Virtual Reality for Emotion Elicitation – A Review

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Abstract—Emotions are multifaceted phenomena that affect our behaviour, perception, and cognition. Increasing evidence indicates that induction mechanisms play a crucial role in triggering emotions by simulating the sensations required for an experimental design. Over the years, many reviews have evaluated a passive elicitation mechanism where the user is an observer, ignoring the importance of self-relevance in emotional experience. So, in response to the gap in the literature, this study intends to explore the possibility of using Virtual Reality (VR) as an active mechanism for emotion induction. VR can simulate controlled environments with high immersion, presence, and interaction to induce intense emotions. Therefore, researchers can evaluate emotional experiences in a realistic context. For the success and quality of research settings, VR must select the appropriate material to effectively evoke emotions. Therefore, in the present review, we evaluated to what extent VR virtual environments, videos, games, tasks, avatar, images, and 360-degree panoramas can elicit emotions. Further, we present public datasets, discuss challenges and recommendations, and review emotion-sensing interfaces related to VR research. The conclusions reveal the VR’s potential to evoke emotions effectively and naturally by generating motivational and empathy mechanisms, which makes it an ecologically valid paradigm to study emotions.

Index Terms—Emotions, emotion induction, virtual reality, elicitation, affective computing

1 INTRODUCTION

Emotions are a significant part of human associations correlated with nonverbal communication [1], behaviour [2], physical and mental changes [3]. It is a sensory condition associated with cognition, behaviour, and arousal that leads to physical and psychological changes [4], [5]. The conceptualization of emotional definition is complicated by the broader mechanism involved in the phenomenon and although, there is no consensus on the definition of emotion, the following factors can be interpreted without debate: involvement of several components of the human body, response based on subjective evaluation, and readiness to deal with stimuli.

Neuroscience portrayed the role of emotions in human creativity [6], cognition [7], [8], decision making [9], [10], [11], and brain activity [12], [13], and therefore it is important for computers to have the expertise to identify and express emotions to facilitate Human-Computer Interactions (HCI) [6]. At the same time, with the focus on Artificial Intelligence (AI), Affective Computing (AC) emerged as a computing paradigm that concerns emotion modeling, recognition, and synthesis. As conceptualized by Paiva, et al. [14], the Affective Loop of emotive machines and users consists of emotional elicitation, recognition, and behaviour generation (expression, adaptation, and synthesis) as seen in Fig. 1. This emphasizes the gravity of understanding emotions in HCI and underscores the significant need to understand the underlying mechanisms of emotions. It is essential in the affective science to design an effective emotional environment to create ecologically valid affective statuses to obtain reliable results. This often depends on successful emotion induction [15].

Multidisciplinary science has used numerous emotion induction mechanisms to evoke a range of emotions in controlled experiments which can be broadly grouped into passive and active. However, passive methods are a more pronounced source compared to active methods which are more realistic, hence evoke natural and ecologically valid emotions [16]. Although many studies have successfully manipulated emotions using active mechanisms, to date, there is still controversy over the most optimal mechanism for selecting a medium with appropriate content and subjective and objective measuring criteria to create real feelings in laboratory settings. The use of Virtual Reality (VR) has witnessed remarkable growth in psychological studies in recent years. Therefore, we hypothesize VR as an effective and powerful emotional induction mechanism to generate a variety of emotions and empathy machines [17]. Although VR has already proven to be an appropriate medium for emotion elicitation, it is important to also highlight its limitations and ways to improve its quality. Further, more elaboration is required for the type of VR medium, content, and environmental condition to induce affective state, and ways of measuring subjective and objective emotional experience (e.g., surveys, devices).

Several studies have used VR as a major stimulant [18], [19], [20], [21], [22], but few survey publications discuss the VR potential in emotion induction [23], some rarely mention [24] or some did not refer [25] to it as an elicitation material. In comparison to the review [23], we cover 134 studies...
(where previous work used 42), and additionally, investigate the importance of seven VR mediums in inducing emotions and their content, focus on head wearable devices that can be used with HMDs, subjective and objective measures, and challenged and recommendations for the use of VR in AC.

The exact mechanism of manipulating interactive content to generate specific emotional experiences has been debated [26], [27]. Inspired by the lack of a comprehensive empirical study, the purpose of our review is to assess the potential of VR in the emotion-inducing process which is required for laboratory experimental conduct. In consonance with that, this study investigates the past paradigm of literature and makes recommendations for selecting the materials for emotion elicitation. Data sources are a mandatory requirement for psychological research and the establishment of a database can be quite cumbersome and expensive. Therefore, in our survey, we will highlight publicly available datasets generated using VR media content and further about applicable subjective and objective measures in establishing a novel dataset. Moreover, the findings of the analysis will be directed to the formulation of a more rigorous and successful research framework. These will lead to more realistic elicitation of emotion, which are important for detection, synthesis, and analysis of the underlying mechanisms of emotions.

In this survey, first we explored the number of research papers that incorporated VR in emotional studies. Fig. 2 shows the upward trend of VR usage over the past decade from 2011 to 2021 (up to December 2021). The results were obtained from Google Scholar, searching the keywords “Virtual Reality” AND (“Affective computing” OR Emotions) AND (Elicitation OR Induction) AND (HMD OR “head mounted display”) anywhere in the article. The graph clearly shows that literature has an increasing interest in the utilization of VR to study emotions or to utilize emotions in interaction designs. We then defined a new search criterion; “Virtual Reality” AND (“Affective computing” OR Emotions) AND (Elicitation OR Induction) AND (HMD OR “head mounted display”) from 2017-2021 to address the most recent work in detail. A panel of 763 studies was identified from Google Scholar. Fig. 3, shows the PRISMA [28] and snowballing [29] approach for selecting the relevant papers. As shown in the figure, first we removed the duplicates (n=19) and screened the papers by abstract. We excluded 636 papers as they were not related to AC, some were books, chapters, reviews, theories, designs, conference abstracts and programs, some were non-English and did not have full text. Then we performed a snowballing and did a full text analysis to the remaining papers. The reasons for excluding 30 papers were not-relevance to AC, theories, and design papers, and not using VR. Overall, 134 studies were used in the survey.

Different methods and mediums generate different intensities of emotions [25], [30], depending on the content and level of engagement. Therefore, we categorized the selected studies based on the VR medium to analyze the distribution as shown in Fig. 4. Accordingly, Virtual Environments (VE) (where user interact with virtual entities), videos (where user is exposed to 360-degree videos, movie clips), games (where user play interactive games), tasks (where user performs structured interactive tasks), avatar (where user exposed to graphical representation of a person), images (where user exposed to static images), 360-degree panoramas (where user exposed to 3-dimensional panorama) and combinations of several media types are commonly used. Therefore, in section 4 we discuss those media in detail.

The survey was constructed covering papers related to VR technology in affective computing and psychology. While
we have witnessed a revolutionary development of VR-related studies in the literature, we have limited the focus of this review to the evaluation of the emotional induction material, which is the primary basis for affective computing studies. As technology evolves, researchers need to study and apply those techniques in academic implementations. Consequently, validation of state-of-the-art technology is required to design an innovative and reliable paradigm. This review is among the first surveys in emotional studies, that the effect and feasibility of VR to study emotions are analyzed. In addition, we investigate the potential to induce emotions as explained by discrete and dimensional theories using several VR media contents by categorizing VR media content into seven main categories as VE, videos, games, tasks, avatar, images, and 360-degree panoramas and analyzed in detail. The results can inform the type of media content to be used to evoke emotions successfully in future emotional studies.

