personalizing[24][25]. It is suggested that increased attention to individual characteristics are required for future study of VR use for pain control[26]. i Badia, Sergi Bermudez, et al. prepared a software and hardware setup generating personalized 3D maze from bio sensor inputs[23], however it obviously requires sensor attachment.

1.2. Uniqueness of the study

We discovered that pain tolerance increases when subjects watch contents with very small value of field of view (FOV) of a virtual camera in VR environment. Contents displayed with very small value of FOV of a virtual camera look similar to the contents viewed with telescopes. The method to display contents with the very small FOV was named “Virtual telescope method” in this study.

I proposed the newly developed “Virtual telescope method” and asses the pain reduction effectiveness of the method. This proposed method was not studied in the past except our research.

The method is also considered to have advantages for practical usage in actual medical fields. Two dimensional images or videos can be used with the method, and no hardware modification is required to use the method. These usages may let deploying the method in medical clinics easier. Ordinal two-dimensional photos or videos can be used, which means that expensive VR contents creation is not needed. The proposed virtual telescope method can be thought as an innovative pain reduction method in the actual medical field.

1.3. Virtual telescope method

Smartphone-based VR goggles were used, and iPod touch was set to the goggles. The setups were used as VR-HMDs in this study. The VR-HMD was connected to PC, and contents created in the PC were displayed on the screen of the VR-HMD.

Hacosco Tatami 1-gan (Figure 1-1) was used for the first experiment and ELECOM P-VR1G01 (Figure 1-2) was used for the rest of the experiments. Both goggles are monocular lens goggles.

Figure 1-1. Hacosco Tatami 1-gan

Figure 1-2. ELECOM P-VR1G01

Unity game engine was used to develop dedicated software for the virtual telescope method. Gyro information on VR-HMD was sent to PC, and contents to display were created based on the information. FOV of a virtual camera in VR environment is set to the actual FOV of VR-HMDs in usual cases. However, we manipulate the value of FOV of the virtual camera in order to change the view of the VR-HMDs. The value of the FOV was changed to extremely small value 2° instead of 108° which is the same as actual FOV of VR-HMDs. FOV is described as the open observable area a person can see through his or her eyes or via an optical device. In the virtual telescope method, only FOV of a virtual camera was manipulated, and the actual FOV of VR-HMDs was not changed. Using the setup, the view in the VR-HMDs become similar to a view of telescopes. As the same as actual telescope, the view is very sensitive to the movement of the apparatus. With the 2° set up for the virtual telescope method, only 2° movement makes targets in the view go out of the range. 8m x 6m virtual screen was located in the virtual environment, and contents were displayed on the screen. In the normal environment, the screen was located at 4m distance from the viewpoint. On the other hand, the screen was located 1,200m away from the viewpoint when the virtual telescope method was used. These two environments were switched by the software during the experiments.

The screen is 8m x 6m flat screen, and two-dimensional contents were displayed on the screen for the experiments. Photos, videos and target markers were used as 2D contents to display on the virtual screens.

Table 1-1. Parameters of normal and virtual telescope method

Type	Screen size	FOV	Distance
Normal	8 x 6m	108°	4m
Virtual Telescope Method	8 x 6m	2°	1,200m

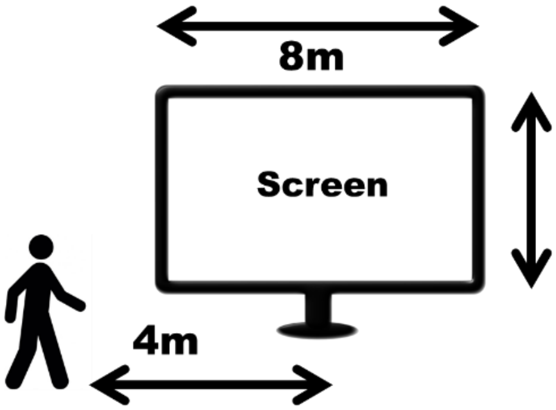

Figure 1-3. Schematic drawing of normal environment

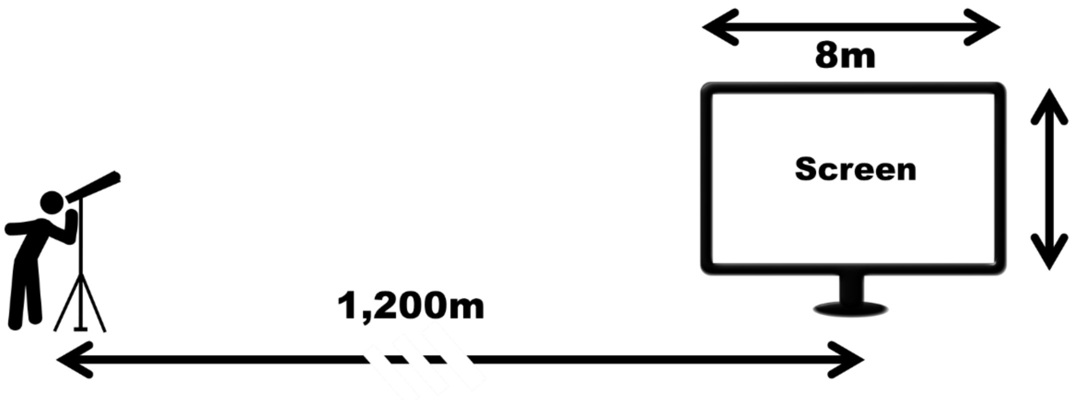

Figure 1-4. Schematic drawing of the virtual telescope environment

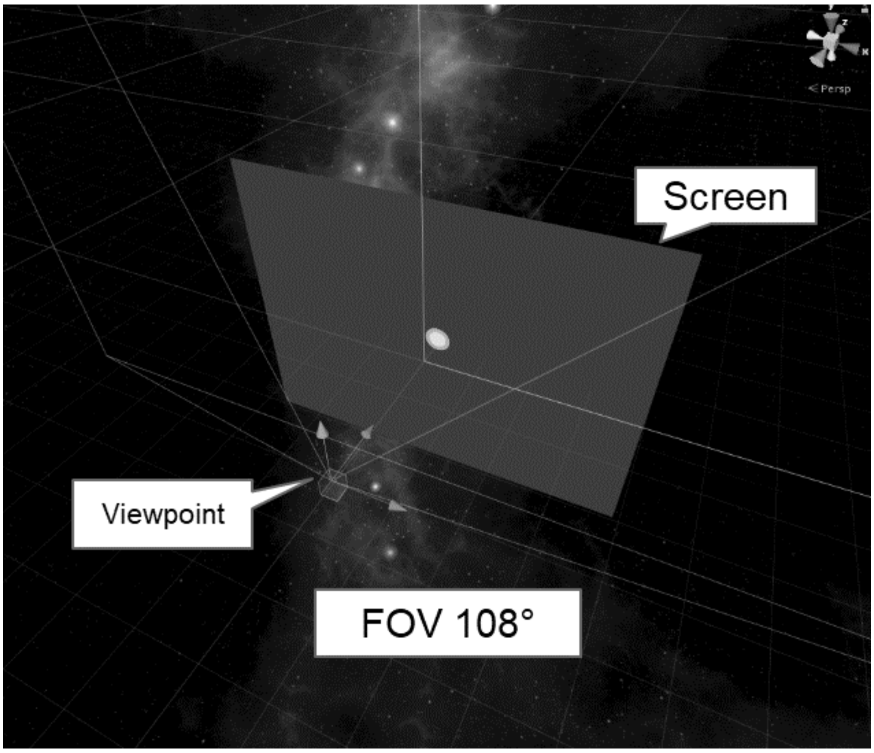

Figure 1-5. Bird's-eye view of normal environment

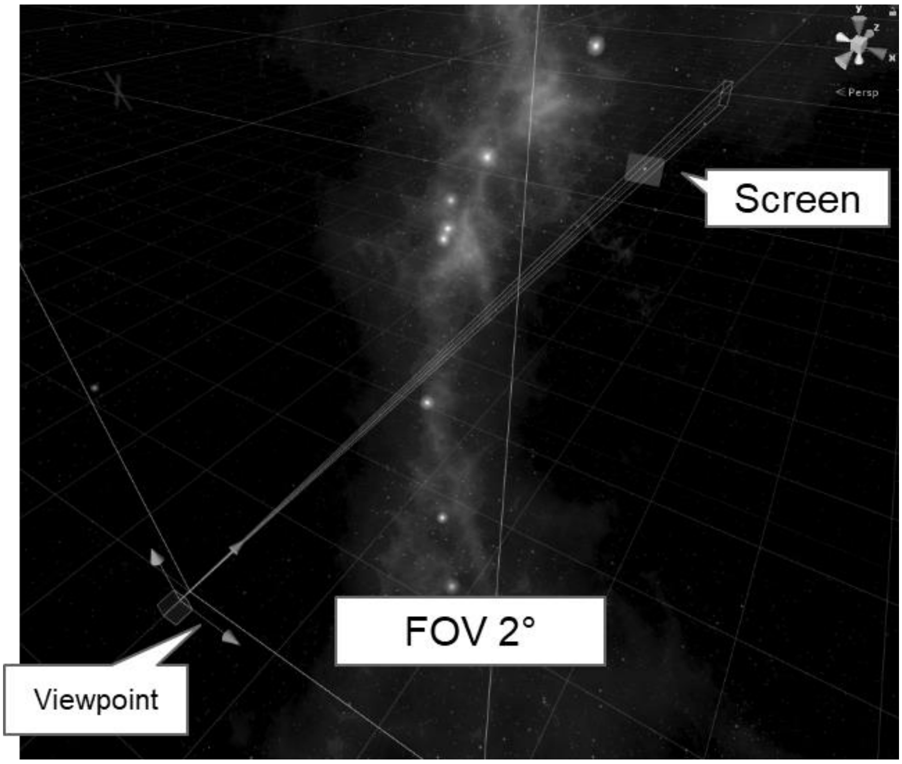

Figure 1-6. Bird's-eye view of the virtual telescope environment

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Chapter 2.
Pain Tolerance Experiment

2.1. Introduction

VR distraction is widely studied as pain reduction with various conditions[1][2]. It is known that interactive contents induce greater effect than passive contents[3] and high-quality VR-HMD induces greater effect than low-quality VR-HMD[4]. Presence is considered as an important factor of the effectiveness of distraction of pain[5].

The virtual telescope method requires much attention to keep screen in subjects' view, which is expected to work as a distraction tool to reduce pain since patients will have less attention available to process pain[6]. Subject's view with the virtual telescope method is like telescope and was not designed to generate high presence to subjects. We carried out the experiments to examine whether the virtual telescope method works as pain distraction although it doesn't induce high presence to subjects.

2.2. Methods

2.2.1. HMD

Smartphone based HMD was built up with 5.8-inch smartphone and VR Headset (ELECOM P-VR1G01WH). The HMD is 20.3 x 19.3 x 11.8 cm size and 482g light weight including the smartphone. Subjects wear the HMD, and the HMD displays contents based on its gyroscope. The HMD is connected to a PC, which controls the contents of the HMD and records logs of the experiment. We used monocular lens goggles instead of binocular lens used for typical VR goggles since binocular lens VR-HMD is not recommended for people under 13 years old because of the risk of crossed eyes. This study is expected to be used for children as well as adult people.

2.2.2. Virtual screen and FOV

FOV (Field of view) of a virtual camera was manipulated in VR HMD to change the view of contents for subjects. Decreasing FOV makes view of angle narrow, therefore the view in VR is similar to telescope, in which environment the view moves a lot with even small movement.

With smaller value of FOV for a virtual camera, the view in VR is more sensitive to HMD movement and requires subjects to keep concentrating not to move their heads to watch target images properly.

8m x 6m flat screen was located at 1,200m from eyes in virtual environment with 2°FOV virtual camera, which works like telescope view. With the virtual telescope method, only 2°movement of the HMD makes the screen out of the view.

2.2.3. Software

Software for the experiment was installed to a smartphone, and the smartphone was attached to a VR headset, which was used as a VR-HMD. The VR-HMD was connected to a PC, which controls the display of the VR-HMD based on its gyroscope. The software shows a virtual screen with a target marker in VR and displays a sight marker at the center of the view as shown in Figure 2-1. The created visions look identical in both normal and telescope environments when subjects face the screen, but the screen moves more in telescope environment with HMD movements.

