Head-Movement Analysis of 360° Affective Experience

by

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***Abstract*—The current study aims to analyse VR measures in correspondence with 360° virtual affective experiences to understand the underlying spatio-temporal attention processes. We selected extreme pleasant and extreme unpleasant emotional videos from the Stanford affective database and displayed to participants on HMD VR. The participants' task was to explore the video and report their affective experience using the Self-Assessment Manikin (SAM) scale. The exploration behaviour was analysed using head-tracking parameters, such as standard deviation of all the three head-rotation axes (yaw, pitch and roll), angular speed and region-wise analysis. We observed a positive correlation between standard deviation of yaw and valence, and angular speed and valence. The result suggests that affective experience not only increases the scope of attention spatially (wide scanning), it also motivates to seek more information that leads to more head-movement during exploration. In region-wise analysis, we observed front field-of-view was primarily explored, and rear field-of-view was least explored, showing natural responses similar to real environments. In addition, we used Beck Depression Inventory-II (BDI) to assess participants' emotional state, specifically depression symptoms. The relation between virtual affective experience and 360° exploration behaviour is discussed in light of the BDI categories. The study findings broaden the scope for VR affective research by enabling psychomotor assessment in more ecologically valid settings.**

***Index Terms*—Emotion, Depression, Affective State, 360° Exploration, Head-Tracking**

I. Introduction

Virtual Reality (VR) is similar to Lewis Carroll's Alice's Adventures in Wonderland, which begins with a dramatic fall into a fantasy world through the rabbit hole and takes her on a surreal journey of realising an alternate world of logic, emotion, and perception, as she interacts with the objects in the fantasy land. Likewise, VR is used to artificially stimulate our senses, our body, and trick our mind into believing another version of reality that may not match our current physical reality. The ability of VR to make us feel 'being present' in a parallel reality and the ability to create a controlled environment is enabling the cognitive and psychology researchers to think about once unthinkable empirical subjects such as spatial learning [34], emotion perception [26], [40], body image and feeling [4], empathy [32], treating PTSD [28] and depression [12] patients in controlled settings, to name a few. The current work focuses on analysing the head-movement correlates of affective experience while exploring the 360° emotional videos using head-mounted display (HMD).

A. Emotion and Virtual Reality

Emotion is an essential part of our everyday experiences. It is a powerful tool that shapes our thinking and behaviour. Studies focusing on emotion have used faces [3], [10] everyday objects and natural scenes [24], [33], dynamic scenes and movies [23], [29]. Recently, the emergence of 3D and immersive virtual technologies, commonly referred as VR, has enabled us to present the stimulus on 3D displays compared to traditional 2D displays [6], [34], [40]. The high perceptual-and-control realism of VR enables an increased sense of presence and more real psychological responses in the context of emotional stimuli as compared to the traditional two-dimensional interactions [23], [29], [40].

The increasing importance and relevance of HMD in studying emotion [7], [40] and psychological disorders [12], [28] demand evaluation of 360° exploration behaviour of VR affective experience and its relation with other psychological processes, such as attention and memory, and psychological disorders, such as depression and anxiety. The virtual 360° exploration using head-movement is assumed to vary as per the task and stimulus conditions similar to other psycho-motor measures like eye-tracking. The seminal work of Yarbus [42] has shown a difference in eye-movement while viewing the same image ("The Unexpected Visitor" - a painting by Ilya Repin) with different questions in mind. The free view task demonstrated a dispersed scan. Whereas the specific questions, like age or clothes, showed a more focused scan pertinent to the question. People showed higher scan at faces when asked to report the age and showed higher scan at clothes when asked to report the clothes people wearing [42]. Since Yarbus's [42] successful demonstration of task dependent eye-movement, eye-tracking measures have been used to explain various cognitive phenomena such as attention [9], [31], memory [37], decision-making [14] and emotion [1]. In the following section, we briefly discuss the relation between affective experience and cognition, using behavioural, eye-tracking, and HMD studies.

Studies investigating the relationship between emotion and cognition [16], [35] have shown a differential effect of positive and negative stimuli on cognitive processing. The theory of positive emotion [16] suggests that positive emotion broadens the scope of attention and helps in building thought-action repertoires. Studies [13] using affective stimuli have shown that pleasant experience widens the scope of attention spatially and temporally. The spatial widening of attention enables processing of peripheral relevant [35] or irrelevant information [13]. Whereas the temporal broadening of attention allows faster switching of attention from one task to another [35]. The broadening and narrowing of attention in correspondence with pleasant and unpleasant affective experience also indicate the need of attentional resources required for processing any given information. It has been argued that broadening compared to narrowing of attention requires lesser attentional resources and enables better attentional control to switch attention between multiple tasks. The building aspect of theory of positive emotion [15], [16] highlights the motivation, urge, and seeking to do more, an appetite to learn more while performing the given task. Studies using eye-tracking measures [39] have supported broaden and build theory [16] by showing higher fixation time for peripheral information under positive condition compared to neutral condition.