The rest of the paper is organized as follows. Section 2 describes the main emotional frameworks and then in section 3 on emotion elicitation, we discuss what elicitation is and the main emotion induction modalities as passive and active. In section 4, we will discuss in detail VR and report the main media content that can be used to induce emotions by VR. Next, the possibility of VR to analyze emotional phenomena as defined by discrete and dimensional representations is reviewed in section 5. In section 6, we present the public datasets generated using VR, and subjective measurements in emotional studies in section 7. After that we discuss the emotion sensing interfaces in section 8 and the challenges and recommendations when using VR in emotional research in section 9. Finally, we present the discussion in section 10 and conclude in section 11 by directing future research.

2 Emotion Representation

Emotions are a major factor influencing human development. It is an aggregated sensation associated with mental, psychological, and physiological changes. Accordingly, emotional modeling and computerization are critical domains in the fields of psychology, computer science, and cognition which was later termed as Affective Computing (AC) [6]. Numerous paradigms have been developed to study emotion by data-driven and theory-driven approaches such as Discrete, Dimensional, and Appraisal frameworks.

Being one of the theoretical frameworks in AC, discrete models hypothesize that there are a significant number of core emotions each arouses a response to address an evolutionary requirement [31], [32]. Grandjean, et al. [33] identified basic emotions as affect programs triggered by events that cause changes in facial expressions, physiology, and functionality. Contrariwise, Paul Ekman [34] argued that basic emotions are common in human and species cultures, so the need to define core emotions are reasonable, while others are more likely to vary between cultures and are unique to species. Gu, et al. [35] defined basic emotions as internal regulations of neuromodulators that cause external behaviours, and as primary, inner conditions that have been adjusted through evolution to deal with the individual goals derived from the background. By contrast, Ekman [36] discussed several features that distinguish basic emotions from others, highlighting distinctive universal signals, automated assessment mechanisms, emotion-oriented physiology, and universal antecedents as prominent.

Notwithstanding the acceptance of the basic theory of emotion, there is no agreement on the exact number of core sensations [35]. For instance, after closely observing facial expressions, Paul Ekman [34] suggested a more extensively used model that contemplates six fundamental emotions: fear, surprise, happiness, anger, disgust, and sadness. Izard [2], [37] categorized basic emotions as positive (joy, interest) and negative (fear, sadness, disgust, anger). Additionally, he emphasized that social emotions (guilt, shame, contempt) and emotional patterns of love and attachment can be conditionally incorporated into basic emotions assuming their principles for evolution, development, psychology, and adaptation.

Table 1 illustrates the discrete views of emotions defined by various theorists, and implicitly demonstrates that many theorists have agreed to define basic emotions like happy, fear, sad and anger. Apart from them, several psychologists also consider surprise and disgust as emotions within the basic framework.

Table 1: Basic Emotions and Their Definitions

The dimensional theory of emotions states that emotional terms can be defined by a point in a continuous space of numerous continual elements [31]. From the beginning of the definition of dimensions as pleasure-unpleasantness, excitation-negation, stress-relaxation [33], these models play a major role in emotional evaluation. Following the initial interpretations, several models emerged, with variations in the number and type of scales. Among them, the two-dimensional Circumplex Model of Affect [46] is the most widely used, representing the entire affective states by valence and arousal [47]. Valence defines the range from positive to negative, and Arousal characterizes the activation of emotions ranging from active to passive [48]. In addition to these two dimensions, another scale was introduced as the Dominance to the PAD model to represent control [24]. Nevertheless, the following Table 2, which reviews the dimensions hypothesized by various psychologists, shows that they have come to a weightier conclusion for interpreting emotion dimensions as valence and arousal as shown in Fig. 5.
The other emotion framework which has recently gained more attention in the AC community is the appraisal model. Several studies have already highlighted the importance of taking a multi-componential approach to emotions [21], [53]. Appraisal theories address emotions as processes and components [54]. The main components identified by appraisal theory on the emotional episode can be identified as; an appraisal component which evaluates the event, a motivation component that defines action tendencies, a physiology component with changes in bodily functions, an expression component with motor expression and a feeling component showing emotional experience. Component Process Model (CPM) which is a variant of appraisal theories has four major evaluations in the appraisal component as; relevance (how the event is related?), implications (what are the implications of the event?), coping potential (how to cope with the event?), and normative significance (what is the significance of the event?) [55]. However, yet there are very limited studies available in the literature that assume the appraisal theories, even though these models describe the full emotional experience rather than a single perspective like feeling. Therefore, in this review, we will not consider appraisal theories in detail. However, we recognized the importance of considering the full appraisal components in AC, and the necessity to go beyond the two dimensions (valence, arousal) to define the emotional experience [21], [53].

### TABLE 1
Discrete Emotions Defined by Psychologists

| Reference | Theorists | Discrete emotions |
|-----------|-----------|-------------------|
| Ekman, et al. [38] (1971) | Paul Ekman and Wallace V. Friesen | Anger, happiness, fear, surprise, disgust, sadness |
| Frijda, et al. [39] (1986) | Nico Frijda | Desire, happiness, interest, surprise, wonder, sorrow |
| Ekman [34] (1992) | Paul Ekman | Happiness, surprise, fear, sadness, anger, disgust |
| Parrott [40] (2001) | W. Gerrod Parrott | Anger, fear, joy, love, sadness, surprise |
| Cicero and Graver [41] (2002) | M. T. Cicero and M. Graver | Fear, pain, lust, pleasure |
| Izard [37] (2007) | Carroll Izard | Joy, interest, fear, sadness, disgust, anger, guilt, shame, contempt, love, attachment |
| Jack, et al. [42] (2013) | Rachael E. Jack, Oliver G.B. Galrod and Philippe G. Schyns | Fear, anger, joy, sadness |
| Gu, et al. [43] (2015) | Simeng Gu, F. Wang, T. Yuan, B. Guo, and J. H. Huang | Fear, anger, joy, sadness |
| Pereira Junior and Wang [44] (2016) | Fushun Wang and Alfredo Pereira Junior | Fear, anger, joy, sadness |
| Zheng, et al. [45] (2016) | Zheng, Simeng Gu, Yu Lei, Shanshan Lu, Wei Wang, Yang Li, and Fushun Wang | Fear, anger, joy, sadness, missing |

### TABLE 2
Emotion Dimensions Defined by Psychologists

| Reference | Theorists | Dimensions |
|-----------|-----------|------------|
| Schlosberg [49] (1954) | Harold H. Schlosberg | Pleasant-unpleasant, tension-relaxation, excitation-calm |
| Ekman [50] (1957) | Paul Ekman | Pleasant-unpleasant, active-passive |
| Wundt [51] (1969) | Wilhelm Wundt | Valence, arousal, intensity |
| Osgood, et al. [52] (1975) | Charles Egerton Osgood, William H. May, and Murray Samuel Miron | Arousal, valence, potency |
| Russell [46] (1980) | James Russell | Valence, arousal |

### 3 EMOTION ELICITATION

Induction mechanisms play a crucial role in triggering emotions by simulating the sensations required for a research plan [56]. In human affective disciplines, it is essential to elicit affective states that are decisively trustworthy and morally influential [57]. Choosing the right elicitation mechanism is essential for the success and quality of research behaviour and for drawing reliable conclusions.