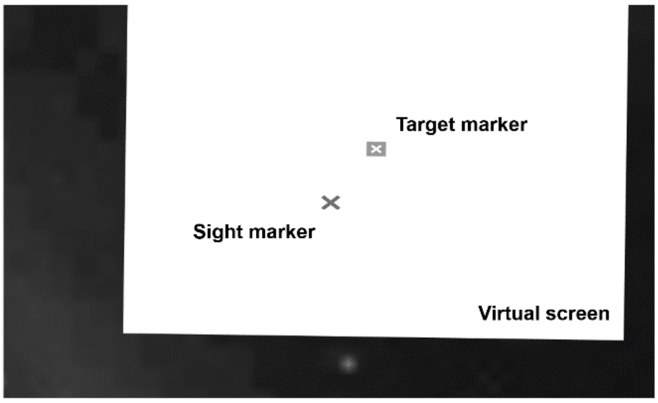

Figure 2-1. Displayed contents screenshot in VR-HMD with annotations

2.2.4. Cold pressor test

Hand immersion into cold water is a standard test for pain tolerance evaluation and is known as the cold pressor test. Wash ball (φ315) was prepared and filled with water and ice for the experiment as shown in Figure 2-2. Participants were asked to place their hand in the cold water until the pain is unbearable. Duration time until subjects removed their hand out of cold water was recorded as pain tolerance. Temperature of water and tolerance time in cold pressor test was studied by Laura M et al.[7]

Figure 2-2. Cold pressor test set up

2.2.5. Procedure

The experiment was carried out in a calm room as shown in Figure 2-3. so that subjects can focus on the VR display and be affected only by the contents of the experiment. Subjects were briefly explained about the procedure of the experiment, but the expected outcome or the purpose of the experiment were not explained to the subjects to avoid the bias of the result. Subjects were told to put their hand into cold water with ice until they cannot keep it due to the cold temperature.

The temperature of the water with ice was kept 0.4℃ in the experiment room. After each trial, we waited for several minutes to keep the temperature same to maintain the condition of the experiment.

Each subject was asked to put their hand twice in total in the experiment. One trial was performed with VR-HMD with the virtual telescope method, and the other trial was performed without VR-HMD. To avoid the effect of the order of the trial and hand dominance, the order of the with/without VR-HMD and the order of the left/right hand was shuffled before the experiment.

After subjects kept a relaxing posture, virtual screen was displayed just in the direction of the eyes of the subject controlled by an operator at the beginning of the trial with VR-HMD. Subjects were asked to try keeping the sight maker close to the target marker on the virtual screen in the virtual telescope environment while they keep putting their hand in the cold water. The duration time of the tolerance of each trial was recorded along with the subject information. Subjects took enough rest for the next trial until they didn't feel coldness of the previous trial on their hand.

The recorded data was analyzed with paired t test to see whether the telescope virtual screen environment affects tolerance of pain.

Figure 2-3. Experiment setup including Smartphone based VR-HMD, controller PC, water with ice in wash ball.

2.3. Result and consideration

14 working adult volunteers (10 males and 4 females) were participated in the experiment as subjects. Ages are 25 to 52 years old, and 28 data was obtained and analyzed in total. Figure 2-4 is a box-and-whisker plot of the data, which shows that tolerance duration of the cold pressor test with VR-HMD tends to be longer than the duration without VR-HMD. Mean value of the duration with VR-HMD was 66% longer than the duration without VR-HMD. 78.6% of subjects kept their hand for longer time with VR-HMD. 21.4% of subjects endured the cold temperature with VR-HMD for more than double of the duration without VR-HMD, and the duration increased 120.8 seconds at most as shown in Table 2-1. Variance of the duration with VR-HMD was 1479.12 which is 5.4 times greater than the variance of the duration without VR-HMD.

P value of the paired t test was 0.04, which indicates that the effect of VR-HMD with the virtual telescope method was statistically significant.

The result indicates that the virtual telescope method increases the tolerance of subjects even without meaningful contents displayed on a screen. This method could be used as a contents independent pain management for medical usage as well as controlling technique of concentration. Customized contents would not need to be prepared for each type of pains.

However, it is needed to be considered that some of people would not be affected by the method. The method significantly worked for certain subjects comparing to others. Tolerance was increased more than double for 3 subjects, however, change rate of the tolerance was less than 10% for 5 subjects as shown in Figure 4 5. This result implies that the effectiveness of the method varies from subjects' characteristics.

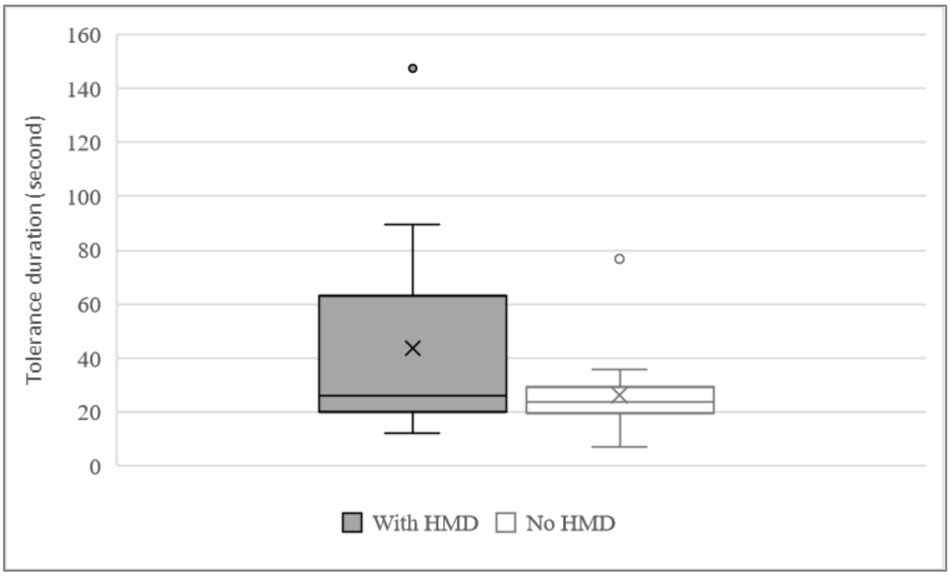

Figure 2-4. Box-and-whisker plot of tolerance duration with and without VR-HMD

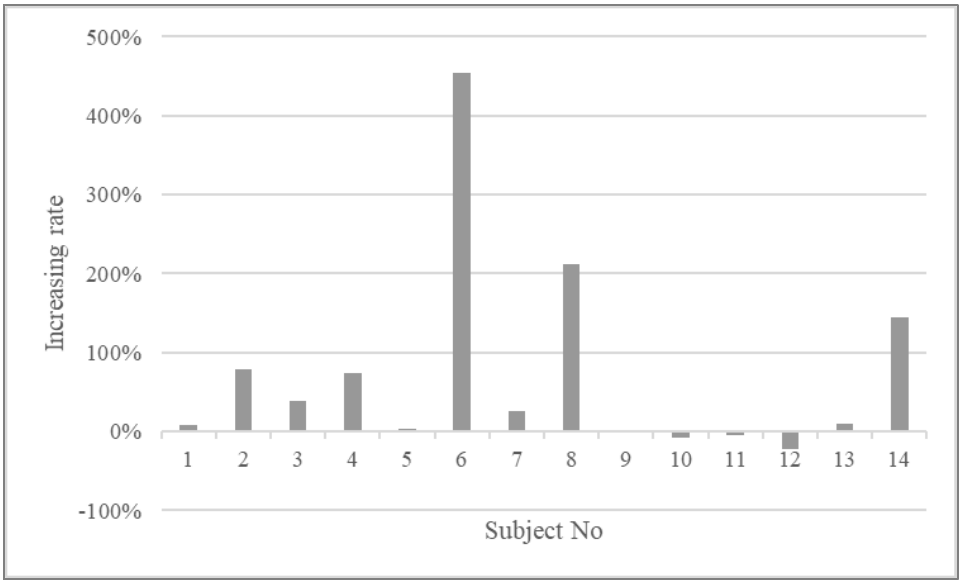

Figure 2-5. Plot of increasing rate of tolerance duration with VR-HMD for each subject

Table 2-1. Recorded and analyzed data of tolerance duration with and without VR-HMD

Subject No	With HMD	No HMD	Increase rate
1	83.30	76.80	1.08
2	17.20	9.60	1.79
3	32.60	23.40	1.39
4	12.30	7.10	1.73
5	24.70	23.90	1.03
6	147.40	26.60	5.54
7	39.30	31.40	1.25
8	89.40	28.70	3.11
9	21.40	21.30	1.00
10	22.90	24.70	0.93
11	21.00	22.00	0.95
12	27.90	36.00	0.78
13	15.90	14.40	1.10
14	56.30	23.10	2.44
Mean	43.69	26.36	1.66
Variance	1479.12	271.98	-
Pearson Correlation	0.44		-
df	13		-
t Stat	1.88		-
P(T<=t) one-tail	**0.04***		-

* $p<0.05$

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Chapter 3.
Relationship with Hypnotic Susceptibility

3.1. Introduction

Pain tolerance experiment shows that the virtual telescope method increases pain tolerance in cold pressor test. However, the effect of the method varies to subjects. Mahrer et al. suggested that future studies in VR requires attention to individual user characteristics[1]. We assume that the dispersion of the result is caused by the characteristics of the subjects. In this study, we carried out an experiment to explore the reason of the dispersion of the result. Hypnotic susceptibility test was carried out, and the result was analyzed with the result of cold pressor test experiment. Experimental data of our previous cold pressor test was used as well as additional experiments for five more subjects.

Hypnotic analgesia is being used in clinics to control dental pain and explained with an endogenous pain inhibitory mechanism within the central nervous system[2]. Subjects with hypnotic susceptibility group reported the use of more cognitive strategies during the retest and showed greater pretest-to retest pain magnitude reductions than did low susceptible[3].

Case report evaluates virtual reality hypnosis in treating chronic neuropathic pain shows that reductions and the duration of treatment effects following VRH treatment were superior to those following a trial of standard hypnosis (non-VR) treatment[4]. Patients treated with VR and posthypnotic suggestions reported less pain intensity and less pain unpleasantness compared to patients treated with VR distraction without hypnotic suggestion[5].

3.2. Methods

3.2.1. Cold pressor test

Same setup and procedures of the previous experiment in chapter 2 were used for cold pressor test. New experimental data was collected for 5 subjects, and the data of 4 subjects were used from the previous experiment.

3.2.2. Hypnotic susceptibility test

Hypnotic susceptibility scale is a test to define the ability of a subject to be induced to hypnotic state. In this study, translated version of “Stanford Hypnotic Susceptibility Scale” [7]was used for the experiment, and each subject was evaluated in 13 scales. This standardized scale is widely used in experimental studies of hypnosis. The test to the subjects was performed by a qualified hypnotic operator of the Japanese Society of Hypnosis.

3.2.3. Procedure

Hypnotic susceptibility tests were performed individually in a dim and quiet room, and it took about 60 minutes to complete for each subject. Subjects were asked to sit on a chair, and a hypnotic operator sat on another chair near the subject. Subjects were briefly explained about hypnosis and the test. The operator read the instruction of the hypnotic susceptibility scale to induce the subjects, and scores were recorded for 12 items in total. The test consists of 12 hypnotic suggestions, and the response was recorded as 0 or 1 point for each item. Hypnotic susceptibility was evaluated as a sum of the points for each subject. Higher score means that the subject is more responsive to hypnosis. The test consists the following 12 items. 1.Postural Sway, 2.Eye Closure, 3.Hand Lowering (left), 4.Immobilization (right arm), 5.Finger Lock, 6.Arm Rigidity (left arm), 7.Hands Moving Together, 8.Verbal Inhibition (name), 9.Hallucination (fly), 10.Eye catalepsy, 11.Post-hypnotic (changes chairs), 12.Amnesia.

3.3. Result and consideration

9 volunteers (6 males and 3 females) were participated in the experiment as subjects. 6 subjects are working adults and 3 subjects are students. Ages are 23 to 52 years old. The result of the cold pressor test was shown in Table 3-1, and the result of the hypnotic susceptibility test was shown in Table 3-2. Correlation coefficient of total and each item of the hypnotic susceptibility test was calculated and shown in the table. Weak correlation was found between the increase rate of tolerance time using the virtual telescope method and the hypnotic susceptibility of each subject. The correlation coefficient with the total score was 0.344, and the value of the most correlated item was 0.417 with No 11. Post-hypnotic suggestions.