The proliferation of VR technologies, such as Oculus Rift and HTC Vive, has made some of the questions pertaining to psychological research more accessible to address. Studying emotion, and related psychological processes and psychological disorders are one of such psychological investigations that have become a central focus of VR psychological research [17], [25], [26], [28]. However, unlike other VR psychological research, such as spatial cognition, the studies focusing on emotion and VR have not exploited the VR measures to explain the affective responses and experiences. Studies using VR to examine emotion responses have been majorly focused on evaluating fearful experiences [26], [36], and have used self-reported measures like affective rating scales [26], [36], verbal strategies [26], clinical self-report or clinical observations [17], [28]. To the date, only few studies [25] have reported head-movement analysis of affective experience using VR emotional stimuli.

In Li et al. [25] study, 73 immersive videos were shown to 95 participants, in which at least 15 participants explored each video. The participants' subjective response on valence and arousal was collected using SAM scale (described in section II-E1) after viewing every video. Their head-movement around the three axes that is X, Y and Z were logged to assess their scanning behaviour. The side-to-side movement along Y-axis is defined as yaw, up-down movement along X-axis as pitch, and tilt movement towards the shoulder along Z-axis as roll [25]. They observed significant positive correlations between valence and standard deviation of yaw movement, and between arousal and standard deviation of pitch movement, indicating increased side-to-side angular movement in a pleasant environment compared to negative context and increased up-down angular movement in high arousal state versus low arousal state, respectively [25].

Li et al. [25] finding can be explained in light of theory of positive emotion. It can be argued that pleasant experience broadens the scope of attention and allows capturing a large peripheral information, and therefore enables wider scan to explore the virtual environment. However, the unpleasant experience narrows the scope of attention and allows more focused processing of information, and therefore requires smaller scan to explore the virtual environment. In nutshell, the pleasant and unpleasant experience leads to differential attention processing while exploring the 360° affective videos. However, it isn't clear whether varying scope of spatial attention transcends to temporal engagement. If spatio-temporal attention are orthogonal in nature [35], then we can expect that the pleasant experience will not only broadens the spatial scope of attention, but will also increase the temporal scope of attention and may lead to longer temporal engagement while exploring VR affective stimuli. The previous finding [25] help us to deduce the relation between spatial scope of attention and its relation with affective experience, however, we felt limited to conclude anything meaningful with respect to the temporal scope of attention, suggesting for the building aspect of theory of positive emotion [15], [16]. This led us to investigate the relationship between affective experience and head-movement while exploring the 360° emotional video.

In order to address the orthogonal nature of scope of attention, i.e. spatio-temporal, we planned to analyse the speed of scanning and region-wise coverage along with standard deviation of yaw movement while experiencing pleasant and unpleasant feeling. Why is this important? The broaden and build theory [16] argues that positive emotional state not only increases the scope of attention, it also increases the thought-action repertoires suggesting for curiosity and urge for seeking more information, which might lead to more head-movement during exploration. If pleasant video broadens the scope of attention and increases the information-seeking behaviour, then larger scanning behaviour, and increased region-wise coverage would be expected with pleasant videos compared to unpleasant videos. The breadth of attention covers the spatial as well as the temporal scanning behaviour [35], which refers to covering more region as well as covering more distance per unit time while experiencing the pleasant compared to unpleasant 360° videos. Thus, the use of VR can be extended to examine the existing cognitive theories of affective state and corresponding exploration behaviour to understand the underlying cognitive mechanism.

The objective of this study examines the correlation between affective state and 360° exploration behaviour. It is assumed that if pleasant experience allows capturing more spatio-temporal information, it will lead to more wider and more longer scan than unpleasant experience.

II. Method

A. Participants

A total of 32 college students volunteered for this study. We used nonprobabilistic sampling techniques, namely convenience and snowball sampling, to recruit students for this study. Due to some technical issues during the experiment, the self-report and head-tracking data for two participants were incorrectly captured. Therefore, only 30 participants' data (age range: 18 – 27 yrs; average age: 20.96 yrs; 22 males, 8 females) were considered for analysis. All participants performed Snellen Visual Acuity test, Ishihara Colour Blindness test, BDI, two emotion state surveys, two VR surveys, and a demographic survey. The current study aimed to collect data from healthy control (HC) participants, and therefore BDI [8] was adopted to exclude participants (if any) who demonstrate a propensity to depression and might interact with the emotional videos differently [18], [21]. All participants were naive to the purpose of the experiment and had no or minimal experience of using VR before this experiment.