Stimulus presentations should be organized in a manner that provides the same viewing experience for all participants [16]. Previous implementations seek to control for the stimuli presenting duration [18], [58], screen resolution [16], [59], screen brightness [16], screen size [26], VR headset types, environmental conditions [60], standing or seating position. Also, most of the studies organized all the participants to experience the same content in a randomized manner [20], [21]. This provides the generalizability of the research outcome eliminating any biases due to the content order or visual characteristics.

The studies evaluated in this survey, confirm the use of different emotion elicitation sources in controlled experiments. Accordingly, studies in the literature have adopted mainly two methods for emotion induction as passive and...
active [16]. Passive elicitation involves the subject as an observer of an emotional event (e.g., watching movies) and, conversely, in an active scenario subject is actively participating in the emotional encounter. Active methods mainly consist of avatar mediation, immersive and interactive virtual reality, and interactive games. So compared to passive elicitation, the involvement and emotional experience of the participant is more realistic and powerful. The following sections will therefore focus in detail on passive and active emotion elicitation modalities, explaining the features of each method in different situations. We also highlight the relevance of VR content in the active elicitation section.

3.1 Passive Elicitation
Most of the studies over the years have been researched by a passive elicitation mechanism and these include watching images (International Affective Picture System (IAPS); [61], Geneva Affective Picture Database (GAPED); [15]), observing emotional video [12], [13], [53], recalling experience [25], listening to music (International Affective Digitized Sounds (IADS-E); [62]). For an exemplar, AlzeerAlhouseini, et al. [63] have used picture clips from the IAPS to generate happiness, calm, fear, and sadness, and showed the relationship of Electrocardiography (ECG) with arousal and higher relability of Electroencephalography (EEG) than ECG in identifying emotions. Similarly, S. Katsigiannis and N. Ramzan [64] have used film clips to evoke nine emotions and have achieved accuracies higher than 61% for each of valence, arousal, and dominance. As another paradigm, Estupínán, et al. [18] manipulated the images of GAPED in an immersive VR environment to evaluate the possibility of VR to improve the emotional experience by images. They identified an increase of arousal and a higher negative experience of valence in VR conditions.

Visual stimuli (static and dynamic) are a powerful way of eliciting emotions and have been used to study the discrete representation of emotions relative to music, recall, situational procedures, and imagery. This was confirmed in a recent survey by Siedlecka and Denson [25] who assessed five emotional stimuli assessed on visuals (image, video), music, recall, situational procedures, and imagery, reviewed against anger, surprise, fear, disgust, and sadness. Moreover, Domínguez-Jiménez, et al. [65] used video clips to trigger happy, amusement, and neutral emotions. They have reported an accuracy of 100% in predicting target emotions. Other than the potential of films to induce emotions, the use of films as a mode in AC comes with the desirable features as being dynamic, easy to install, accessible, and ecological valid [66]. There is a wealth of literature on the effectiveness of video stimuli in creating a multiplicity of emotions [3], [65], [67], [68].

Broadly speaking, extensive use of images in the literature can be justified by its simplicity [48], cost-effectiveness [24], flexible processing, and easy control of experimental features [16]. Contrariwise, the lack of environmental validity [21] relative to active methods has led to criticism of these traditional approaches in assessing the strength of the impact. Also, observing emotional material limits the full-dimensional experience with a real sense of emotional variations [69]. On another note, static images are influenced by environmental factors and inadequate emotional immersion [70].

Although passive mechanisms are used extensively due to their readily available characteristics, they potentially limit the generation of reliable frameworks due to the observational role of the subject in the induction process which lacks any direct self-relevance. The following section will therefore focus on active participation.

3.2 Active Elicitation
The quality of understanding the emotional process depends on the naturalness of the sensations [71], [72], social acceptability and believability [11]. Accordingly, active emotional stimuli are an optimal solution that led to the generation of more intense experiences. The presence of genuine interactive content in a shared space facilitates natural social interactions and emotions [73]. Active methods mainly involve: 1) interactions with humans and computer-generated avatars that respond with facial expressions and behavioural changes, [74], [75], [76], 2) virtual reality [22], [77] which provides the viewer with an immersive and interactive experience, as in the realistic world, and 3) games that provoke user engagement while completing tasks or tackling challenges [78], [79].

In contrast to passive methods, active methods are high in ecological validity [16] and inactivity in an interactive setting [80]. However, most studies in the literature have focused on passive methods. Possible reasons for this may be that there is a great wealth of literature, which provides standards, norms, and practices of experimental conduct using readily available passive content to induce emotions. Therefore, the selection and evaluation of emotional content can be done by referring to the literature [3], [53], [67]. To our knowledge, however, there is minimal analysis of VR equipment usage in emotion studies, their type of media contents, screening processes, and the public datasets. Hence, it emphasizes the need for a literature analysis and a guide to VR-based emotional research. Therefore, the subsequent assessments will focus on VR-based emotional research to fill the gap.

Virtual Reality (VR) is a computer-aided design that provides an interactable virtual three-dimensional environment [81], [82]. VR has been used as a medium for games [22], [83], entertainment [60], [84], [85], education [82], [86], physical and cognitive training [87], [88], rehabilitation and therapy [20], [60], [89], [90], [91], and surgery [92], as VR promotes user connectivity and naturalness. Recent studies have revealed that there is a significant increase in interest in human emotional behavioural studies using VR to effectively evoke emotions in the data collection procedure. VR can be integrated with numerous elicitation modes as images [18], [93], videos [58], [94], games [19], [21], and 360-degree panoramas [95], [96], [97]. Lists of literature on VR usage in Affective Computing, psychology, and Human-Computer Interaction (HCI) based on the content type is provided in the Supplementary material, which can be found on the Computer Society Digital Library at http://doi.ieeecomputersociety.org/10.1109/TAFFC.2022.3181053 for interested readers; VE (Supplementary material A, available online), videos (Supplementary material B, available online), games (Supplementary material C, available online), tasks (Supplementary material D, available online), avatars (Supplementary material E, available online), images (Supplementary material F, available online),
et al. have elicited joy, sadness, anger, 

VR sources have the power to induce emotions according to the dimensional space. For example, Marin-Morales, et al. [95] successfully developed a computer-based emotion predictive model by eliciting active emotions via Immersive Virtual Environment (IVE). Their finding validated the use of VR in eliciting and recognizing emotions. Another similar study based on Virtual Reality (VR) games was able to achieve satisfactory accuracy in classifying emotion for valence and arousal dimensions [19]. The reader may refer to the following works which had investigated arousal [98], [99], [100], [101], [102], [103], [104], [105], [106], [107], [108], [109], valence [110], [111], [112], [113], [114], valence and arousal [19], [58], [88], [94], [95], [115], [116], [117], [118], [119], [120], [121], [122], [123], [124], [125], and valence, arousal, and dominance [72], [73], [86], [126], [127], [128], [129], [130], [131], [132] using VR.