Table 3-1. Tolerance time of cold pressor test

Subject No	1	2	3	4	5	6	7	8	9
With HMD (second)	89.4	17.2	21.4	32.6	21	56.3	16	6.71	28.38
Without HMD (second)	28.7	9.6	21.3	23.4	22	23.1	13.23	22.5	22.4
Increase rate	**3.11**	**1.79**	**1.00**	**1.39**	**0.95**	**2.44**	**1.21**	**0.30**	**1.27**

Table 3-2. Score of hypnotic susceptibility test and correlation coefficient

Subject No	1	2	3	4	5	6	7	8	9	Correlation coefficient
1, Postural Sway	1	1	1	0	0	1	1	1	0	0.259
2, Eye Closure	1	1	1	0	0	1	1	1	0	0.259
3, Hand Lowering	1	1	1	0	0	1	1	1	1	0.217
4, Immobilization	0	1	0	0	0	0	0	0	0	0.131
5, Finger Lock	0	1	1	0	0	1	0	0	0	0.220
6, Arm Rigidity	0	1	1	0	0	1	0	0	0	0.220
7, Hands Moving Together	0	1	0	0	0	1	0	0	0	0.415
8, Verbal Inhibition	0	0	1	0	0	1	0	0	0	0.150
9, Hallucination	0	1	0	0	0	1	0	0	0	0.415
10, Eye catalepsy	0	0	1	0	0	1	0	0	0	0.150
11, Post-hypnotic	0	0	0	0	0	1	0	0	0	0.417
12, Amnesia	0	1	0	0	0	0	0	0	0	0.131
Total score	**3**	**9**	**7**	**0**	**0**	**10**	**3**	**3**	**1**	**0.344**

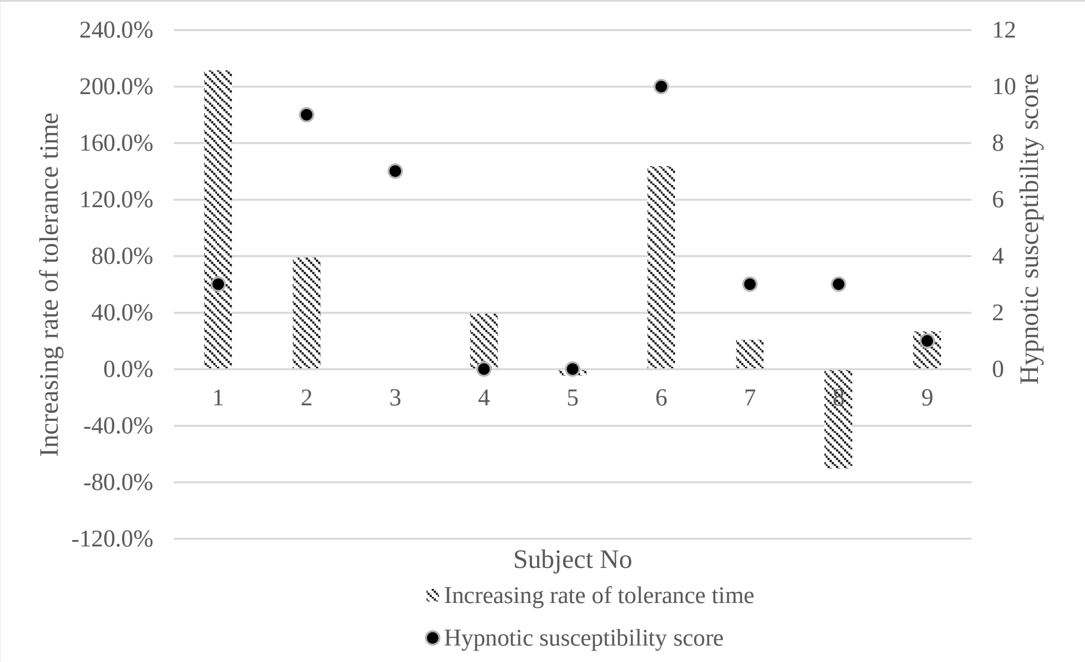

Figure 3-1. Increasing rate of tolerance time and Hypnotic susceptibility score

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Chapter 4.
Emotional Evaluation Experiment

4.1. Introduction

Cold pressor experiment shows effectiveness of pain distraction of the virtual telescope method in the previous chapter. In order to achieve greater pain reduction, further experiments were studied to explore the characteristics of the method to improve its effect.

Emotional effect was examined with pictures displayed with the virtual telescope method. The emotional response was evaluated with Self-Assessment Manikin (SAM) [1] using International Affective Picture System (IAPS)[2] as stimulus. SAM is a questionnaire that assesses valence/pleasure (unpleasant-pleasant), arousal (calm-excited) and dominance with 9 ratings respectively. IAPS is a collection of photographic images classified into affective categories using average ratings of affective valence/pleasantness and arousal.

Rhudy et al. studied emotional modulation of pain responses and showed that picture-evoked emotional valence led to this pattern of pain modulation, whereas picture-evoked arousal determines the degree of modulation[3]. Pleasant inhibits pain responses, and unpleasant facilitates pain responses. Greater arousal induces greater inhibition/facilitation. If increased subjective arousal is observed with the virtual telescope method, there might be additional explanation to the reason of the effectiveness of the pain reduction of the method.

Evoked arousal enhancement was studied in different conditions in previous studies. Emotional arousal was analyzed with 2D images and 3D converted same images by Kawai T. et al., resulted that evoked arousal was greater with 3D images. Estimates of time are longer when 3D and disparity modified stimuli are presented for longer durations[5][6]. Reeves, Byron, et al. studied the effects of screen size and message content on attention and arousal. The result of the experiment suggest that screen size can increase attention and arousal regardless of content[7]. Note that the tendency is significant in the case of images classified as evoking high arousal in both studies. IAPS pictures were used as image stimulus, SAM was used to evaluate emotional responses and arousal level was analyzed in both studies as they are used in this virtual telescope experiment.

4.2. Methods

4.2.1. Virtual screen and FOV

FOV (Field of view) of a virtual camera was manipulated in VR HMD to change the view of contents for subjects. Decreasing FOV makes view of angle narrow, therefore the view in VR is similar to telescope, in which environment the view moves a lot with even small movement.

With smaller value of FOV for a virtual camera, the view in VR is more sensitive to HMD movement and requires subjects to keep concentrating not to move their heads to watch target images properly. Two types of virtual screen environments were prepared for the experiment.

Both screens are 8x6m size square flat screen in virtual environment and displayed as approximately same size and fitted to HMD screen width. However, normal screen was located at 4m from eyes in virtual environment, and the FOV for a virtual camera was set to 108°, so that the virtual environment was similar to an environment in which actual 8x6m size screen was located at 4m from subjects. On the other hand, a screen was located at 1,200m from eyes in virtual telescope environment with 2°FOV virtual camera. The screen environment works like telescope view with the screen located at 1,200m distance from subjects.

Table 4-1. Parameters of two virtual screen environments

Type	Screen size	FOV	Distance
Normal	8 x 6m	108°	4m
Virtual Telescope Method	8 x 6m	2°	1,200m

The created visions with both normal and the virtual telescope method look identical when subjects face the screen, but the screen moves more in telescope environment with HMD movements (Figure 4-1).

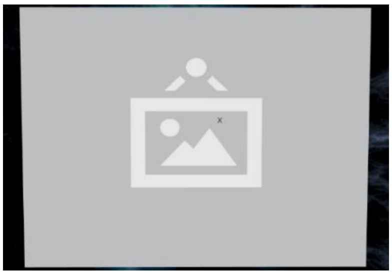

Figure 4-1. Created vision in HMD. Pictures were displayed in the experiment.

4.2.2. HMD

Hacosco Tatami 1-gan was built up with 5.8-inch smartphone and Cardboard type VR component kit. The HMD is 18.5 x 16.1 x 1.1 cm size and 224g light weight including the smartphone. Subjects hold the HMD in front of their face, and the HMD displays contents based on its gyroscope. The HMD is connected to a PC, which controls the contents of the HMD and records logs of the experiment. We used monocular lens goggles instead of binocular lens used for typical VR goggles since binocular lens VR-HMD is not recommended for people under 13 years old because of the risk of crossed eyes. This study is expected to be used for children as well as adult people.

4.2.3. Self-Assessment Manikin (SAM)

Self-Assessment Manikin (SAM) was developed by Lang P.J. and used to evaluate emotional response of the subjects. SAM is a widely used non-verbal assessment technique which measures pleasure, arousal, and dominance with cartoon characters graphic scales. Manikin images for rating (Figure 4-2) was prepared to measure arousal level in 9 scales and selected by subjects after a picture appears in HMD.

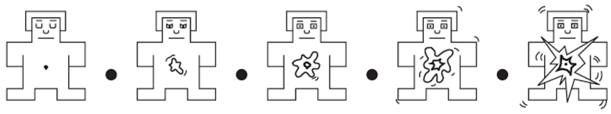

Figure 4-2. Self-Assessment Manikin (SAM) scales for arousal

4.2.4. Pictures

International Affective Picture System (IAPS) was used as emotional stimuli in the experiment. IAPS is a widely used database of pictures designed to provide a standardized set of pictures for studying emotion and attention in psychological research. Lang P.J. et al show its effectiveness as an affective rating tool.

Pictures of the experiments were selected from IAPS photo data set. All pictures of IAPS are rated in reactions of arousal, valence and dominance. Pictures were sorted by arousal rating and selected 20 most high rated and 20 most low rated pictures. The two groups of pictures are named "High arousal" and "Low arousal" group. Pictures of high arousal group were expected to stimulate subject's emotion, and pictures of low arousal group were expected to keep subject's emotion calm.

IAPS picture numbers used for the emotional evaluation experiment.

- Low arousal pictures: 2190, 2840, 3170, 5130, 5740, 5800, 7000, 7004, 7006, 7010, 7020, 7031, 7060, 7080, 7110, 7187, 7217, 7490, 7491, 7950.
- High arousal pictures: 3000, 3010, 3060, 3069, 3080, 3170, 4220, 4290, 4668, 4800, 5621, 6230, 6350, 6550, 8030, 8179, 8185, 8492, 9410, 9940.
- Injured pictures: 3000, 3010, 3060, 3069, 3080, 3170.

4.2.5. Software

Software for the experiment was installed to a smartphone, and the device was attached to a goggle, which was used as a VR-HMD. During the experiment, randomly selected images from a list are displayed after a countdown on a virtual screen in the VR-HMD. FOV of a virtual camera in VR also randomly changes, and relationship between FOV and emotional response were recorded.

Software randomly selects a type of the virtual screen and a picture to display. Two types of the environment "Normal" and "Virtual Telescope" were selected by 50% probability, and the two photo set groups "High arousal" and "Low arousal" were also selected by 50% probability. The software choses a picture to display at random from the selected group of the photo set. Selected type of the virtual display was used to show the selected picture in the HMD by the software.

4.2.6. Procedure

The experiment was carried out by two people in a calm room, and lights were tuned off so that subjects can be relaxed during the experiment. Subjects were asked to wear acoustic earmuff to reduce environmental noise while they use VR-HMD (Figure 4-3). One person controls PC and another person recorded the result. Beginning of the experiment, overview of the procedure was explained to subject about what they need to do, but the expected outcome or the purpose of the experiment were not explained to the subjects. Subjects were mentioned that unpleasant pictures may appear on screen and they may stop the experiments if they feel uncomfortable. Subjects were also asked not to tell other people about the detail about the experiment because of prior information control of the psychological experiment.

One session was composed with 20 picture displays. In a session, a loading image appears for 8-13 seconds and a picture appears for 6 seconds. The duration of the loading image varies from 8 to 13 seconds because subjects should not know exactly when the picture appears. After the picture disappear, the subject points their arousal level with the SAM picture. Picture type, VR environment type (Virtual telescope / Normal) and arousal level were recorded along with picture and subject number.

Figure 4-3. The condition of the experiment

4.3. Result and consideration

12 volunteers (9 males and 3 females) were participated in the experiment as subjects. Ages are 21 - 61 years old. Emotional responses were recorded in 227 trials for the 12 subjects. Two subjects stopped their sessions at their 11th and 18th trials due to a feeling of unwellness. The data before they stopped their session was included in the result. The interruption is considered to be due to the emotional response of the experiment rather than VR sickness since the two subjects use VR-HMD for their works and tolerant of it. The screen type and picture type were determined at random by the software at each trial. Actual numbers of observation were not distributed equally. Normal pictures appeared 61 times in normal environment and 45 times with the virtual telescope method. High arousal pictures appeared 59 times in normal environment and 62 times with the virtual telescope method.

T test result with all pictures data set indicates that watching pictures in the virtual telescope environment make subject feel more arousal.

To understand more about the relationship of the virtual telescope method and the arousal level, recorded data was also analyzed with categorized pictures set. Virtual telescope method does not affect emotional responses significantly with low arousal pictures. The tendency is significant in the case of high arousal rated pictures, which is the same result as the previous experiments with 3D converted images[5][6] and different size of screens[7].

Injured pictures data set was selected from high arousal pictures for further analysis, which include mutilation and tumor pictures. The mean of the arousal ratings of injured pictures set were higher than the ratings of high arousal pictures set.

F test was performed first to determine the equality of variances of the data. Welch t test was performed assuming unequal variances for all pictures data set. On the other hand, t test assuming equal variances was performed for low arousal, high arousal and injured pictures data set. The results of t test were $p=0.04$ for injured pictures set, $p=0.05$ for high arousal pictures set and $p=0.46$ for low arousal pictures set, which indicate that the virtual telescope method makes subjects feel more arousal with higher arousal rating pictures (Table 4-2). The result of higher arousal rating pictures is consistent with previous studied of 3D images[6] and screen size[7].

VR HMD was used for the experiment, however the contents used in the experiment were ordinal two-dimensional pictures. Emotional evaluation with 360 photos or immersive three-dimensional contents need to be examined in the further study to apply this method to recent VR contents.