B. Material

The current study has used 360° HMD videos, BDI, two emotion state surveys i.e., Emotional Reactivity Scale [27] and Emotional State Questionnaire [20], two VR experience surveys i.e., Sense of Presence Survey [41] and Simulator Sickness Questionnaire [22], followed by demographic survey. We have not described and discussed the data of emotional response surveys and VR surveys due to page limit of the manuscript. The 360° HMD videos and BDI are described as follows:

1) 360° Head-Mounted Display Videos: Due to lack of Indian VR affective videos, 360° HMD videos were selected from Stanford VR affective database [25]. The database consists of 73 videos, and a total of 10 videos were selected for this study. The criterion for selection was based on extreme values of valence that is for the extremely pleasant category the valence ranged from 7–to-9 points and for the extremely unpleasant category, it ranged from 1–to-3.5 points on a 9 point likert SAM scale (section II-E1). Arousal values were kept as close as possible to minimize the variability for another dimension of affective experience and hence the arousal data was not statistically analysed. The values of arousal ranged from 3.2 to 5.6 points. In total, 19 videos fit the criterion, of which the videos with lower resolution, longer duration and inappropriate object size ratio were excluded. The final set comprised of 10 videos, equally divided into pleasant and unpleasant videos as per Stanford sample affective rating. The link to the videos with description, duration, observed valence and arousal ratings, and Stanford study's valence and arousal ratings are provided in table I. The numbers with video names are the indices as per Stanford database.

2) Beck Depression Inventory-II (BDI): It consists of 21 items of multiple-choice self-report statements and is widely used to assess the propensity to depression. Participants were instructed to pick out one statement in each item that best describes the way they had been feeling during the past two weeks. The standard scores were divided into four categories: 0-13 minimal depression; 14-19 mild depression; 20-28 moderate depression; and 29-63 severe depression [8].

C. Equipment

Virtual Reality System: The HMD Oculus Rift CV1 was used for displaying the 360° videos. It consisted of 1,080 × 1,200 pixel resolution per eye, and 2,160 × 1,200 for both eyes with 90Hz refresh rate and 360° positional tracking. The head-position and orientation in real space were tracked by optical 360° tracking sensor, which translated the same to virtual space, with <5ms latency and with 1,000Hz rotational and 60Hz positional update rate. The Alienware 15 gaming laptop with 1,920×1,080 resolution, NVIDIA GeForce GTX 1060 graphics card, and 60Hz refresh rate, was used to render the 360° pleasant and unpleasant videos. Unity 3D game engine was used as a platform to transform the YouTube 360° videos into 3D scenes and log the real-time head-movement data.

Logging head-orientation data: To analyse scanning behaviour while experiencing VR environment, head-orientation data, that is the angle (in degrees) at which the participants' head was oriented in X, Y and Z direction over time, was logged. In order to log the observers' head-position in virtual space, the centre of the camera was used, as the camera view updates with the change in head-movement. Since the FOV of the device was known, the displayed view was calculated using centre of the camera as a reference point.

D. Procedure

The session began by welcoming participants and making them comfortable for the experiment. The participants signed the consent form and performed the visual screening tests before starting the HMD video exploration. They were instructed with detailed description of valence and arousal using SAM scale ratings. HMD headset was adjusted to clear vision, and participants were instructed to stand and explore the environment as naturally as possible. They were informed that they could move their head to the left, right, up or down, and turn around or move around while viewing 360° affective video. After each video exploration, they were asked to rate their affective experience in terms of valence and arousal using SAM scale (section II-E1).

Similar to Li et al. [25], each participant explored four videos and at least 11 participants explored each video. The videos were shown in a pseudo-randomized order, where no two videos belonging to the same category were presented in sequence, and the two categories of videos were counterbalanced across participants. After all the four videos

TABLE I

DESCRIPTION OF VIDEOS ALONG WITH DURATION, MEAN VALENCE AND AROUSAL VALUES FOR OBSERVED (HEALTHY CONTROLS) AND STANFORD'S STUDY [25] SAMPLES. THE FIRST FIVE VIDEOS (INDICES: 3, 14, 16, 19, 21) BELONG TO THE UNPLEASANT CATEGORY AND THE LATTER FIVE VIDEOS (INDICES: 23, 26, 47, 49, 70) BELONG TO THE PLEASANT CATEGORY

	Video name (with indices as per Stanford study)	Video Description	Observed Valence	Observed Arousal	Stanford Valence	Stanford Arousal	Duration (sec)
1	Abandoned City(3)	A city after apocalypse with garden and trees, with no people around.	4	3.8	3.33	3.33	45
2	War Zone(14)	Different scenes of riots depicted one after the other.	2.88	4.5	2.53	3.82	165
3	Solitary Confinement(16)	A prison with an audio describing devastating life experiences.	4.29	3.29	2.38	4.25	208
4	The Nepal Earthquake Aftermath(19)	Multiple destruction sites presented one after the other.	3	4.2	2.73	3.8	230
5	Zombie Apocalypse Horror(21)	A thrilling environment with people preparing to attack zombies.	4.34	4.78	3.2	5.6	235
6	Instant Caribbean Vacation(23)	A vacation on a ship with people taking water rides and cherishing moments.	7.4	4.2	7.2	3.2	150
7	Getting Licked by a Cow in Ireland(26)	Cows crossing by and licking the viewer.	5.75	3.38	7.07	3.21	50
8	Puppy Bowl XII(47)	A field game competition among puppies.	6.72	4.43	7.44	4.75	177
9	India's first ever 360° Wedding Video(49)	Traditional Indian wedding scenes with lights and decoration.	6.63	2	7.07	4	153
10	Tahiti Surf(70)	Underwater and above water surfing experience.	6.8	5.2	7.1	4.8	172