Earlier research has used VR as a medium to induce and analyze emotions according to the discrete theory. For example, Felnhoyer, et al. [133] have elicited joy, sadness, anger, anxiety, boredom by five virtual park scenarios. Also, Meuleman and Rudrauf [21] have used VR games to elicit a diverse range of discrete emotions and showed the potential of VR in AC. Moreover, VR as an active method induces emotions better than passive methods. Compared to the VR and desktop/2D environments, a higher level of happiness [134], surprise [134], pleasantness [98], relief and positive influence [135], presence [136], skin conductivity [134], and HR [134] and was revealed. Interested readers can refer to the following literature for more details, that have investigated discrete representation of emotions using VR [20], [21], [22], [26], [27], [58], [60], [69], [71], [73], [79], [80], [83], [84], [98], [99], [100], [101], [103], [105], [110], [112], [115], [127], [129], [130], [132], [133], [134], [135], [136], [137], [138], [139], [140], [141], [142], [143], [144], [145], [146], [147], [148], [149], [150], [151], [152], [153], [154], [155], [156], [157], [158], [159], [160], [161], [162], [163], [164], [165], [166], [168], [169], [170], [171], [172], [173], [174], [175], [176], [177], [178], [179].

The success of VR can be explained by its ability to perform better than traditional non-immersive content, to keep subjects immersed in a collaborative environment [180] and enhanced performance and enjoyment by flow feature [181]. According to Slater, et al. [182], immersion is a description of technology, which explain the capability of computer displays in triggering inclusive (physical reality removal), extensive (sensory modalities), surrounding (panoramic VR), and vivid (resolution, fidelity, evoked energy) features. Further VR features includes sense of presence which referred to as the feeling of being physically present in a mediated environment [181], [183]. This sense of “being-there” is a conscious state, in which participants experience a more engaging reality [182]. The concept of flow in VR can be defined as an autotelic experience which brings cognitive, physiological and affective states [184]. When people experience the flow state, they are deeply involved, highly concentrated and enjoying the activity for their own sake [185].

Clearly, with the usage of low-cost Head Mounted Display (HMD) [77], VR technology has proven to produce immersion [22], [26], [80], [186], a sense of presence [22], [69], [86], interactivity [142], flow [19], [181], and isolation of participants from external stimuli [95] in affordable controlled experiments. For example, Hidaka, et al. [69] recorded VR scenes of happiness, depression, relaxation, fear, and distress which were viewed by the subjects. They concluded that the VR sources provided by the wearable HMD were more effective than the traditional display where they achieved a higher average value for effectiveness, efficiency, and environment setting for HMD than the display.

A VR system usually consists of a headset with visual and audio facilities, controllers, and tracking stations (or tracking built-in using computer vision approaches for localisation). As given in supplementary material A-H, available online, recent research mainly uses HTC Vive versions and Oculus HMD versions for their research. One reason may be that VR materials such as games, videos, and scenes, are readily available on streaming platforms such as Vive Port and Steam for HTC Vive and Oculus Store for Oculus Rift. HTC Vive platform is affordable [77], provides free movements and accurate positioning within the boundaries of virtual space [187], and can be integrated with VR developer engines [187], [188], [189], [190]. Similarly, Oculus Rift is available at an affordable range [82], [171], [187], [191], is portable [82], [191], can be easily integrated into game engines for software development [82], and provides precise location details in the VR space [82]. Moreover, both of these commonly used HMDs are designed as wired, wireless, consumer graded [79] and provide 360-degree rotations [60], [94], [192].

The novelty of VR for emotion studies arises from its’ ability in triggering ecologically valid immersed emotive content in controlled research settings [71], [95]. VR can immerse participants in the virtual world and users can get fully engaged in that narration with intense emotions [22], [193]. It has the potential to effectively elicit emotional events leading to synchronous changes throughout the participant’s entire body [21], [22]. Therefore, VR can be an optimal solution to date for the study of emotions to evoke natural feelings.

4 ELICITATION MATERIAL RELATED TO VIRTUAL REALITY

4.1 Virtual Environments (VE)

Immersive Virtual Environment is a visual stimulus with dynamic content where the user can interact with virtual entities, traverse, and move the head. VE allows the audience to explore the entire interactive graphical world with or without control. As a distinguishing feature, VE provides researchers with the ability to simulate realistic, imaginative, and physically impossible moments and tasks.

VE scenes generated to induce joy and happiness include fantasy [69], [105], [128], relaxations and peace include nature scenarios [27], [69], [105], [110], [133], [135], [139], sad includes natural disasters [105], fear and anxiety include abandoned places [105], [128], gloomy scenarios

1. https://www.vive.com/
2. https://www.oculus.com/
3. https://www.viveport.com/
4. https://store.steampowered.com/
5. https://www.oculus.com/experiences/quest/
[27], [133], and dangerous animals and zombies [69], [84], [127], [159], [164], anger includes construction sites [133], boredom includes empty environments [133], disgust includes eating food after unpleasant animal encounter [137], arousal includes amusements rides like rollercoasters [104], [194], island and city [117], and valence includes city [117] and steel girder construction of a city [157]. List of VEs used in literature with dominant emotional experience is given in the Supplementary material A, available online.

4.2 Videos
Videos in VR can be presented as a 360-degree video or film excerpts. These are dynamic audio-visual stimuli used in the study of emotions [27] where participants follow a narrative story. The film-based studies performed thus far are mainly aimed at obtaining audio-visual stimuli through film libraries [107], film excerpts [88] and Immersive Virtual Environment (VE) [27], [195]. As examples, [196], [197] yielded significant results for the four-class classification of emotions which were induced via 360-degree videos based on Russell’s model of emotions. Further, a 360-degree video dataset was established by Suahami, et al. [80] using commercially available video content from streaming platforms. Those videos were based on a couple in a relationship, skydive experience, evil encounter, mysterious underwater experience, golden retriever puppies, bunnies, tree climbing experience, and an experience from a tower. A neutral stimulus or wash out clip is presented before each emotional clip to generate the baseline. For neutral stimuli, researchers usually use screensavers [16], or grey backgrounds [107] as wash out clips. See supplementary material B, available online for more details.

4.3 Games
Games are interactive content with decision making, and physical and mental involvement. Gaming has ranked itself as one decisive landmark of entertainment, which has seen incredible growth over the last decade. Games can arouse a broader spectrum of affluent and diverse emotions by the collaboration between players and player-agents through effective game events and gameplay [198]. VR gamification is responsible for creation of engagement [19], [88], entertainment [19] and involvement/flow [181]. Accordingly, the experience of flow (refer to section 3.2) stimulates a deeply concentrated and enjoyable moment. Therefore, the generation of extremely intense flow states will enrich the emotional experience. This flow has been studied by Granato, et al. [19] with VR racing games and analysing physiological signals. Game sessions reveal that players were enthusiastically absorbed in the elicitation session. Another research [181], studied the correlation between flow and presence, with role-playing games. They pointed out that games are a great source for getting a flow experience.