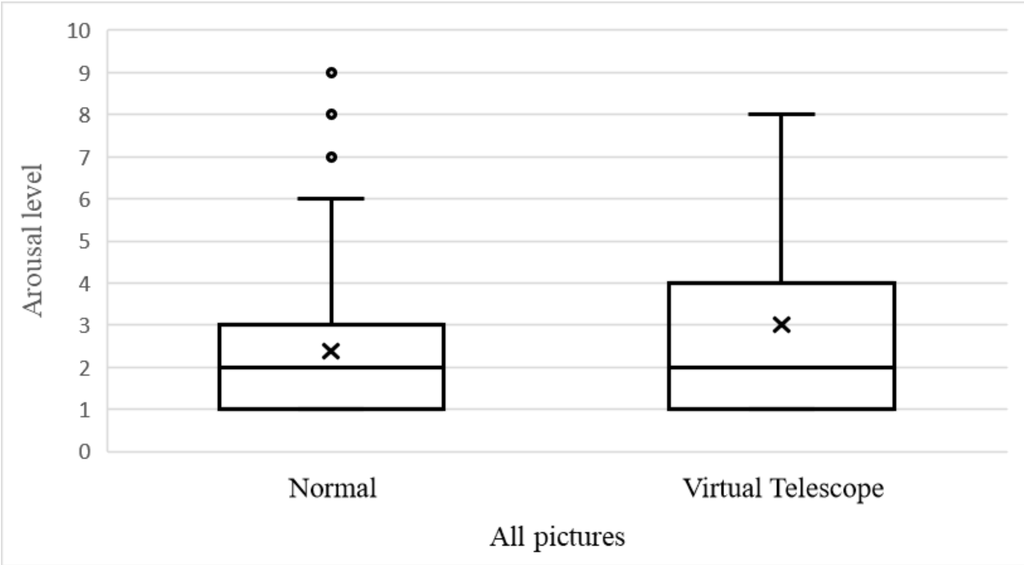

Figure 4-4. Arousal level comparison with all pictures

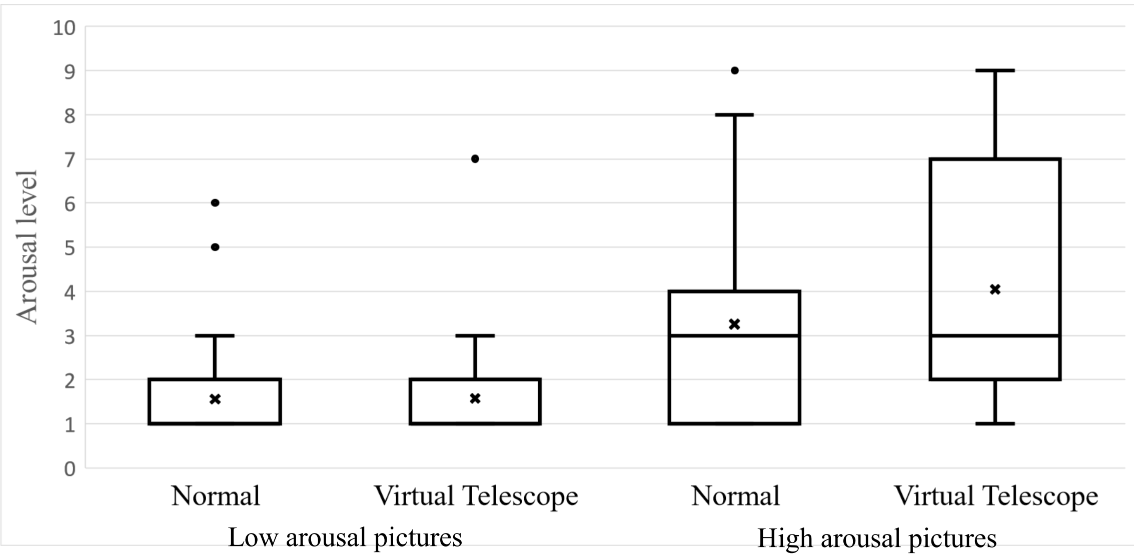

Figure 4-5. Evoked arousal level comparison with arousal level of pictures

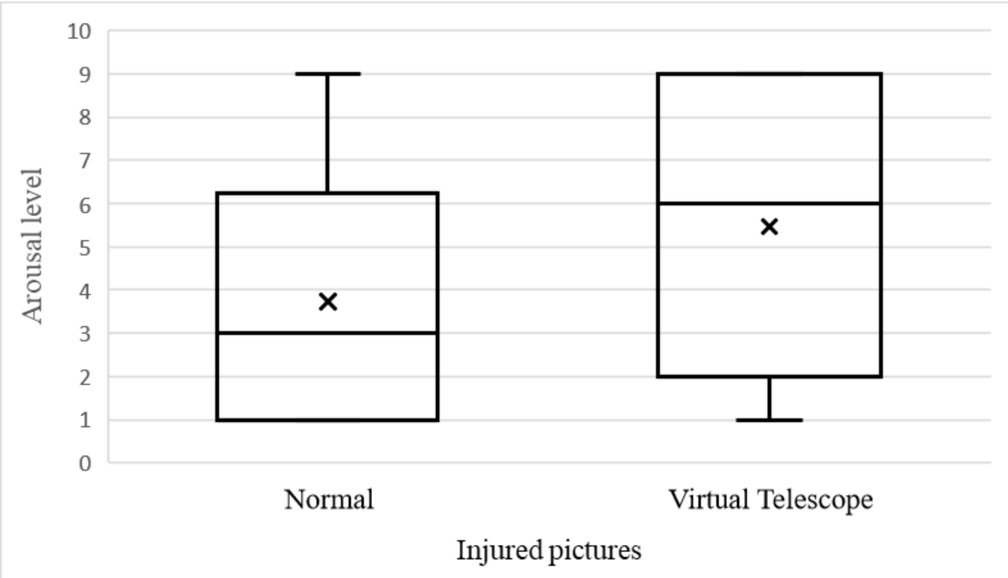

Figure 4-6. Arousal level comparison with injured pictures in high arousal picture group

Table 4-2. t test result and statistics of recorded arousal level for selected picture data set.

	Normal (FOV:108°)			Virtual Telescope (FOV:2°)				
Used pictures data set	n	M	SD	n	M	SD	F test result	t test result
All pictures	120	2.4	2.0	107	3.0	2.6	F(106,119)=0.73, p<0.05	t(196)=1.65, p<0.05
Low arousal pictures	61	1.6	0.9	45	1.6	1.0	F(44,60)=0.63, p>0.05	t(104)=1.66, p>0.05
High arousal pictures	59	3.3	2.3	62	4.0	2.9	F(58,61)=0.65, p>0.05	t(119)=1.66, p=0.05
Injured pictures	22	3.7	2.8	17	5.5	3.2	F(16,21)=0.46, p>0.05	t(37)=1.69, p<0.05

Note: n=Number of samples, M=Mean, SD=Standard deviation.

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Appendix

Table 4-3. Affective rating of IAPS pictures used in the emotional evaluation experiment.

IAPS No	Description	Valence Mean	Valence SD	Arousal Mean	Arousal SD	Dominance1 Mean	Dominance1 SD	Dominance2 Mean	Dominance2 SD
2190	Man	4.83	1.28	2.41	1.80	5.92	2.01	-	-
2840	Chess	4.91	1.52	2.43	1.82	5.56	1.93	-	-
3000	Mutilation	1.45	1.20	7.26	2.10	2.99	2.10	-	-
3000	Mutilation	1.59	1.35	7.34	2.27	2.73	2.17	-	-
3010	Mutilation	1.71	1.19	7.16	2.24	2.88	2.41	-	-
3010	Mutilation	1.79	1.28	7.26	1.86	2.88	2.14	-	-
3060	Mutilation	1.79	1.56	7.12	2.09	2.97	2.11	-	-
3069	Mutilation	1.70	1.41	7.03	2.41	-	-	2.62	2.30
3080	Mutilation	1.48	0.95	7.22	1.97	2.85	2.10	-	-
3170	BabyTumor	1.46	1.01	7.21	1.99	2.70	1.89	-	-
4220	EroticFemale	8.02	1.93	7.17	2.69	5.33	2.12	-	-
4220	EroticFemale	6.60	1.72	5.18	2.33	5.90	1.63	-	-
4290	EroticFemale	7.61	2.56	7.20	2.63	5.00	2.36	-	-
4668	EroticCouple	6.67	1.69	7.13	1.62	5.73	2.34	-	-
4800	EroticCouple	6.44	2.22	7.07	1.78	5.51	2.11	-	-
5130	Rocks	4.45	1.13	2.51	1.72	5.84	1.98	-	-
5621	SkyDivers	7.57	1.42	6.99	1.95	5.81	2.38	5.50	2.34
5740	Plant	5.21	1.38	2.59	1.99	6.27	2.21	-	-
5800	Leaves	6.36	1.70	2.51	2.01	5.72	2.03	-	-
6230	AimedGun	2.37	1.57	7.35	2.01	2.15	2.09	-	-
6350	Attack	1.90	1.29	7.29	1.87	2.73	2.16	-	-
6550	Attack	2.73	2.38	7.09	1.98	3.01	2.41	-	-
7000	RollingPin	5.00	0.84	2.42	1.79	6.14	2.14	-	-
7004	Spoon	5.04	0.60	2.00	1.66	6.74	1.99	-	-
7006	Bowl	4.88	0.99	2.33	1.67	6.18	1.96	-	-
7010	Basket	4.94	1.07	1.76	1.48	6.70	1.48	-	-
7020	Fan	4.97	1.04	2.17	1.71	6.16	2.15	-	-
7031	Shoes	4.52	1.11	2.03	1.51	6.14	2.12	-	-

IAPS No	Description	Valence Mean	Valence SD	Arousal Mean	Arousal SD	Dominance1 Mean	Dominance1 SD	Dominance2 Mean	Dominance2 SD
7060	TrashCan	4.43	1.16	2.55	1.77	5.85	2.10	-	-
7080	Fork	5.27	1.09	2.32	1.84	7.04	1.84	-	-
7110	Hammer	4.55	0.93	2.27	1.70	6.07	1.86	-	-
7187	AbstractArt	5.07	1.02	2.30	1.75	6.10	2.04	-	-
7217	ClothesRack	4.82	0.99	2.43	1.64	6.25	1.86	-	-
7490	Window	5.52	1.41	2.42	2.23	5.81	2.10	-	-
7491	Building	4.82	1.03	2.39	1.90	5.93	1.96	-	-
7950	Tissue	4.94	1.21	2.28	1.81	6.30	2.11	-	-
8030	Skier	7.33	1.76	7.35	2.02	4.70	2.66	-	-
8179	Bungee	6.48	2.18	6.99	2.35	-	-	4.73	2.68
8185	Skydivers	7.57	1.52	7.27	2.08	5.47	2.42	-	-
8492	Rollercoaster	7.21	2.26	7.31	1.64	4.63	2.41	-	-
9410	Soldier	1.51	1.15	7.07	2.06	2.81	1.99	-	-
9940	Explosion	1.62	1.20	7.15	2.24	2.45	2.22	-	-

Table 4-4. Table 2 4. Analyzed data of all pictures data set

(1) Quartile of the data set

	All pictures	
	Normal	Virtual Telescope
minimum	1	1
first quartile	1	1
medium	2	2
third quartile	3	4
maximum	6	8
mean	2.4	3.0

(2) F-test two-sample for variances

	All pictures	
	Normal	Virtual Telescope
Standard deviation	2.0	2.6
Mean	2.4	3.0
Variance	3.9	6.7
Observations	120	107
df	119	106
F	0.57	
P(F<=f) one-tail	0.00	
F Critical one-tail	0.73	

(3) t-Test: Two-Sample Assuming Unequal Variances

	All pictures	
	Normal	Virtual Telescope
Mean	2.4	3.0
Variance	3.9	6.7
Observations	120	107
Hypothesized Mean Difference	0	
df	196	
t Stat	-2.00	
P (T<=t) one-tail	0.02	
t Critical one-tail	1.65	
P(T<=t) two-tail	0.05	
t Critical two-tail	1.97	

Table 4-5. Analyzed data of selected data set

(1) Quartile of the data set

	Low arousal pictures		High arousal pictures		Injured pictures	
	Normal	Virtual Telescope	Normal	Virtual Telescope	Normal	Virtual Telescope
minimum	1	1	1	1	1	1
first quartile	1	1	1.75	2	1	2
medium	1	1	3	3	3	6
third quartile	2	2	4	7	6.25	9
maximum	3	3	7	9	9	9
mean	1.6	1.6	3.3	4.0	3.7	5.5

(2) F-test two-sample for variances

	Low arousal pictures		High arousal pictures		Injured pictures	
	Normal	Virtual Telescope	Normal	Virtual Telescope	Normal	Virtual Telescope
Standard deviation	0.9	1.0	2.3	2.9	2.8	3.2
Mean	1.6	1.6	3.3	4.0	3.7	5.5
Variance	0.9	1.1	5.5	8.3	8.3	11.0
Observations	61	45	59	62	22	17
df	60	44	58	61	21	16
F		0.79		0.67		0.75
P(F<=f) one-tail		0.20		0.06		0.27
F Critical one-tail		0.63		0.65		0.46

(3) t-Test: Two-Sample Assuming Equal Variances

	Low arousal pictures		High arousal pictures		Injured pictures	
	Normal	Virtual Telescope	Normal	Virtual Telescope	Normal	Virtual Telescope
Mean	1.6	1.6	3.3	4.0	3.7	5.5
Variance	0.9	1.1	5.5	8.3	8.3	11.0
Observations	61	45	59	62	22	17
Pooled Variance		0.98		6.96		9.48
Hypothesized Mean Difference		0		0		0
df		104		119		37
t Stat		-0.10		-1.66		-1.75
P (T<=t) one-tail		0.46		0.05		0.04
t Critical one-tail		1.66		1.66		1.69
P(T<=t) two-tail		0.92		0.10		0.09
t Critical two-tail		1.98		1.98		2.03

Chapter 5.
VR-HMD Movement Evaluation

5.1. Introduction

HMD movement evaluation experiment was carried out to explore the reason of the result of previous chapter. Greater pain tolerance and emotional response were considered as the result of greater attention and state of concentration. Experiment was carried out to show subjects keep HMD not moving during the usage of the virtual telescope method which makes subjects use more attentions.