were explored, participants were asked to fill five surveys (section II-B) followed by collection of demographic details. The experiment was conducted in a dimly lit room.

E. Measures

The current study employed SAM scale to measure subjective affective experience (section II-E1) and head-tracking parameters to measure exploration behaviour while viewing 360° HMD videos. The scoring details for both the measures are given below:

1) Self-Report Affective State: SAM scale was used to measure valence and arousal state of an observer after viewing the video. The scale varies from 1 to 9, where '1' represents unpleasant and low arousal experience, and '9' represents pleasant and high arousal experience in correspondence with valence and arousal affective state.

The two affective state, valence and arousal, assessment was based on 2D circumplex model [30] of affect , in which the 'valence' refers to the feeling of pleasure, and 'arousal' refers to the intensity or alertness in response to the given stimulus. The circumplex 2D model depicts the position of a particular affective state on valence and arousal coordinates, in which the horizontal axis represents the valence dimension and vertical axis represents the arousal dimension [30].

2) Head-Tracking Parameters: Total 3 head-tracking metrics were incorporated by using participants' head-orientation with respect to the starting position in a given virtual space. The 3 head-tracking metrics comprised: standard deviation of head-movement around all the three axes; scanning speed; and region-wise analysis. The logged head-orientation data during advertisement section (present in a few videos at the beginning and at the end) were not considered for statistical analyses. The details of head-tracking metrics are as following:

Standard deviation of head-movement (degree): First, the mean angles of head-orientation around all three axes were calculated. Circular mean, instead of linear mean, of all the logged values was computed to reduce the error caused by the 360° nature of data points. Further, the standard deviation of head-movement was analysed to evaluate the spread of the head-orientation around the mean.

Scanning speed (degree per sec): This measure represents the rate of change of angular movement at which the scene was explored. To do this, the total distance was calculated, which represents the total amount of degrees covered by the participant while exploring the video. Distance covered by yaw movements was calculated by summing up the differences between two consecutive time stamp logged values in 'Y' direction. Similar calculations were performed along 'X' and 'Z' axes for pitch and roll movements, respectively. After distance calculation, the scanning speed was calculated by taking total distance covered per sec (unit time). Median values were calculated to evaluate the central tendency of speed with which the participant explored the given environment.

Region-wise analysis: For each video, it was observed that the starting point, by default, was 90° and hence was taken as a reference point to define regions. Also, it was observed that for each video, the stimuli orientation in the 360° view was constant, irrespective of participants' initial viewing settings. The 360° region was divided into 4 regions, 90° each. The starting point that is 90° was considered as the midpoint and from this point, region 1 was defined by taking 45° region

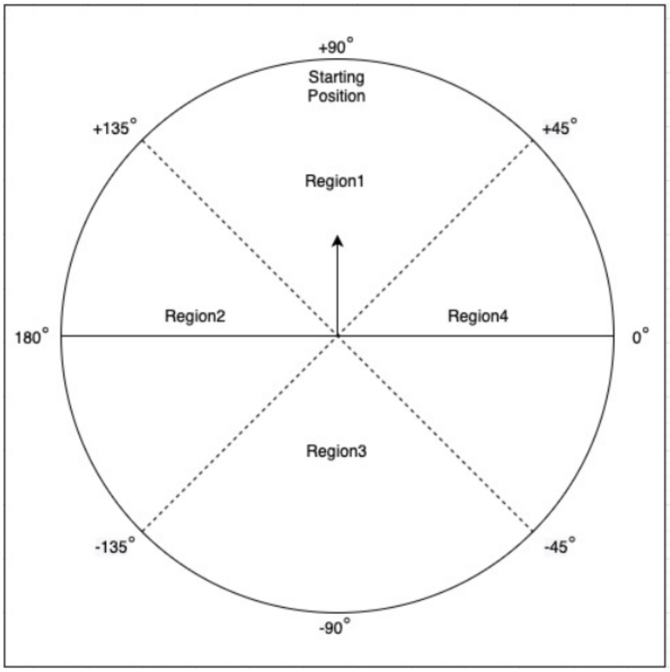

Fig. 1. Pictorial depiction of distribution of 360° view into four regions (region 1 = front view; region 2 = side view(left); region 3 = rear view; region 4 = side view(right)).

clockwise and 45° anti-clockwise that is from 45° to 135°. Likewise, other regions were defined as region 2, 3 and 4, as shown in figure 1.