Although there are similarities between the content of the games and the audio-visual stimuli (please refer to section 4.1, 4.2, 4.6), there is a significant difference in the participants’ level of interaction [83]; while games engage with players actively, audio-visuals engage with the audience passively. For example, while watching a video, audience cannot alter the story and characters and they need to follow the storyline. However, in games, players have control over the events and decision-making power, thus the next gameplay and outcomes will be based on the actions and decisions of your own previous activities. Therefore, games stimulate natural decision making, interactivity, and experience.

In terms of measurements, games can create measurable variations in physiology to objectively monitor emotional components. This was demonstrated in [199], where they used multimodal analytics: Blood Volume Pulse (BVP) and Skin Conductance (SC) to predict emotions. They observed that the proposed approach could accurately predict anxiety, fun, excitement, and relaxation using features extracted from statistical analysis (average, standard deviation, max, min, range etc.) and Convolution Neural Networks (CNN). Furthermore, the authors have used an automated feature selection where they fed selected features into training models. The results revealed an increase in accuracy while fusing both BVP and SC. Similarly, VR games, evaluated by self-reporting and bio-signals, indicated the experience of higher levels of happiness, surprise and presence [134].

In addition, games can create motivating tendencies to win, immerse, and socialize [88]. These features of games indicate the ability to effectively access the motivational aspects of emotions owing to the active involvement of subjects. Most importantly, due to the rapidly changing nature of a game, we can expect variability in the emotions of the subjects [19]. This is a good alternative for studies focusing on models based on appraisal theory [12], [53] that assume rapidly changing processes [200].

With the advent of VR technologies in the gaming market, the use of traditional video games has changed dramatically to an immersive state [79]. In VR, the player actively encounters events like the real environment, where in video games player is separated from the scenario by a screen [21]. VR controllers allow players to interfere with actions, tasks, and touch in a mediated environment similar to the real world. Because of that VR games are more advantageous than traditional video games [83], [134] in evoking intense immersive experiences.

Further, games have a challenge that evaluates a player in terms of their physical and mental involvement [22], [86]. In the physical challenge, the player is evaluated mainly through accuracy, speed, strength, coordination and in the mental challenge player is evaluated through cognitive effort, reasoning, decision making, inspecting, and planning [22]. Peng, et al. [22] conducted a study with several VR games with or without emotional challenges such as reasoning, decision making while the family is facing a sudden nuclear war. They found that games with emotional challenges had the potential to provoke different emotions than traditional challenges and emotions are more enriched in VR. Moreover, they concluded that an emotionally challenging game environment with higher vagueness, virtual characters, complex topics, and actions are more capable of revealing a naturalistic emotional experience.

According to Meuleman and Rudrauf [21], even though non-VR video games involve participants actively, they still separate the subject from the game narration by an avatar. So typical video games still lack in providing complete immersion and subjective feeling. Therefore, VR games are a better medium for emotional studies to provide a fully
dimensional experience [21]. The use of VR games as an active eco-valid method in emotion-related studies can be highlighted as successful because of its ability to perform better than traditional content and to immerse subjects in a collaborative environment. Researchers usually select games from gaming platforms like Steam6 and Oculus7. List of VR games used in literature with dominant emotional experience is given in the Supplementary material C and I, available online.

4.4 Tasks

In tasks user needs to perform structured interactive activities. These task related research mainly focus on emotion elicitation [112], [145], [152], [153], [158], [165], cognitive training [85], [88], and decision making [193]. The content of tasks are time manipulated [138], [153] (sometimes making it is impossible to complete the scenario), instruction oriented to collect objects and complete tasks [145], [152], [165], Stroop tasks [155], and drawing [112].

Research has shown the efficacy of physiological signals in measuring the affective states and cognitive load using VR task-based paradigms. For an example, Reidy, et al. [88] used VR gamification tasks for a cognitive training and collected facial Electromyography (f-EMG) signals. Their results were significant in accurately predicting emotions in terms of valence and arousal. Similarly, 98.1% accuracy for anxiety prediction has been achieved by Petrescu, et al. [165] using seven HR and EDA features. An overview of task usage in VR can be found in Supplementary material D, available online.

4.5 Avatar

In avatar mediation, users are exposed to a graphical representation of a person. Recent works show the potential of avatar mediation in affective studies. These studies mainly focus on studying the impact of full-body ownership illusion generated by avatars [119], impact of avatar facial expressions [20], [119], [192], impact of avatars with intelligence [131] in emotional responses, and the impact of storytelling with emotion embodiment [192], and agent interaction [150], [201].

Past research has implemented avatars to evoke basic emotions that demonstrate facial expressions. As an illustration, Bekele, et al. [59] have expressed happy, surprise, contempt, fear, disgust, sad, and anger at four arousal levels as low, medium, high, and extreme by computer-generated avatars playing facial expressions. Another similar research was done by Gutiérrez-Maldonado, et al. [20], where they induced happy, sad, fear, anger, disgust, and neutral emotions via male and female avatars showing changes in the facial area. Furthermore, social interaction with VR avatars can be defined as a potential social communication and skill development mode. Research has shown the efficacy of avatar-based systems in reducing stress [150], and developing social skills [20], [201]. Readers can find an overview of avatar usage in Supplementary material E, available online.

4.6 Images

Images are visually presented as static content. Digital or printed images are one of the main stimulants used in academic implementations to evoke emotions in the data collection process so far [27]. Typically, researchers select images from a large dataset after assessing their ability to elicit the required emotions and present one at a time. To minimize the risk of emotional cumulation, researchers usually present specific emotions in a single image stimulus [18], [93]. In addition to the elements mentioned in section 3 (duration, screen resolution, screen brightness, screen size, VR headset type, content), researchers usually keep the image size constant during the presentation. List of image medium used in literature with dominant emotional experience is given in the Supplementary material F, available online.

As we discussed the image datasets in section 3.1, in Table 3, we provide an overview of the image datasets used in VR-based research showing its usage in emotion elicitation. On another note, some studies suggest combining visual content with audio content to increase the effectiveness of mood induction [133].

Selecting static images for a study is easy; also, presenting and collecting data from participants is simple. Similar to the monitor presentation, image stimuli can easily render to the VR environment and present to the participant. However, the emotional intensity evoked by any image is low compared to the other mechanisms (video, virtual environments, games) discussed in the following sections [16]. Therefore, the intensity may not be strong enough to learn emotional differences from images. While watching images, the emotional responses tend to fade quickly [16]. Also, as images are only a symbolic representation of passive stimuli, differences in physiological signals, and expressions are small. Therefore, responses to presented images are primarily collected as subjective reports in most studies. Furthermore, image stimuli are shown to be better in evoking emotions explained by dimensional representations than the discrete representations [16].