5.2. Methods

5.2.1. HMD

Instead of handheld Cardboard type setup used in the emotional evaluation experiment, wearable HMD was built up with 5.8-inch smartphone and VR Headset (ELECOM P-VR1G01WH). The HMD is 20.3 x 19.3 x 11.8 cm size and 482g light weight including the smartphone. Video contents were used instead of pictures in this experiment. Audio of video contents were played from a connected PC.

5.2.2. Videos

In the previous experiment, subjects often moved HMDs when the pictures appeared by surprising. To evaluate the HMD movement just caused by the virtual telescope method, video contents were prepared for this experiment instead of IAPS pictures. One video content was selected and extracted to 100 seconds. The same video data was used for all subjects with both normal and the virtual telescope method in the experiment.

5.2.3. Software

Video playback and screen types are controlled by designated software to evaluate how much subjects keep HMD stable. In a session of the experiment, physical movement of HMD was recorded by the software. The software records psychical rotation angle of HMD on vertical and horizontal axis in 10Hz using gyroscope sensor in the smartphone-based HMD. When subjects tilt the HMD by certain degrees, the angle of the rotation from its initial position is stored in a log file. The rotation angle around vertical axis is recorded as X, and the angle around horizontal axis is recorded as Y. The software switches the type of screen randomly every 10 seconds and resets the screen position to its initial location against HMD. In the 100 seconds session, the software changes the screen 10 times at most and record 1,000 points of data for movement analysis.

5.2.4. Procedure

The experiment was carried out in the same environment as the previous experiment. Only difference is that subject didn’t wear acoustic earmuff at the experimental session because subjects watch a video with audio.

Subjects were told to watch a video with the HMD for 100 seconds, but no further information was told. Subjects were asked not to tell other people about the detail about the experiment after the session. movement information and the screen type were recorded along with the subject information in a log file. Logged data was analyzed after the experiment.

5.3. Result and consideration

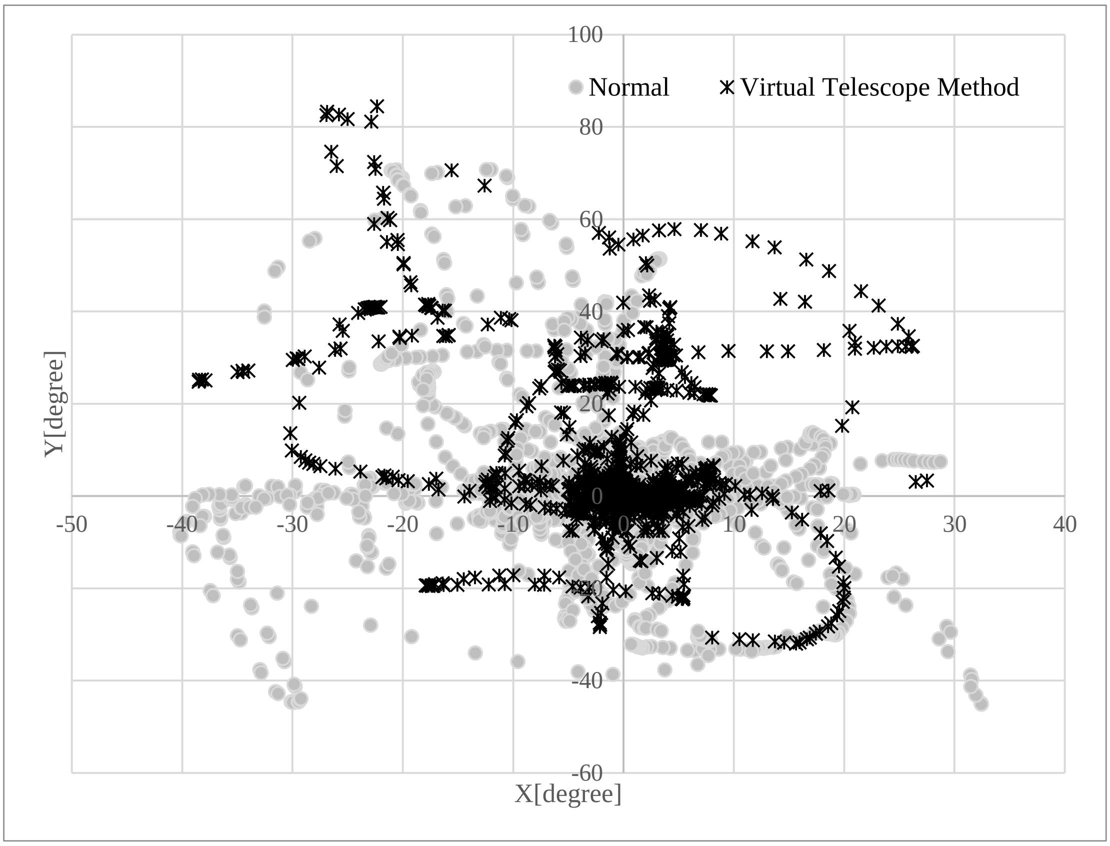

Figure 5-1. Scatterplot of HMD angles of all recorded data for 12 subjects. X as rotation angle around vertical axis and Y as rotation angle around horizontal axis.

12 volunteers (5 males and 7 females) were participated in the experiment as subjects. Ages are 15 - 52 years old. Figure 5-1 is a scatterplot of all recorded data for the 12 subjects which consists of 12,000 data points. The plot indicates that HMDs are more moved when they watch video with normal environment comparing to the virtual telescope method.

Distance from the center of the plots were averaged for each screen type as an indicator of movement, and the result shows that the value of normal environment is more than doubles of the value of the virtual telescope method. (Table 5-1)

Table 5-1. Average of distance from center

Type	Average of distance
Normal	3.072
Virtual Telescope Method	1.539

Smaller value is more stable

Average of distance from center with both normal and the virtual telescope method of each subject was plotted in Figure 5-2. Screen always appeared on the display of the HMD during the normal mode, however screen was out of range for 20.9% of the total time with the virtual telescope method. When subjects moved HMDs more than 2°, the screen went out from subjects' field of vision, and they needed to move their HMDs back to the center to keep the screen visible.

Table 5-2. Average of distance from center and t test result

Subject No	Normal	Telescope	Difference
1	9.650	7.099	2.551
2	0.597	0.491	0.106
3	0.907	0.369	0.538
4	1.531	0.186	1.345
5	1.853	0.314	1.540
6	6.758	3.258	3.499
7	0.210	0.235	-0.025
8	0.750	1.675	-0.925
9	1.614	0.672	0.942
10	0.216	0.099	0.117
11	1.782	0.140	1.643
12	0.313	0.408	-0.094
Mean	2.182	1.245	0.936
Variance	8.650	4.220	-
df		11	-
t Stat		2.596	-
P(T<=t) one-tail		**0.012***	**-**

$*p<0.05$

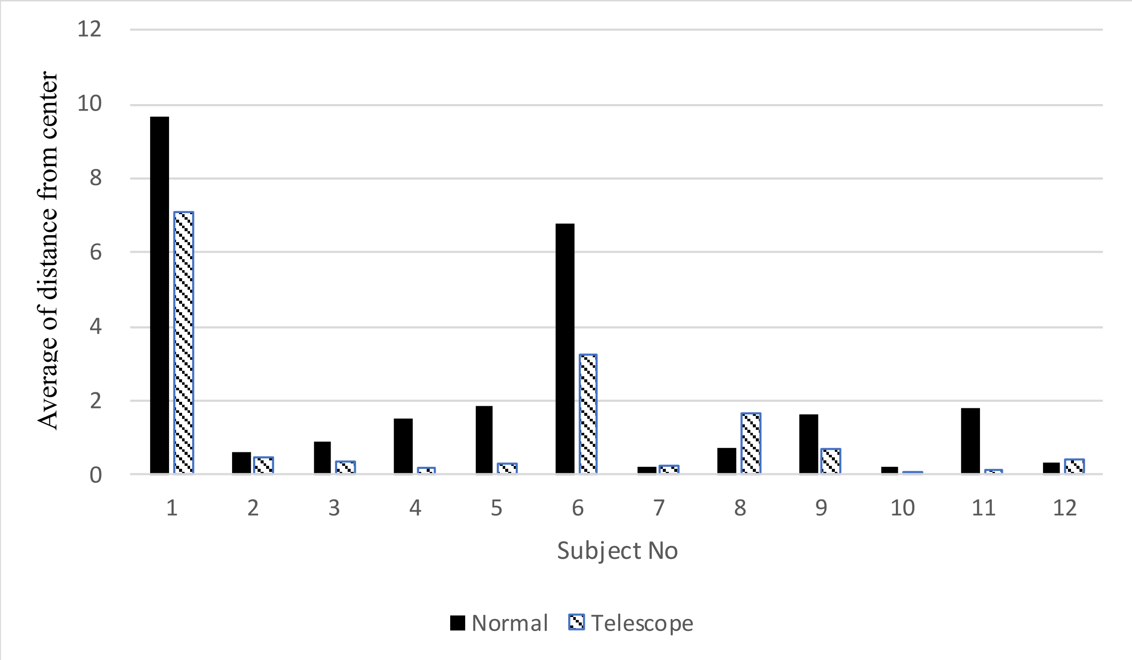

Figure 5-2. Plots of average of distance from center with both normal and the virtual telescope method for each subject

To analyze the data statistically, average of the distance was calculated for each subject. The data was evaluated with paired t test, and the result is significant. (Figure 5-2)

Even though the statistical analysis shows the significant difference of the two data set, three subject 7, 8, and 12 had less motion with normal screen, which is not our expectation. However, the motions with both normal and telescope of subject 7 and 12 were small comparing to other subjects, so the data seems not affected to the result of t test. In order to investigate the reason of the unexpected data for subject 8, HMD movement data was plotted as Figure 5-3. One big HMD movement was observed when the screen type was telescope. We assume this one exceptional movement caused unexpected result of subject 8.

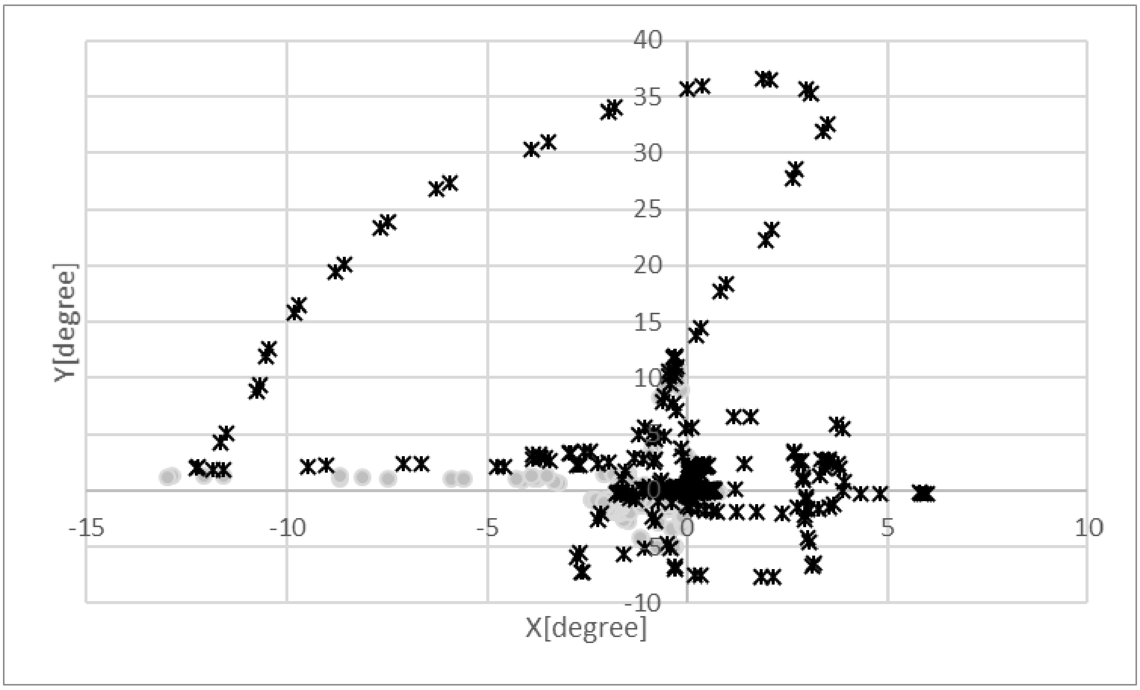

Figure 5-3. Scatterplot of HMD movement of subject 8.