III. Results and Discussion

The results are described in two sections. First section III-A, focuses on reporting affective experience using SAM scale with respect to the affective videos and BDI categories. Second section III-B focuses on the relation between the affective experience and the HMD 360° scanning behaviour.

As mentioned above, we conducted BDI to exclude participants, if any, with propensity to depression. However, our data revealed that 43.3% of the current sample's (n=30) score on BDI fall under either mild, moderate or severe depression scores, and therefore compelled us to include their data for analysing affective experience and corresponding 360° HMD exploration behaviour. Participants' distribution as per BDI categories were minimal (n = 17), mild (n = 7), moderate (n = 1) and severe (n = 5). The minimal category is treated as equivalent to normal healthy category. To consider the impact of propensity to depression on emotional state, VR scanning behaviour, and VR experience, the current study included data from mild and severe categories to compare with minimal or healthy control (HC) category. The data from moderate category were not included for comparative analysis as it consisted of only one participant. However, the correlational analysis used all the 30 participants' data.

A. *Affective Experience using SAM Scale:*

This section describes the affective experience after exploring the HMD 360° affective videos and the comparison of affective experience between the groups as per BDI scores.

The mean value of self-reported valence ratings for each video was calculated and submitted to the Wilcoxon Signed-Rank test to evaluate the effect of pleasant and unpleasant videos on affective experience. The data of samples from severe group were not submitted to the statistical analysis due to very small sample size (n=5). The subjective ratings of affective experience from the two groups, minimal, and mild BDI scores, were analysed separately. The minimal group showed significantly higher affective ranks for pleasant videos ($M = 6.56$) than for unpleasant videos ($M = 3.74$), $W = 34$, $z = -3.62$, $p < 0.001$, $r = -0.62$. The effect was consistent with the mild group ($W = 2$, $p < 0.05$, $z = -2.36$, $r = -0.63$), suggesting a similar judgement was used for the virtual emotional experience. The minimal group showing a significant difference in pleasant and unpleasant experience is not a novel finding. Reporting a difference between pleasant and unpleasant experience and its impact on other cognitive processing is already well-established [16], [35]. However, mild propensity to depression showing a similar trend as minimal propensity to depression is a novel finding. The current result is encouraging and should be subjected to test further for investigating the mood congruency effect and attention biases in case of propensity to depression. Such studies would help to identify the cognitive and biological risk factors for clinical depression with more ecologically valid settings.

The mood congruency effect shows a correspondence between an emotional state of the participant and the affective nature of the stimuli. The studies investigating the role of mood on memory showed better recall of positively inclined words when participants reported pleasant mood compared to unpleasant mood [11], [19]. The better recall of mood-congruent affective stimuli indicates a biased attention processing for the corresponding stimuli. In case of depression, participants are shown depression specific negative or unpleasant stimuli to investigate the attention bias to mood-congruent stimuli [11], [19]. Depression is a clinically diagnosed state of mind which disrupts the cohesion of our mood pattern that is lasting longer than a few weeks, say more than a year [2]. The studies investigating the role of depressive predisposition in attention processing for affective stimuli have shown attentional biases for unpleasant compared to pleasant stimuli [11]. If participants with mild propensity to depression show a similar trend in subjective reporting, then they would also resemble in attention processing and may show generic attention biases to unpleasant stimuli, instead of mood-specific congruency [11]. The generic attention bias could be defined as differential response to the unpleasant compared to pleasant stimuli because of the difference in attention mechanism. As mentioned, theory of positive emotion [16] states that positive emotion broadens the scope of attention and accommodate more information spatially as well as temporally [35]. Whereas, negative emotion narrows the scope of attention and demands looped focus to the previously presented stimuli, thereby reducing intake of new spatio-temporal information [35].

Further, the current study analysed the effect of propensity to depression as per BDI depression scores on affective experience. Two separate comparisons were performed for pleasant and unpleasant subjective affective experience by using the Kruskal-Wallis test. The Kruskal-Wallis test did not show any significant difference between the three groups for valence subjective reporting. For pleasant videos, the test-statistic value observed was H(2) = 2.85, p = 0.24, z = 1.17, r = 0.217, and for unpleasant videos H(2) = 2.35, p = 0.30, z = 1.04, r = 0.193. The current result is contrary to the previous finding [11], [19]. It could be because the chosen stimuli might not have been a mood-congruent and therefore, could not yield a difference. The other potential explanation for the no effect of propensity to depression on affective experience can be credited to skewed unmatched sample size of mild (N=7) and severe (N=5) depression with minimal group (N=17), unequal distribution of specific videos under a given group (e.g. 'Tahiti Surf' video was viewed by 5 minimal, 5 mild and 2 severe groups of depression) varying video duration and its impact on affective experience. The current data suggest for selecting videos with equal duration, larger sample size, and matched distribution of video contents for better comparisons.