4.7 360-Degree Panoramas

This is a technology that provides a 360-degree panoramic view of a virtual environment. By integrating to the VR technology, it provides the ability to view the background

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TABLE 3

| Overview of Image Dataset Used in VR-Based Emotional Research |
|---------------------------------------------|
| **Image dataset** | **Description** | **Annotations** | **Usage** |
| International Affective Picture System (IAPS) [61] | Colored images which have a range of events and objects that are related to humans. | Arousal, pleasure, dominance | [59], [202] |
| Geneva Affective PictureE Database (GAPED) [15] | 730 images of positive, neutral and four negative contents (siders, snakes, violation of legal and moral norms) | Valence, arousal | [18] |
| Nencki Affective Picture System (NAPS) [56] | 1356 high-quality photos of people, faces, animals, objects, and scenes | Valence, arousal, approach-avoidance, luminance, contrast, entropy | [118] |

6. https://store.steampowered.com/steamvr
7. https://www.oculus.com/experiences/
or scene in a full rotation. For example, Marín-Morales, et al. [95] generated architectural environments that can be visualized in 360 degrees. They generated four environments that are relevant to valence-arousal space by modifying the factors such as illumination, colour, and geometry. Using Support Vector Machine (SVM) they achieved an accuracy of 75% for arousal and 71.21% for valence prediction. Even though this shows the possibility of using 360-degree panoramas in studying valence and arousal, the overall emotional induction capacity seems limited (refer Fig. 8). Further, participant rated discrete theory based emotional experience was not reported using the 360-degree panorama (refer Fig. 7). Accordingly, within the selected scope, it shows the limited capacity of 360-degree panorama and images in inducing emotions with either discrete or dimensional representations. Therefore, the effectiveness of 360-degree panorama and images in inducing emotions as defined by dimensional theory is limited and not reported for discrete emotional interpretations. Within the scope, the effectiveness of triggering strong emotions by 360-degree panorama and images is limited, possibly due to its passive nature with fewer interactions. An overview of 360-degree panorama usage in VR can be found in Supplementary material G, available online.

Some of the research tend to use a combination of VR medias in inducing emotions and to compare the efficacy of several media in inducing emotions. We analyzed those studies and included in the Supplementary material H, available online.

5 DIFFERENT EMOTIONS IN VIRTUAL REALITY

Emotional representation can be explained by several models (section 2). Each model consists of distinct items to define emotions based on the events as framed in dimensional model (valence, arousal, dominance), Geneva Emotion Wheel [203], Positive and Negative Affect Schedule [204], Differential Emotions Scale [205] and appraisal models. The assessment of emotional reactions using many entities is important to capture the variations in a more generalisable system and to understand the complex emotions and capture emotion differences. Consequently, it is important to analyze the VR potential in inducing different emotional entities. Therefore, this section analyzes the possibility of using diverse VR media types for the induction of different types of emotions. Supplementary material J, available online provides an overview of the research works done using VR, including the details about stimuli content, outcome, annotations, and measures. Accordingly, the increasing number of publications with a successful outcome, indicates that VR has a great potential in studying emotions, and triggering changes in physiology.

Fig. 6 shows the distribution of main discrete theory-based emotions studied by the publications given in Supplementary materials, available online. According to the illustration, it can be noted that VR material has been frequently used for inducing joy, fear, relief, anxiety, amusement, stress, sadness, interest, anger, pleasure, and disgust. However, emotions like shame, disappointment, neutral, distress, depression, admiration, compassion, regret, contempt, confusion, unconfident, and hate have not been reported frequently in the literature. This may be due to the high complexity of those emotions, inattention of affective studies to study those emotions via VR or lack of readily available VR contents to induce such emotions. Given the higher efficacy of VR in generating a realistic experimental paradigm, future research should investigate ways to induce such emotions more effectively.

Next, we analyzed the material of frequently reported emotions explained by discrete theory. Fig. 7 shows the frequency of each emotion experienced by research publications based on the material used. Accordingly, it can be observed that VE seems to be used more often to induce relief, anxiety, amusement, stress, sadness, interest, pleasure, and disgust compared to the rest of the material. However, while the videos worked better, they outperformed other materials in terms of boredom and empathy induction. These can be explained by the minimal availability of the materials that induce diverse emotions and the less attention in the domain to utilize and generate relevant VR content. Games have been more widely used in inducing joy, fear, anger, contentment, pride, tension, guilt and hope

Fig. 6. Distribution of discrete representation of emotions induced in the VR literature.
than the other two types. And it has not performed well in
disgust, empathy, shame, neutral, compassion, contempt,
unconfident and hate. This bias towards using games for posi-
tive emotions is not very surprising as it would be challeng-
ing to find games that activate negative emotions as game
developers focus primarily on entertaining the community.
Task and avatar showed a moderate efficacy in inducing
emotions explained by discrete theory. However, in VR,
images and 360-degree panoramas don’t seem effective in
inducing emotions explained by discrete theory. Altogether,
the possibility of using VR as an affective medium to study a
wide range of emotions is validated. However, the efficacy of
different VR material is not uniform across different emotions.
In addition, further research works are required to arrive at
more solid conclusions related to complex emotions.

Fig. 8 shows a summary of research works conducted on
dimensional model of emotion using different materials.
Thus, within the scope of our selection criteria, VE, videos,
games have become an effective medium for the study of
valence, and arousal. Despite the limited research, VE seems
to be a better option to study dominance so far in the litera-
ture. Hence, more research is required to improve the
understandability of this emotion dimension and draw a
stronger conclusion regarding suitable material. Neverthe-
less, usage of avatar, images, tasks, and 360-degree panora-
mas were moderate across all three dimensions. This can also
be partially explained by the limited research that uses these
materials, so the individual capacity is not revealed. On
another hand, recent works on componential appraisal
model based study, interpreted emotional experience using
several dimensions as valence, arousal, motor expressions,
novelty, action tendencies and norms [12]. Similarly, Moham-
madi, et al. [66] translated emotional experience into action
tendency, pleasance, novelty, valuation of norms, arousal and
goal relevance. As both of these studies, induced emotions
using films experts in non-immersive environments, the
adoption of VR-based immersion in future research could
lead to a richer explanatory definition. Moreover, research
attention could be given to induce and study the features of
these additional dimensions.

6 DATASETS

Generation of an empirical database on affective computing
is quite difficult owing to the lack of necessary expertise
[206], [207], [208], unavailability of gold standard equip-
ment [207], the involvement of subjects, time constraints,
lack of budget, proper controllable environment and porta-
ble devices [64], [68]. Therefore, public datasets are a great
resource for scholars to augment research on emotion,
mood, and feeling perspectives [64], [207], [209]. Hence, in
this review we provide the details of the publicly available
datasets generated using VR in Table 4.

We have seen a similar distribution of material (Fig. 4)
used in public databases that many datasets have used VE
and video to evoke emotions. Also, public datasets focused
primarily on the emotional definitions given in the dimen-
sional model, with a greater focus on valence and arousal
dimensions. Many datasets focus on subjective and objec-
tive measures that can be used to enrich our understanding
of emotions. Accordingly, we realized the importance of
public datasets to the research community and identified
the importance of future research in generating public
datasets using a variety of materials such as VE, video and games, and focusing on discrete and appraisal theories.