The overall result shows that subjects keep VR HDMs more stable when video contents appeared with the virtual telescope method. Keeping VR HMD in the same position requires much concentration and directs much attention to the screen. Therefore, the virtual telescope method made subjects focus on the screen and induced greater emotional responses, which can explain the result of the first experiment.

The results with t test statistically show that emotional responses were enhanced with only displaying software with manipulated FOV in the same VR HMDs. The result indicates that the method directs attentions to screen and induce concentrations as well.

This hardware and contents independent method could apply VR applications including psychological therapy, learning, rehabilitation of development disorders etc. without expensive hardware or contents cost.

Appendix

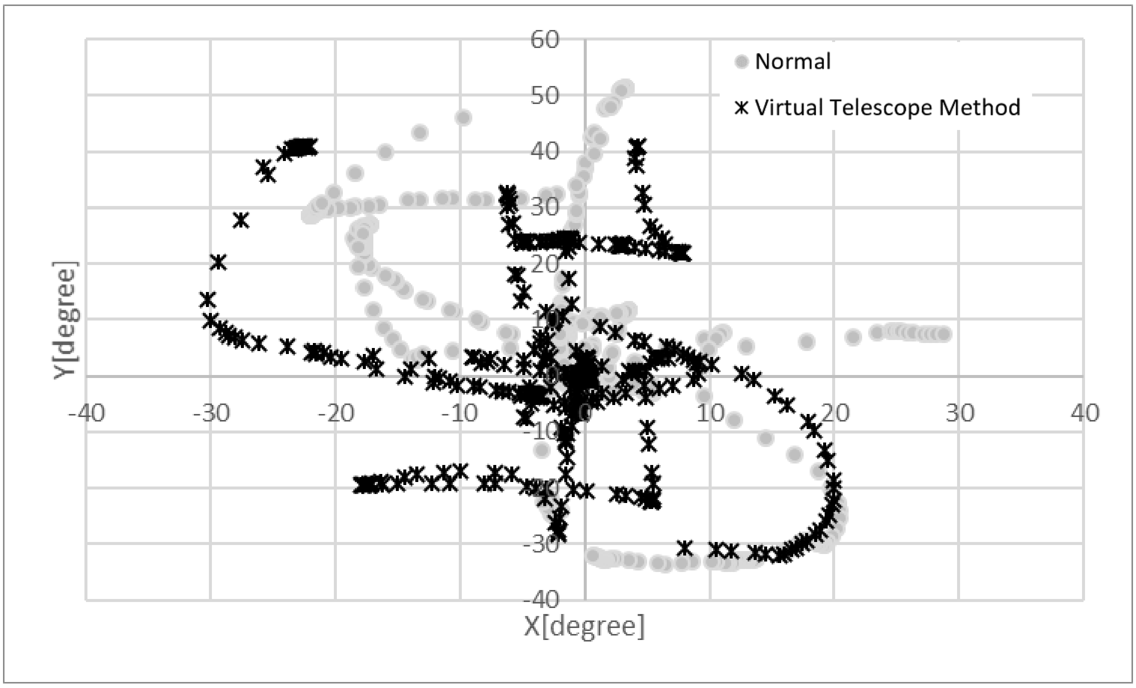

Figure 5-4. Scatterplot of HMD movement of subject 1

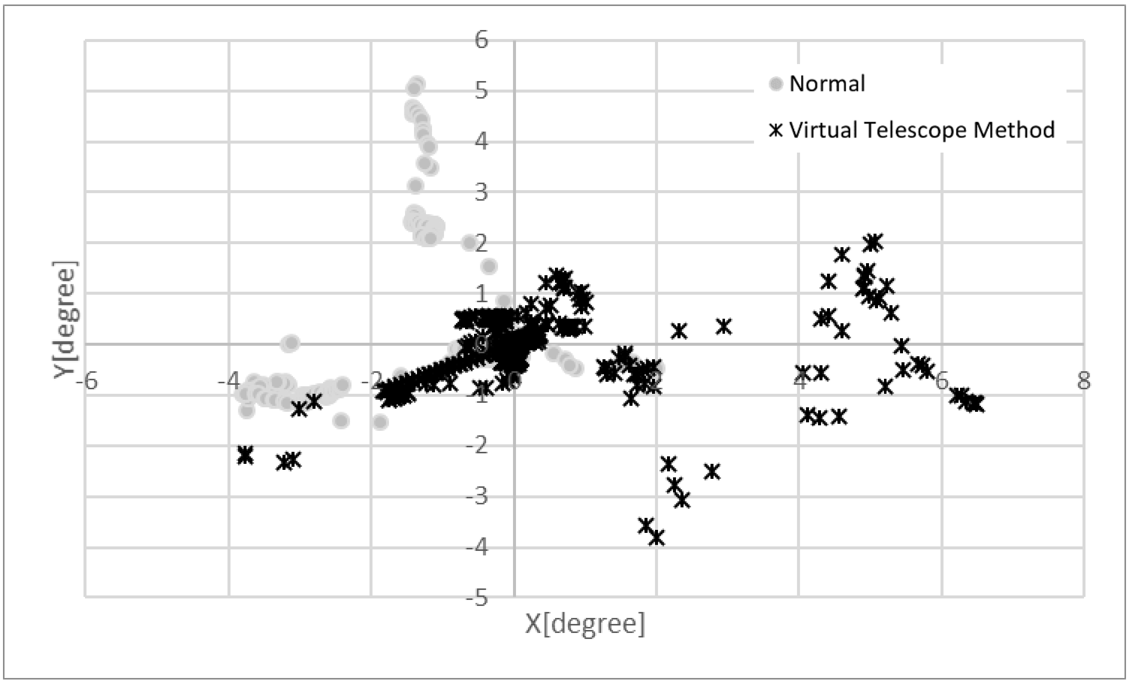

Figure 5-5. Scatterplot of HMD movement of subject 2

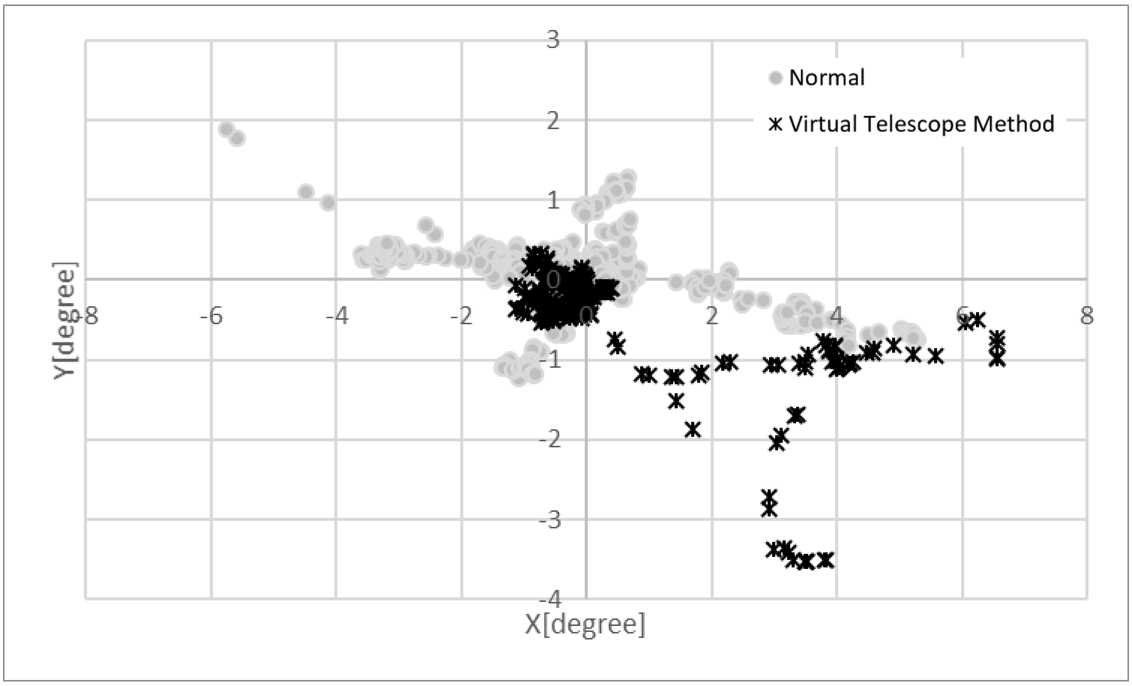

Figure 5-6. Scatterplot of HMD movement of subject 3

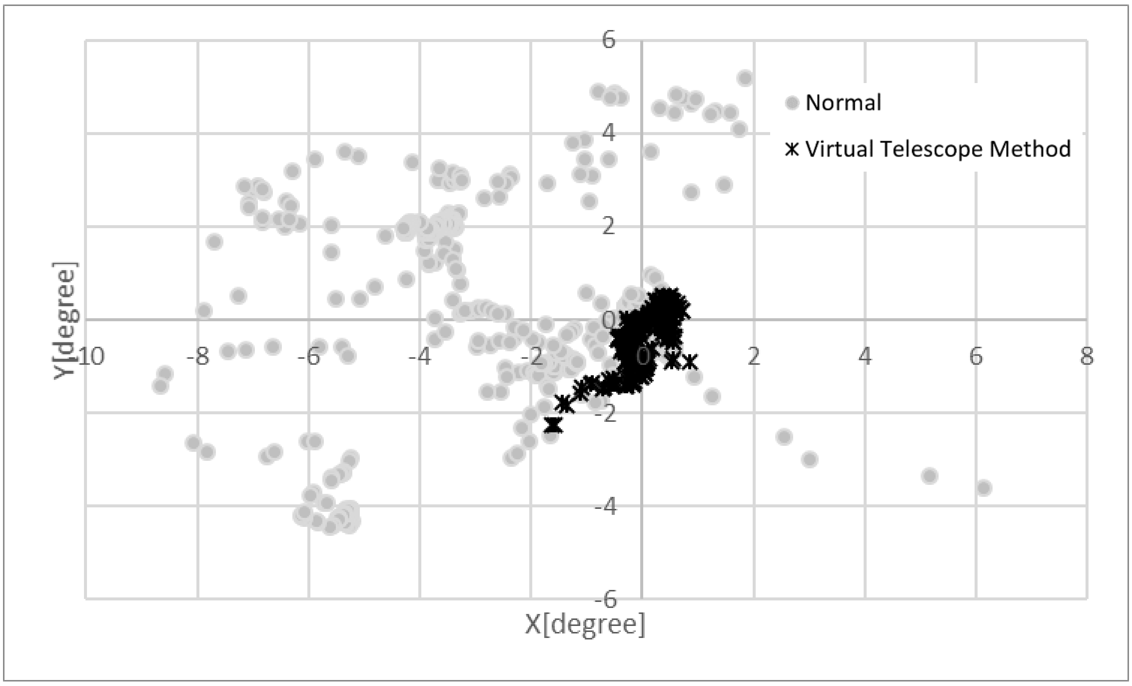

Figure 5-7. Scatterplot of HMD movement of subject 4

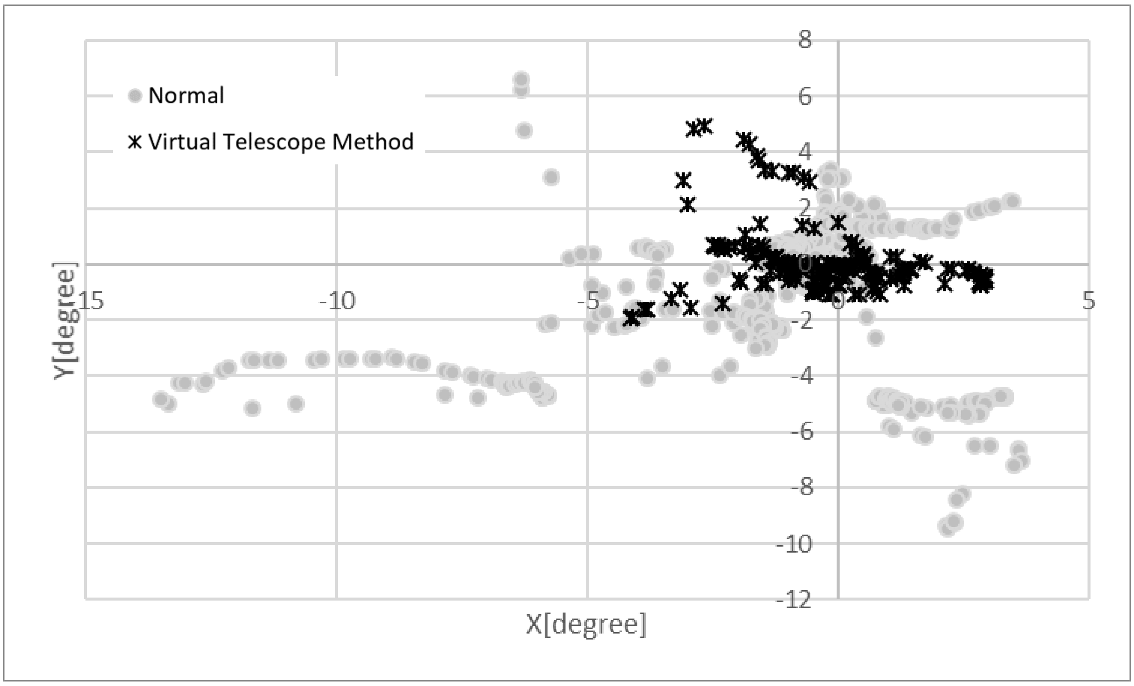

Figure 5-8. Scatterplot of HMD movement of subject 5

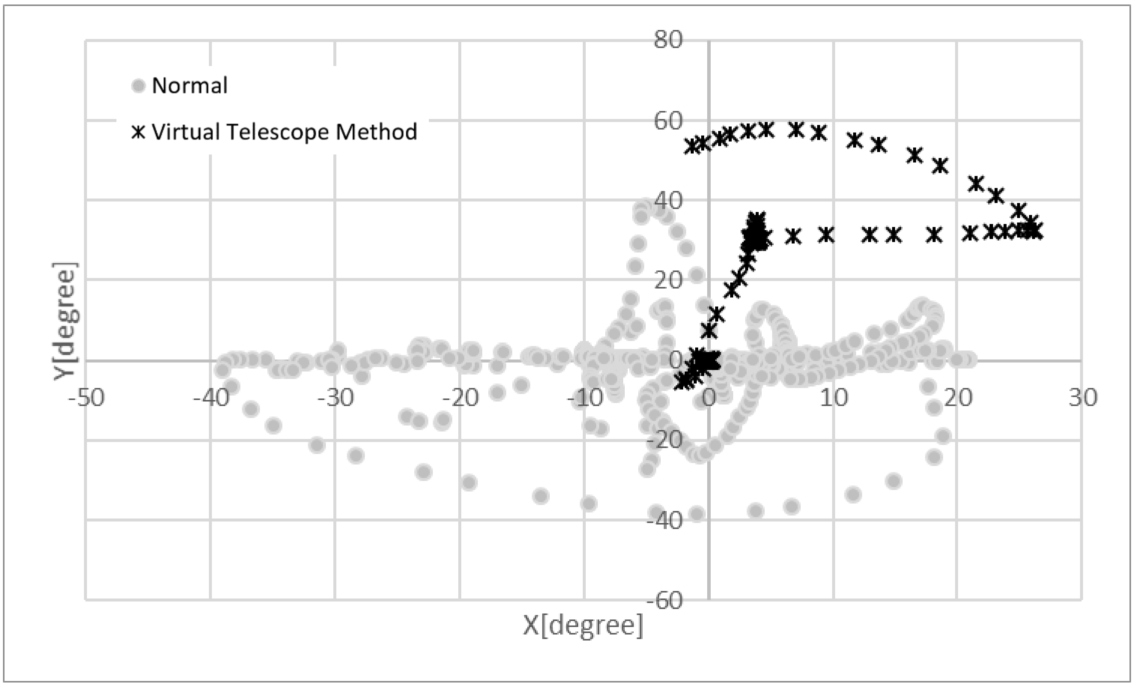

Figure 5-9. Scatterplot of HMD movement of subject 6

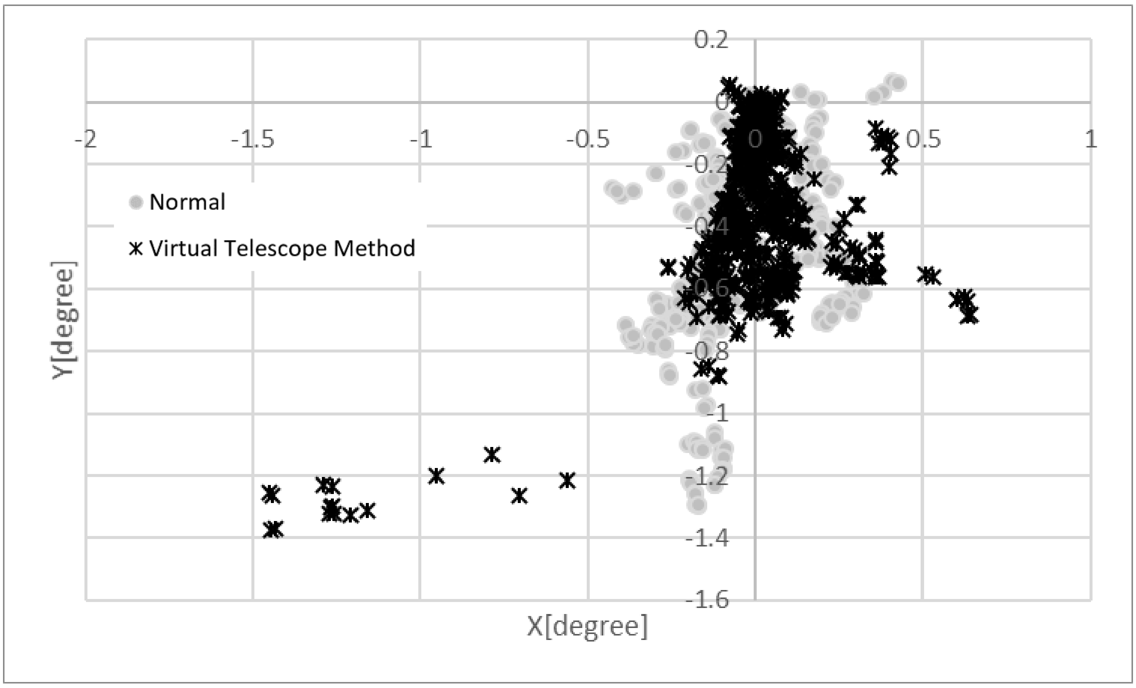

Figure 5-10. Scatterplot of HMD movement of subject 7

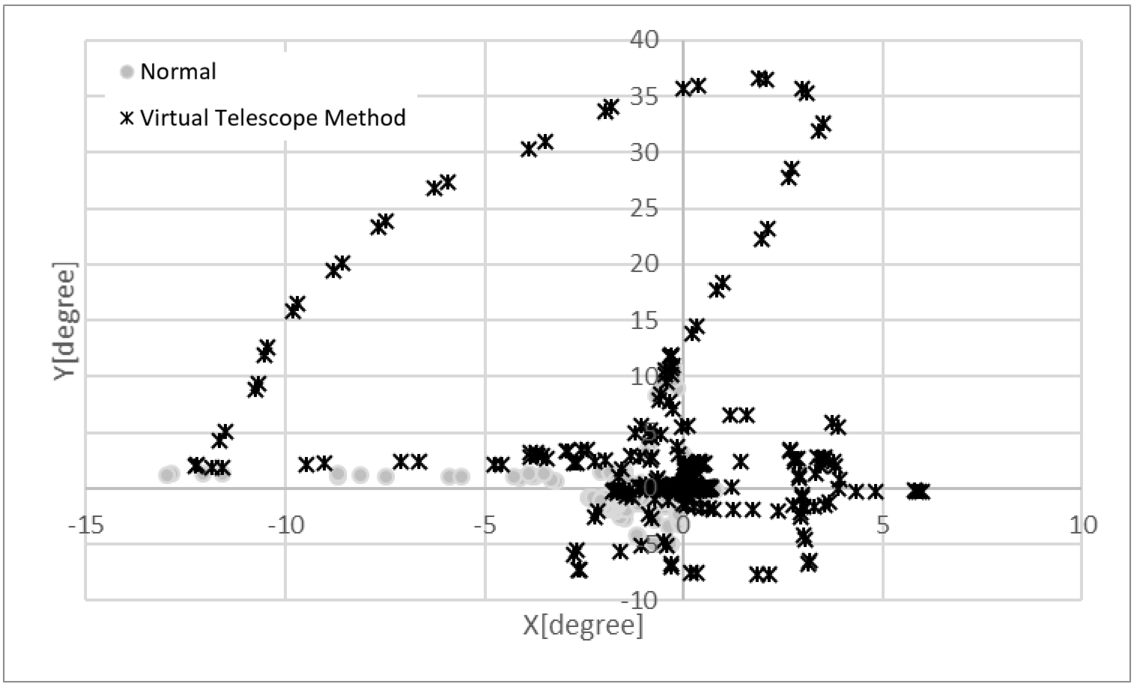

Figure 5-11. Scatterplot of HMD movement of subject 8

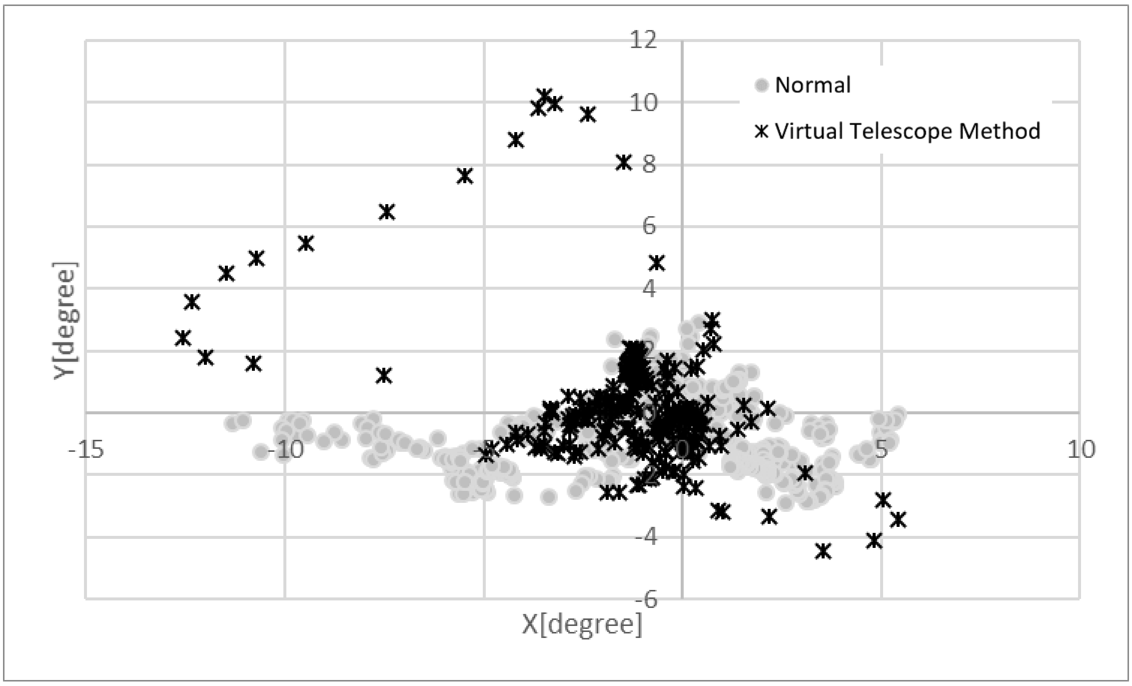

Figure 5-12. Scatterplot of HMD movement of subject 9

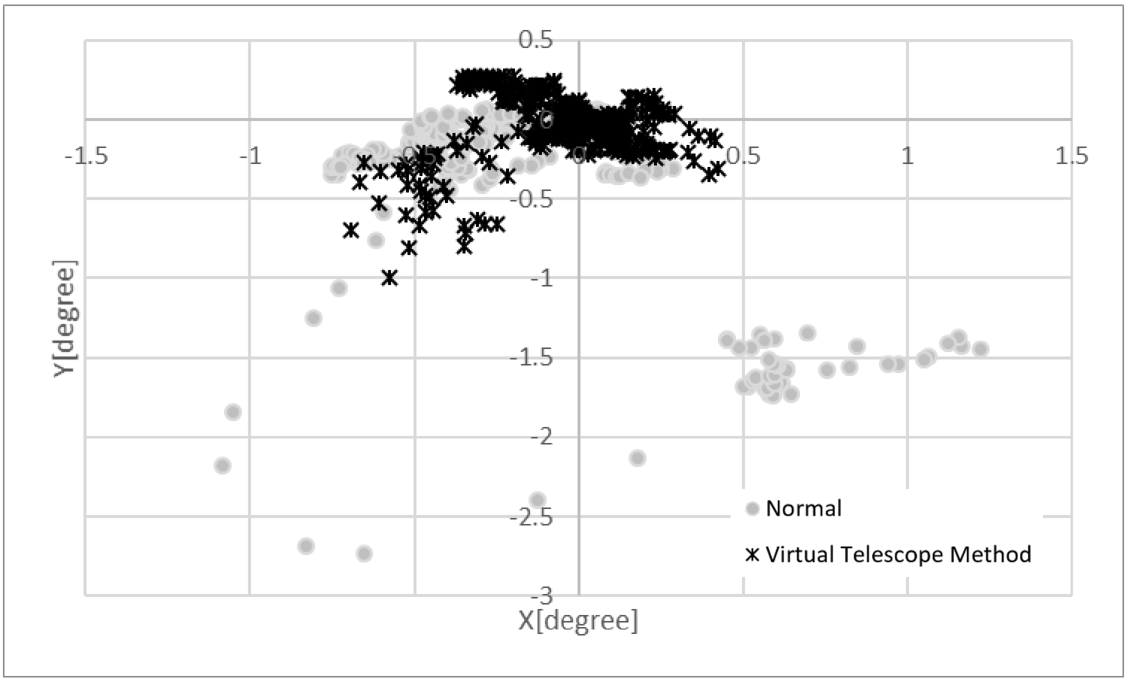

Figure 5-13. Scatterplot of HMD movement of subject 10

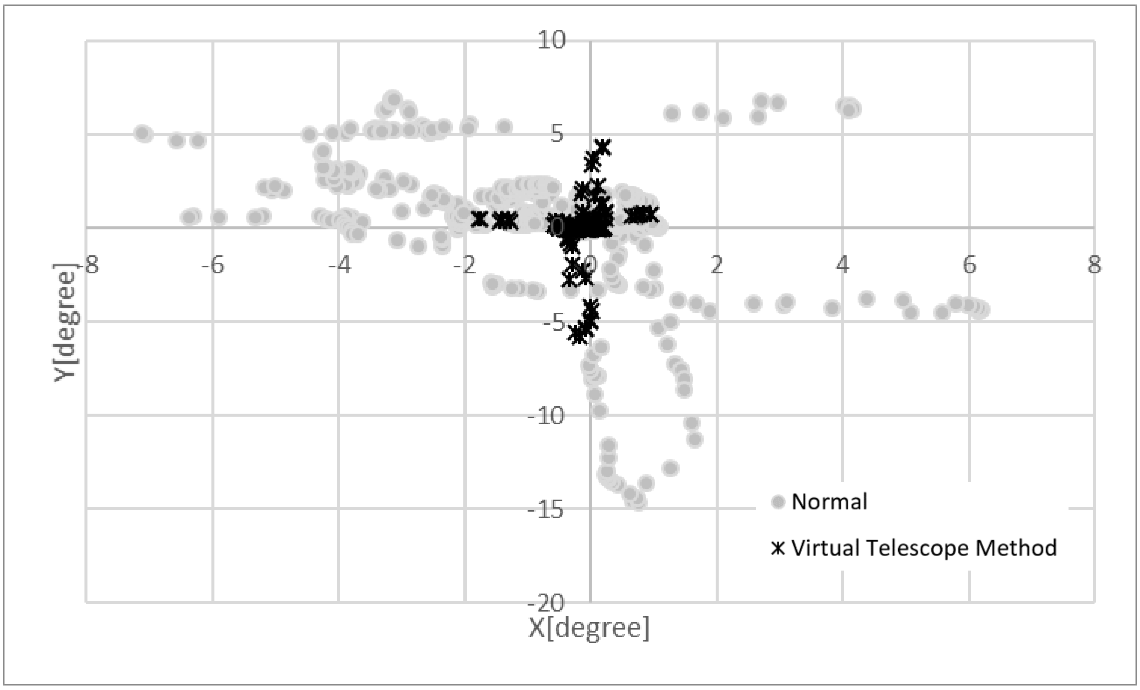

Figure 5-14. Scatterplot of HMD movement of subject 11

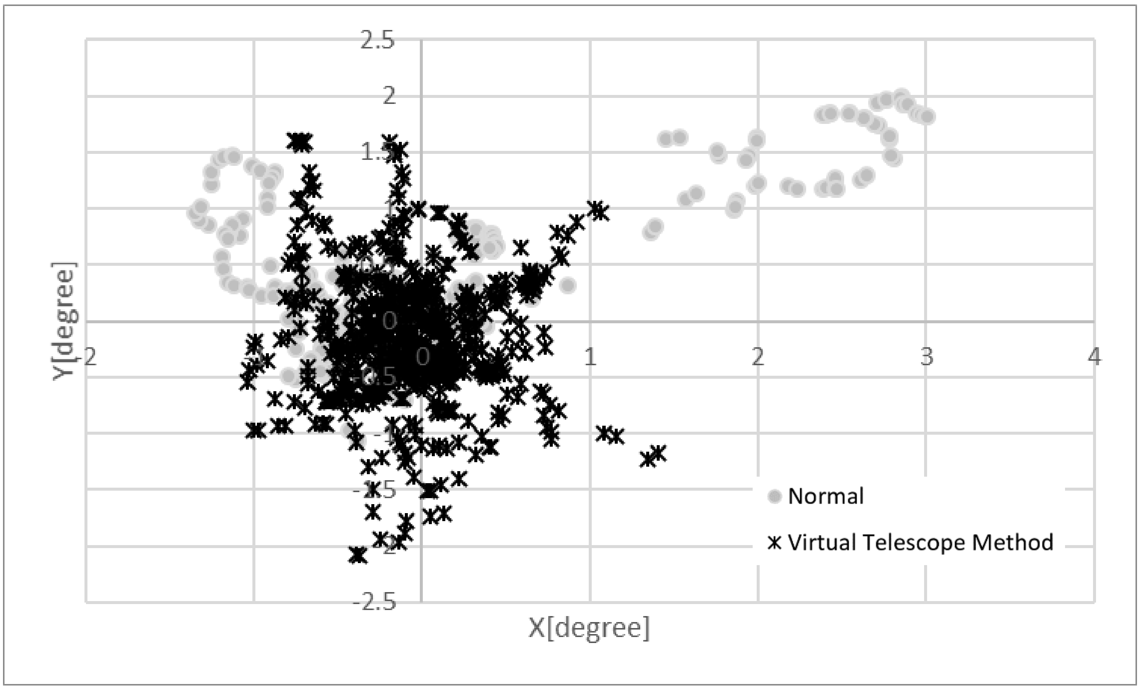

Figure 5-15. Scatterplot of HMD movement of subject 12

Chapter 6. Conclusion

6.1. Conclusion

In this dissertation, I proposed the virtual telescope method for pain reduction. Psychological effect of extremely small field of view of virtual camera in VR environment has not been studied before except our study. The result of the experiment in this study shows that increased tolerance time of pain with the virtual telescope method was significant. It is concluded that extremely small FOV of a virtual camera in virtual environment increases tolerance for at least experimental cold pressor pain, and it is suggested that the virtual telescope method works as VR distraction tool for pain reduction.