B. Head-Tracking Scanning Behaviour

This section reports the HMD 360° scanning behaviour using head-movement data in relation to affective experience and predisposition to emotional state, and region-wise analysis.

Total 30 participants' data of valence ratings were analysed. Each participant explored 4 videos and rated after every video exploration. In total, 120 ratings and 120 head-tracking files were recorded. Since two head-tracking files got corrupted, we used 118 head-tracking files for statistical analyses. We performed non-parametric Spearman's rho correlations between valence and head-movement parameters because we observed violation of normality assumptions in some of these variables by using Shapiro-Wilk test. We analysed the relation between valence and head-movement, that is, how self-reported perceived emotion is reflected in one's scanning behaviour. The current study shows a significant positive correlation between valence and standard deviation of yaw movement [r(118) = 0.223; p = 0.015]. The current result is in line with the finding reported in the Stanford VR affective database study [25] where valence and standard deviation of yaw were found to be positively correlated [r(73) = 0.27, p = 0.03]. The result suggests that as the environment varies from extreme unpleasant to extreme pleasant, the length of the horizontal scan (yaw) increases. The result shows significant positive correlations between valence and standard deviation of roll movement [r(118) = 0.183; p = 0.047]; valence and scanning speed w.r.t. yaw [r(118) = 0.241; p = 0.009], valence and scanning speed w.r.t. pitch [r(118) = 0.199; p = 0.03], and valence and scanning speed w.r.t. roll [r(118) = 0.207; p = 0.025]. The current results support our hypothesis of broadening and narrowing nature of the attention [16], [35], [39] in correspondence with positive and negative stimuli, suggesting larger scan when pleasant compared to unpleasant affect was experienced. Higher scanning speed with pleasant video suggests that pleasant experience increases the urge to seek more information as hypothesized considering broaden and build theory [16]. The scatter-plots for the observed correlations between valence and yaw head-movement are provided in figure 2.

To analyse the relation between predisposition and 360° scanning behaviour, Spearman's rho correlation was performed between BDI scores and head-movement data. The result showed a significant positive correlation between BDI score and standard deviation of yaw head-movement [r(118) = 0.307; $p < 0.001$] suggesting that higher the propensity to depression, higher the degree of yaw movement scan would be. The current trend is contradictory to the previous finding that shows reduced psychomotor response when diagnosed with major depressive disorders [5], [38]. Despite interesting results, the current study is limited in explaining the contradictory finding because of lack of knowledge of their medication history, which plays a crucial role in psychomotor retardation.

Further, the current study evaluated the region-wise scanning behaviour across the 10 videos. The total distance covered in each region was calculated. For each participant, only one of the four regions was explored the most. We observed that region 1 was the most explored region for all the videos except the 'Solitary Confinement' video. There are two possible explanations for preferring region 1 (front-view) for exploration. First, people might be able to immerse themselves and hence they showed similar exploring behaviour as in natural settings, that is after exploring the front-view (region 1), they looked mostly either to their left (region 2) or right (region 4), but rarely viewed their rear-view (region 3). Second, to explore the rear-view (region 3), they might have to perform larger angular movement using whole body, which they might have lacked incentive for. We have also plotted the 360° region-wise exploration with pleasant and unpleasant experiences for normal healthy participants (figure 3).

The nature of audio and video account for a lot of variables, due to which the findings may deviate from the ground reality. However, we should consider those variables and design the study with a more systematic approach that can address the deviation generated from such variability. These issues are discussed as limitations of the study in section V. Future studies would be required to report and explain the most preferred viewed region during 360° affective exploration.

IV. Summary

The current study was conducted to examine the relation between the affective experience and 360° scanning behaviour by employing HMD VR. Three novel observations were made. First reports a significant positive correlation between the standard deviation of yaw and the valence, independent of the propensity to depression. The result suggests that when participants feel positive, they tend to scan the environment more widely than when they feel not so positive or negative. Second reports a significant positive correlation between scanning speed and valence, suggesting that pleasant experience