7 MEASURING SUBJECTIVE EXPERIENCE IN VIRTUAL REALITY

To investigate research objectives and motivations, most VR-based studies apply a subjective experience evaluation, in which participants are asked to imply about the experience through some standard questionnaires. These self-reporting questionnaires are presented in paper-based, digital [107], [129], verbal [58], [211] and VR [19], [122]. In emotional studies, researchers often focus on the evaluation of discrete [83], dimensional [19], [94], and appraisal [21] models of emotion. The following Table 5 shows an analysis of emotion measuring frameworks that have used in VR studies. This can be referred as a guide in future AC research to appropriately measure the emotional experience. However, we noticed that only one framework is available to evaluate the appraisal model of emotion, hence attention may need in developing new frameworks or versions assuming to measure more solid and rich emotional representation and perspectives.

8 EMOTION SENSING INTERFACES FOR VIRTUAL REALITY

In previous section, we discussed about the recognition of affective state using subjective measures. However, emotion recognition can be better enhanced with objective measures than subjective measures. In AC, usually subjective measures are used as a ground-truth to develop affective recognition models, based on objective measures. As there are few reviews ([24]) that discuss the physiological measures in AC, we focus mainly on measuring affective state and its challenges using head wearable devices that can be used with VR headsets and their insights and measures.

Emotions transmitted can be assessed through a variety of bodily indicators using different technologies, methods, and tools. These approaches differ from each other by their performance in emotion differentiation, accuracy, usability [48]. The study of emotion involves the development of various frameworks for effectively automating emotion detection. Most such models have laid the foundation based on the analysis of facial, speech, gesture, and physical phenomena [219]. Nevertheless, the VR headset covers about half of the user’s face, preventing face expressions from being detected by traditional camera tracking methods. Therefore, embedding physiological sensors to the user’s face and collecting data is highly accepted in contemporary studies.

There is a wealth of literature on the use of wearable technologies for AC. Picard and Healey [220] hypothesized the concept of recognizing affective states of a wearer equipped with sensors and devices and termed as “Affective Wearables”. Prolonged physical connection with the user helps to understand the individual patterns of human behaviour.
TABLE 5
Frameworks to Measure the Emotional Experience in Virtual Reality

| Frameworks                               | Emotional model | Usage |
|------------------------------------------|-----------------|-------|
| Geneva Emotion Wheel (GEW) [203]         | Discrete        | [21]  |
| Positive and Negative Affect Schedule (PANAS) [204] | Discrete | [20], [71], [127] |
| Differential Emotions Scale (DES) [205]  | Discrete        | [133] |
| Emotion Annotation and Representation Language (EARL) [212] | Discrete | [22] |
| Visual Analogue Scale (VAS) [213]        | Discrete        | [27], [84] |
| Self-Assessment Manikin (SAM) [214]      | Dimensional     | [70], [94], [95], [105] |
| Affective Slider (AS) [215]              | Dimensional     | [19]  |
| Russell’s circumplex model [46]          | Dimensional     | [88], [191], [216] |
| EmojiGrid [122] (immersive tool)         | Dimensional     | -     |
| GRID questionnaires [217, 218]           | Appraisal       | [21]  |

associated with the affected states. Over the past few decades, extensive research has been conducted to develop emotion recognition applications with several biological senses. As suggested by AC concepts [6], the system layout, which includes physiological signals, is more advantageous than conventional methods such as self-reporting, expert reviews due to the inability to hide and control [63], [65], [221] as they are unconscious responses that occur after an event [10]. One of the positives of using biosignals is the ability to create wearable and seamless systems [65]. Furthermore, they are responsible for the continuous measurement of signals throughout the signal acquisition process [69].

The continuous evolving of VR based affect recognition technologies have formulated a novel research trend to incorporate wearable physiological sensors into VR headsets in response to the less portability and mobility of conventional biometric sensors. Recognizing that, real-time data acquisition interfaces have been developed and used in some of the recent literature [88], [180], [222]. So, the following will focus on the contemporary emotion-sensing interfaces for VR and their applications.

Facial Electromyography (f-EMG) is a technique to evaluate facial muscle functions through electrical pulses. But, in the context of VR, computer vision analysis of facial expressions is not appropriate as the user’s face is largely covered by the headset. Hence, among the many physiological signals, EMG-based methods can be used as a more reliable approach to the study of facial expression in VR due to the correlation of muscle activity with emotions [223]. Previous research has shown the potential for emotional recognition through built-in [19], [223], [224] and wearable equipment [88], [180], [225], and commercial versions of the f-EMG interface are currently available, considering the possibility of using f-EMG as a means of emotion recognition due to the onset of feelings of muscle activity.

EmteqVR® system [180], which is the latest progression of Faceteq [226] is commercially for biometric analysis of a VR immersive experience. This platform consists of dry electrodes that are embedded into the emteqGo VR headset or as an interface that can be embedded into the HTC Vive Pro headset [227]. This device comes with seven-channel f-EMG electrodes, a Photoplethysmography (PPG) sensor, an Inertial Measurement Unit (IMU) and real-time data manipulating software. Moreover, studies such as the one conducted by Reidy, et al. [88], demonstrated that EMG signals from Facetq HMD can be used to differentiate valence and arousal with an accuracy of 64% and 76% respectively. In another study using the Faceteq interface, researchers identified arousal detection from PPG sensors [107].

Intending to improve the flexibility of using plug-and-play interfaces with VR HMD, researchers have developed PhysioHMD [222] which is a software and hardware interface for collecting physiological signals. The interface has an array of EEG, EMG, EOG, EDA sensors that can be connected to AR or VR headsets. Their system is integrated into the Unity3D package so that the end-user can easily configure the developer environment and use visualizations for behavioural research.

Another potential interface that can be used in VR research for affective science was introduced by Looxid Labs[10]; LooxidVR headset as a complete VR system and LooxidLink as a VR mask; [228]. The LooxidVR headset enables researchers to integrate to Unity, time sync, track eye movements and EEG signals (6-channel). LooxidLink which is a non-invasive mask can be integrated into Oculus Rift, HTC Vive and Pro versions track 6-channel EEG [229].

Researchers have also explored wearable biosignal sensing devices that can be integrated with commercial VR headsets. For example, [189] has used a 14-channel Emotiv EPOC+11 EEG headset in VR based research, implicitly illustrating the feasibility of a unified experimental design. Similarly, Neurable12 has developed a retrofitted EEG headset that can be assembled into a VR headset and provides a natural translation of user intentions [230]. Moreover, a commercialized wearable VR is manufactured by OpenBCI13. Lakhan, et al. [231] has evaluated the possibility of using OpenBCI EEG device in comparison to research-grade EEG systems for emotion recognition and has claimed the significant accuracy of the device. Researchers have been interested in incorporating this wearable device for neurological research formulated by a VR protocol [85], [111]. Muse14 is another wearable that has been used in VR-based studies [102], [109], [173], [232] to obtain EEG signals.

With the perception of VR-embedded biosignal sensors in mind, these emerging emotion sensor interfaces could expose modern directions for affect and activity recognition, heading to potentially improved knowledge of human behaviour. These technologies, however, have little evidence in neuroscience and psychology research, hence, require further attention and improvement to develop a broader research.

9. https://www.emteqlabs.com/
10. https://looxidlabs.com/
11. https://www.emotiv.com/epoc/
12. https://neurable.com/
13. https://openbci.com/
14. https://choosemuse.com/
domain. It is also advisable to develop interfaces that can measure multimodal signals instead of using multiple devices. This creates a more natural emotion induction and measurement.