In the chapter 2, pain tolerance experiment was carried out with cold pressor test. The result shows that the mean value of the tolerance time in cold water was increased 1.66 times with the virtual telescope method. T test of the result, p=0.04, shows that increased time with the virtual telescope method is statistically significant. However, it is also found that the effect of the method varies to subject. Tolerance time was increased more than double for 3 subjects, however, change rate of the tolerance was less than 10% for 5 subjects.

In the chapter 3, Relationship between the result of pain tolerance experiment and hypnotic susceptibility of the subjects. The correlation coefficient with the total score was 0.344. Weak correlation was found between the increasing rate of tolerance time using the virtual telescope method and the hypnotic susceptibility of each subject.

In the chapter 4, emotional responses were evaluated with the virtual telescope method. International Affective Picture System (IAPS) was used as emotional stimuli in the experiment, and the emotional response was evaluated with Self-Assessment Manikin (SAM) in 9 scales. Mean value of the arousal level with the virtual telescope method was 3.0, and the value of the normal environment was 2.4 on the other side. T test result with all pictures data set shows that watching pictures with the virtual telescope method makes subjects feel more arousal. Moreover, the analysis with selected picture dataset indicates that the method evoked greater arousal level with high arousal or injured picture dataset.

In the chapter 5, HMD movement evaluation experiment was carried out. Greater pain tolerance and emotional response were considered as the result of greater attention and state of concentration. Physical movement of HMD was recorded in rotation angle around X and Y axis. The average of distance from center was calculated as indicator of the movement. The movement value with the virtual telescope method was 0.50 times smaller than the value without the method, which indicates that subjects tends to make their VR-HMDs more stable when contents were displayed with the virtual telescope method. The result indicates that subjects were more concentrating not to move VR-HMDs with the virtual telescope method when subjects are watching contents.

6.2. Future works

Despite the positive result of the pain reduction with the virtual telescope method, some study limitations must be noted.

The primary limitation of this study involves the experimental nature of the pain stimulus and the environments. Cold pressor test was used in the study, which is different from actual pain during clinical treatment. Subjects know the type of stimuli and can predict how they feel the pain, whereas actual pain in a clinical treatment is unpredictable. Also, the timing of the pain is fully controllable by subjects in the experiment. The experiment was taking place in a calm room without external stimuli in order to make the experimental condition same for each subject, however subjects may not be able to pay attention to the screen in VR-HMD during an actual treatment. The result of the same method may differ from the result during an actual medical treatment.