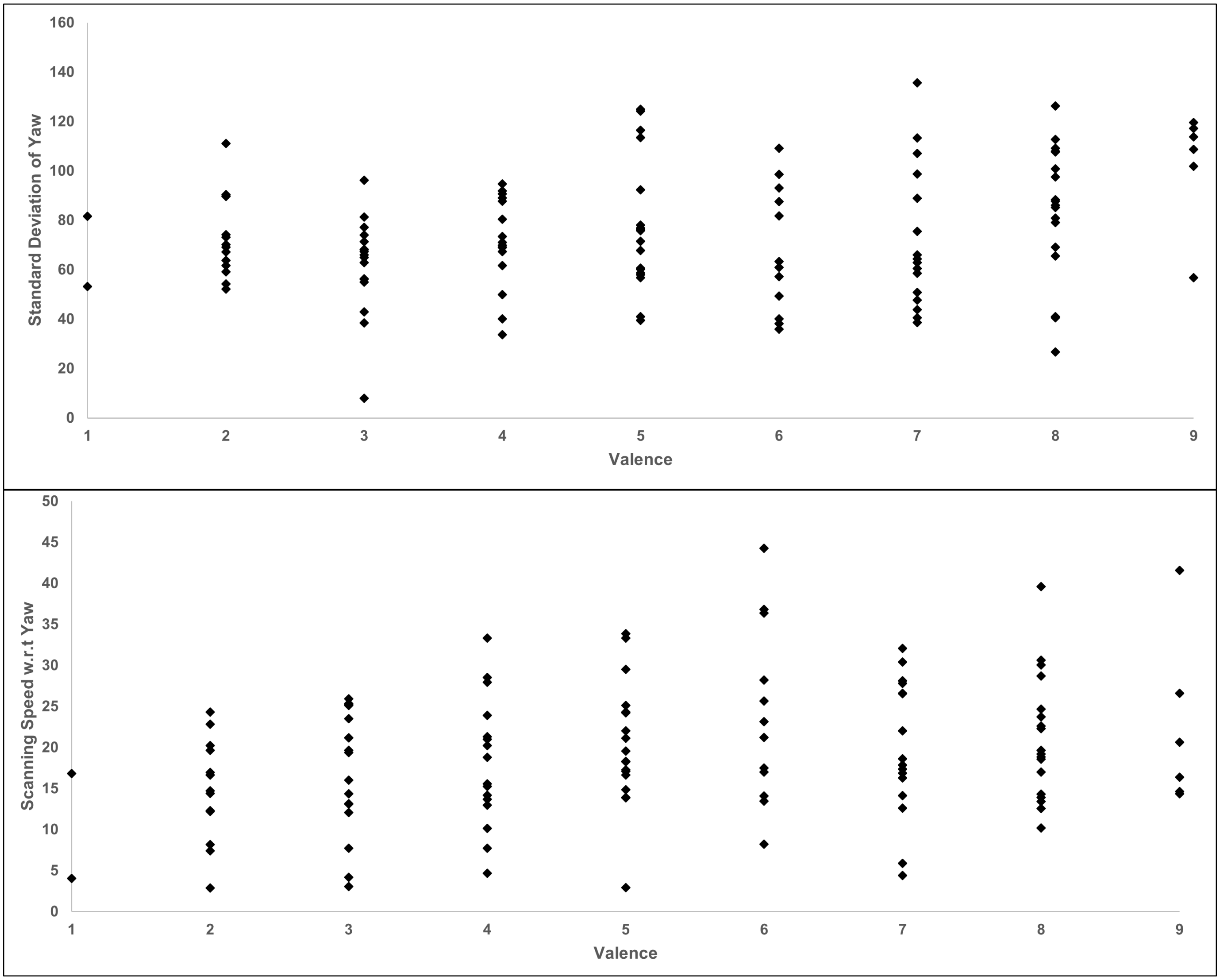

Fig. 2. Scatter plots representing the Spearman's rho correlation between affective experience of valence and the standard deviation of yaw (top) and affective experience of valence and the scanning speed w.r.t. yaw (bottom).

not only modulates the spatial coverage but also motivates to seek more information temporally. Third reports comparatively higher viewing counts to the front field of view, suggesting that until there are changes in videos in other fields, participants tend to use their natural, comfortable viewing orientation.

The positive correlation between standard deviation of head-movement and valence, and positive correlation between scanning speed and valence, suggests that unlike unpleasant experience, the pleasant experience not only broadens the scope of attention [16], as shown in static eye-tracking research [39] but also motivates to seek more information to know the environment. The current results are encouraging and invite future research to investigate the spatio-temporal engagement of attention while exploring affective stimuli as our findings are qualified by the limitations that were inevitable to the study because of the lack of standardized VR affective database. The observed limitations are discussed below.

V. Limitations & Future Directions

The current study enabled us to realise four major limitations of currently available dynamic 360° affective videos database [25]. These limitations are highlighted in light of subjective responses made in regards to the corresponding videos. The affective 360° database [25] videos varied in their display duration, dynamic nature of the video (e.g. dynamic or static), nature and genre of the content. Though the current study tried to match the duration of the video display as close as possible, the average display time of selected videos was 158.5 secs, with SD=65.6, indicating high variability in exploration time subjected to the video display duration itself. We observed that no two videos from the selected videos (Table I) could match on genre and or content. The subjective affective response corresponding to such videos could be a result of any of the aforementioned factors and may not reflect the true affective experience. For example, video (21) and video