9 CHALLENGES AND RECOMMENDATIONS WHEN USING VR IN EMOTION STUDIES

While VR has been increasingly used in emotion research domain, there appear to have a set of constraints. Therefore, standards need to be identified and put into practice. Employing these standards may greatly elevate the efficacy of research conduct and minimize the impact from the limitations. First, researchers should evaluate the probability of different kinetic environments on the average population to lessen the impact of motion sickness. This facilitates in filtering participants at an early stage to collect data. For example, this can be executed primarily through a questionnaire at the initial contact with the participant. There are several questionnaires available in the literature such as the Motion Sickness Susceptibility Questionnaire (MSSQ) [233], [234] and the Virtual Reality Sickness Questionnaire (VRSQ) [235]. The reader may refer to the literature (MSSQ [84] and VRSQ [86]) for in detail usage.

As the second, having participants prior experience with an immersive VR environment is of great importance. For example, some research findings may be influenced by the novelty bias caused by first-time excitement in the VR medium [21], [22]. This can be further explained by the discrepancies between expected and reported emotions. Furthermore, due to the highly immersed VR content, participants tend to report a positive category, even though the material is expected to trigger a negative experience. On another note, it would be more difficult to find emotional content that induces negative emotions. The impact of the first-time VR experience can be minimized by employing participants with prior VR experience or by conducting a training session [129] with targeted participants prior to data collection. This provides additional advantages as, participants are aware of the perspective of a VR environment, and have an overall understanding of the hardware mechanics, especially while playing games using VR controllers. This further reduces the stimulation of unexpected emotions such as frustration when the exact mechanism is not known. Also, by employing this practice, researchers can recruit participants who are less vulnerable to motion sickness.

Another constraint while employing VR in affective research is the limited ability to study full facial expressions. Although there are a few growing interfaces for measuring facial expressions via physiological signals, their potential is limited to a few signal points and hence do not account for measuring detailed facial features. Most importantly, to conduct credible research, the applicability of using those hardware interfaces incorporated with diverse facial structures (i.e., fitting of interfaces) of participants should be verified for effective future directions.

10 DISCUSSION

The definition of emotions has been obtained from various studies through multidimensional data collection settings.

While this understanding of definitions is valid for historical understanding, many studies do not fully account for the natural and realistic emotion generation. As such, most emotional studies focus on passive emotional elicitation, and the participant is an observer of the overall emotional encounter. In that aspect, contemporary studies have directed and focused more on the formation of realistic virtual settings that increase the efficacy of evoked emotion, enhancing engagement and improving immersion by VR technology.

So, in this endeavour, a survey has been conducted on the potential of using virtual reality as a medium to elicit emotions with either discrete or dimensional representations. Here we mainly discussed virtual environments, videos, games, tasks, avatar, images, and 360-degree panoramas as main media content that are already used to induce emotions. We systematically reviewed public datasets generated using VR for emotional studies, familiarizing researchers with literature relevant to their domain, and directing researchers for the induction of realistic emotions by VR. In this review, we also analyzed the contemporary emotion-sensing head-wearable interfaces which can be used for more accurate acquisition of physiological signals and facial expression in affective computing studies designed by a VR protocol. Therefore, it is expected that these commercialized wearable devices will disclose novel research directions by mitigating the inability of facial expression analysis due to the occlusion of the facial activities by the HMD. More, we presented a review of subjective measurement approaches and limitations of using VR in emotional research and recommendations for that.

The followings are the basic conclusion of our study on VR to evoke emotions:

1) Using VR to study emotions, psychological traits and HCI is an elevated trend when formulating experimental procedures.

2) VR based media content are accountable for the elicitation of emotions and study emotions explained by both discrete and dimensional models.

3) The state-of-the-art research has excelled in using virtual environments, videos, and games in combination with VR and has been able to elicit a wide range of emotions.

4) Even though VR games-directed research is limited, it can be used to study different domains compared to other major media types due to the first-person role-play, virtual collaboration, and being an empathy machine.

5) VR provides the possibility to trigger changes in physiology, consequently, researchers can effectively assess bodily functions and reactions to investigate the emotional-physiology relationship.

6) VR games can trigger motivational tendencies to win. These features of games bring the ability to effectively access the motivational aspects of an experience. So, games can be used to evaluate emotional models like Component Process Model (CPM) [55] which treat Motivation as a major component and explore motivation tendencies for an extended time [186].
7) VR games can be used to evaluate rapidly changing physiological models that are defined by assuming a temporal perspective on emotion generation.

Considering the importance of emotions to humanity and society and their particular role in creating a natural human-computer interaction, emotion researchers should consider the following for the proliferation of a reliable model for effectively understanding emotions:

1) Many published examinations have assumed a passive elicitation of emotions and were unable to obtain the active involvement of participants in the data collection process. However, an increasing number of studies have empirically shown that active emotion elicitation methods are more pragmatic in evoking natural feelings. Therefore, a novel direction must be initiated with an active data collection mechanism such as VR to acquire a more reliable explanation in Affective Computing.

2) Benchmark datasets are required to study emotions and make consistent comparisons across different studies. In the long run, this will pave the path for the development of more generalized models that can arrive at a consensus on the evolving debates about the conceptualization of basic emotions and the mechanisms involved in emotion formation.

3) There are relatively few publicly accessible databases based on VR in the literature. As we explained earlier, VR involves the active collaboration of participants in the experiments which is a greater advantage in triggering real emotions. However, the limitation of publicly accessible datasets obstructs the development of novel research directions due to the lack of resources. Therefore, we noted the importance of establishing public datasets.

4) Existing VR contents are more suitable for eliciting positive emotions and there are limited VR contents to study negative emotions.

5) Future research can also consider the usage of emotion-sensing interfaces (Section 8) with VR headsets to measure facial expressions and physiological signals.

6) Few recent research has focused on eliciting multimodal emotions through haptic feedback [127], [236], which is a signpost to a novel direction. However, the domain is still immature, and the data collection methodology requires in-depth investigations to generate more intense emotion.

7) In AC, very limited research has adopted the principles of Appraisal theory [54] and the Component Process Model [55], even though these models can better reconcile with the recent neuroscience findings on emotion [53]. Therefore, we identified the importance of considering such models in future research. Other important theories of emotion such as the theory of constructed emotion [237] has also been neglected by the AC community so far and needs to be incorporated into the current approaches.

11 Conclusion

To our knowledge, this study is one of the earliest surveys on Virtual Reality to induce emotions. We conducted this survey by analysing the literature and we showed the possibility of novel VR technologies to elicit emotions for affective computing studies and potentially beyond. We also discussed the possibility of VR to elicit emotions according to discrete and dimensional models using virtual environments, videos, games, tasks, avatar, images, and 360-degree panoramas as emotive content. Public datasets generated via VR and sensors that can be used in future research were presented. Although it is ahead of the scope of this work, the conclusions imply potential future real-time adaptive VR design based on users’ emotions. With the continuous evolution of the experimental design with various data elicitation mechanisms, the understanding and classification of emotion will lead and enhance functions with computerized systems based on Affective Computing competencies.

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Chapter 11 - A Review of Emotion-Aware Systems for e-
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