Further experiments in different conditions with large number of subjects are also needed to carry out to generalize the result. Quality of display, FOV of the HMD, weight of VR-HMD or other parameter may have caused the result. As mentioned in the emotional evaluation experiment chapter, evoked arousal level affects the degree of pain moderation. The type of displayed contents may lead different result, and it should be explored. Volunteered adults were selected as subjects in this study, however different results may be obtained with child subjects.

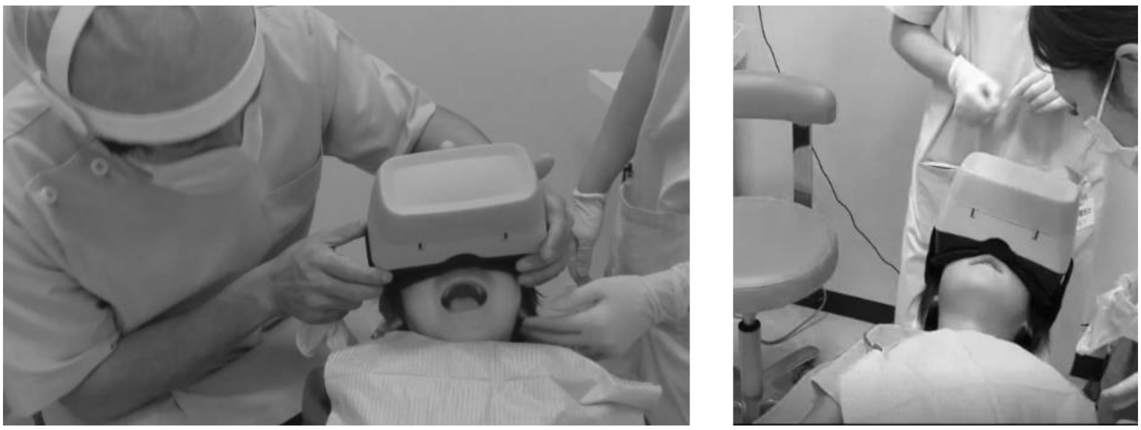

Figure 6-1. Preliminary experiment of the virtual telescope method for children in dental clinic

The virtual telescope method can be prepared with non-expensive hardware, and two-dimensional contents can be used with the method for pain distraction.

Considering advantage of the method and the limitations of the study, clinical case study with the virtual telescope method also seems reasonable to be carried out in the future assuming the actual usage of the method in clinics. We carried out preliminary experiment of the method in child dental clinics and obtained positive feedbacks of the result during dental treatment (Figure 6-1).

The proposed new method in this dissertation was not studied previously and needs to be more explored.

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Finally, I must express my very profound gratitude to my wife for providing me continuous warm-hearted support. This accomplishment would not have been possible without her help.

Research achievements

Journal Papers

Masahiro Yamaguchi, Masayo Matsumura, Hikari Shimada and Kenji Araki, Emotional evaluation for pictures displayed with small FOV telescope Environment in virtual reality headset, Journal of Artificial Life and Robotics, pp.1-7, Springer Japan, 2019.

Peer-reviewed international conference proceedings

Masahiro Yamaguchi, Masayo Matsumura, Hikari Shimada and Kenji Araki, Emotional Evaluation for Images Displayed with Different Type of Screens in Virtual Reality Headset, Proceedings of the Twenty-Third International Symposium on Artificial Life and Robotics 2018 (AROB 2018), pp.557-560, Beppu, Japan, January 18-20, 2018.

Masahiro Yamaguchi, Masayo Matsumura, Hikari Shimada and Kenji Araki, Psychological Effect of Telescope Virtual Screens using VR Headset, Proceedings of the Ninth IEEE International Conference on Awareness Science and Technology (iCAST 2018), pp.175-178, Fukuoka, Japan, September 2018.

National Conferences and Meetings

山口 征浩, 長谷川 明弘, 松村 雅代, 島田 光, 荒木 健治，VR を用いた心理影響増進手法と催眠感受性の関連について，第 32 回日本バーチャルリアリティ学会 VR 心理学研究委員会，映像メディア学会技術報告，映像学術報 Vol.42, No.43, pp.15-18, 2018