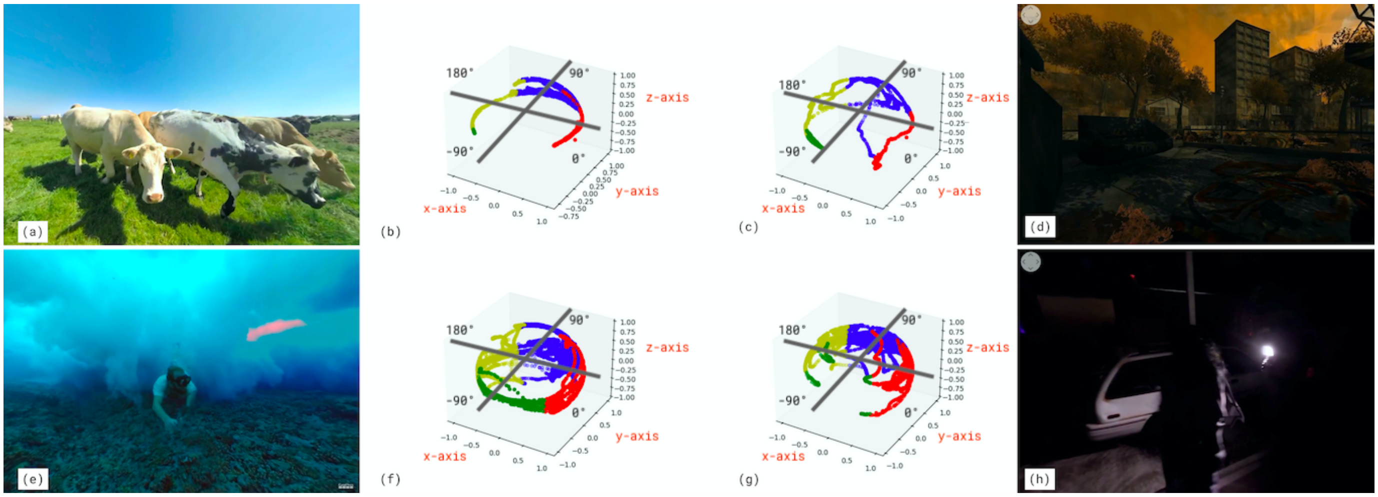

Fig. 3. Comparative exploration behavior of pleasant [(a), (e)] and unpleasant [(d), (h)] affective video experiences. The video names with their indices are as follows: (a) “Getting licked by a cow in Ireland (26)”, (e) “Tahiti Surf (70)”, (d) “Abandoned City (3)”, and (h) ”Zombie Apocalypse Horror (21)”. (b), (f), (c) & (g): Corresponding 3D region-wise plots of head-movement data while exploring VR 360° videos by normal healthy participants (blue = region 1, yellow = region 2, green = region 3, red = region 4).

(70) were grouped under extreme unpleasant and extreme pleasant categories respectively as per Stanford subjective rating [25] but were different in their display duration, content and nature of the video. It is important to understand that if these two videos are compared as per their subjective affective responses and corresponding video exploration behaviour, then the validity of such comparisons need to be matched. Although large sample size can account for some of the confounds, still there is a need for normalisation among videos that can address these variabilities. The current study suggests for collection of 360° culture-specific videos that are more comparable on pleasant and unpleasant experiences to develop the VR affective video database parallel to IAPS and GAPED [6], [24] static affective picture stimuli.

Future studies should consider the 360° video quality challenges and use within-group design to analyse the individual variability across the affective states. As HMD VR offers a more dynamic interaction with the affective stimuli, it might help in better understanding of spatio-temporal cognitive imprints of affective experiences in more ecologically valid settings. These analyses could be used to evaluate the relation between affective 360° exploration behaviour and cognitive processing, to study multidimensionality of various psychological disorders, like depression [38].

Ethics Statement

The study was reviewed by the independent body of Institute Human Ethics Review Board committee evaluated the research proposal based on the recommended code of ethics guidelines from World Medical Association (Declaration of Helsinki) for experiments involving humans, and the Association for Psychological Sciences.

Author Contributions

MG and PS played a critical role in discussion of video selection, design and plan of the experiment, plan and interpretation of behavioural head-tracking and affective data analyses, and worked together in conceptual discussion and writing manuscript. MG performed the video selection, data collection, and performed all the inferential statistics. PS conceptualized the idea, contributed substantially in manuscript writing and advised at every stage of the project. MA and RS played a crucial role in devising algorithms for head-tracking parameters, writing UNITY code for transcribing YouTube videos and then synchronizing them with HMD virtual reality for head-orientation data logging, and performed data coding. RC assisted in data collection and helped critically in video selection and survey descriptive analysis. ARB helped in selecting the appropriate clinical surveys and advised for the protocols to be considered in the current study. MS and PS have worked together on multiple drafts of manuscript and prepared the final version. All authors read and approved the final manuscript.

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Conflict of Interests Statement

The authors in this research declare no conflict of interests while working and preparing this manuscript.

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