RetroSketch: A Retrospective Method for Measuring Emotions and Presence in Virtual Reality

Dominic Potts
dominic.potts@uwe.ac.uk
University of the West of England
Bristol, UK
REVEAL, University of Bath
Bath, UK

Miloni Gada
mg2544@bath.ac.uk
REVEAL, University of Bath
Bath, UK

Aastha Gupta
ag2605@bath.ac.uk
REVEAL, University of Bath
Bath, UK

Kavya Goel
kg674@bath.ac.uk
REVEAL, University of Bath
Bath, UK

Klaus Phillip Krzok
kk2003@bath.ac.uk
REVEAL, University of Bath
Bath, UK

Genieve Pate
genievievepate13@outlook.com
REVEAL, University of Bath
Bath, UK

Joseph Hartley
jh3968@bath.ac.uk
REVEAL, University of Bath
Bath, UK

Mark Weston-Arnold
mdwa20@bath.ac.uk
REVEAL, University of Bath
Bath, UK

Jakob Aylott
jma66@bath.ac.uk
REVEAL, University of Bath
Bath, UK

Christopher Clarke
cjc234@bath.ac.uk
REVEAL, University of Bath
Bath, UK

Crescent Jicol
cj406@bath.ac.uk
REVEAL, University of Bath
Bath, UK

Christof Lutteroth
c.lutteroth@bath.ac.uk
REVEAL, University of Bath
Bath, UK

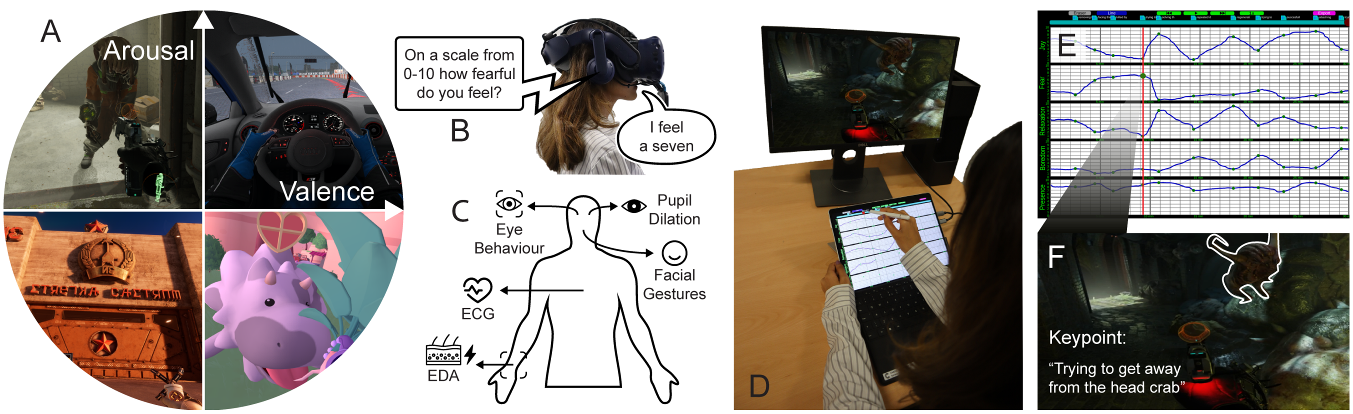


Figure 1: (A) Virtual Reality (VR) experiences are designed to elicit a wide range of emotions, across the dimensions of valence and arousal, as well as a sense of presence. These are commonly measured using (B) Experience Sampling Methodology which can introduce biases and fails to provide continuous measurements, or (C) physiological sensing which is difficult to administer and analyse. We present RetroSketch, a novel measurement method that complements existing methods. (D) Users watch and control a video playback of their VR experience, and provide (E) continuous and temporally aligned measurements for presence and four emotions, as well as (F) keypoints with annotations that offer qualitative insights and provide additional context.

*https://revealcentre.org/

CHI '25, April 26-May 1, 2025, Yokohama, Japan

ACM ISBN 979-8-4007-1394-1/2025/04
https://doi.org/10.1145/3706598.3713957

ABSTRACT

Virtual Reality (VR) designers and researchers often need to measure emotions and presence as they evolve over time. The experience sampling method (ESM) is a common way to achieve this, however, ESM disrupts the experience and lacks granularity. We propose RetroSketch, a new method for measuring subjective emotions and presence in VR, where users watch back their VR experience and retrospectively sketch a plot of their feelings. RetroSketch leaves the VR experience undisturbed and yields highly granular data, including information about salient events and qualitative descriptions of their feelings. We compared RetroSketch and ESM in a large study (n=140) using five different VR experiences over one-hour sessions. Our results show that RetroSketch and ESM measures are highly correlated with each other, as well as physiological measures indicative of emotion. The correlations are robust across different VR experiences and user demographics. They also highlight the impact of ESM on users' experience.

CCS CONCEPTS

• **Human-centered computing** → **Empirical studies in HCI**; **Human computer interaction (HCI)**; **HCI theory, concepts and models**.

KEYWORDS

virtual reality, emotion, presence, emotion measurement, presence measurement, emotion appraisal, experience sampling, physiological sensing, physiological correlates, games

ACM Reference Format:

Dominic Potts, Miloni Gada, Aastha Gupta, Kavya Goel, Klaus Phillip Krzok, Genieve Pate, Joseph Hartley, Mark Weston-Arnold, Jakob Aylott, Christopher Clarke, Crescent Jicol, and Christof Lutteroth. 2025. RetroSketch: A Retrospective Method for Measuring Emotions and Presence in Virtual Reality. In *CHI Conference on Human Factors in Computing Systems (CHI '25), April 26-May 1, 2025, Yokohama, Japan.* ACM, New York, NY, USA, 25 pages. https://doi.org/10.1145/3706598.3713957

1 INTRODUCTION

Measuring presence and emotions in Virtual Reality (VR) is important because they fundamentally impact the user experience. Arguably the most important function of VR is to immerse users in virtual environments and invoke a sense of presence – a feeling of *"being there"* [230] that elicits responses *"as if it were real"* [221]. Measuring presence can help researchers understand how it affects VR experiences, e.g. VR skills training is only effective if a sense of presence is invoked [77, 241], and can help developers improve VR experiences, e.g. by identifying breaks in presence due to design flaws [229, 238]. As a result, measuring presence has been a long-standing topic of research [251]. Of similar importance is the ability of VR to elicit emotions. VR experiences often need to be emotionally engaging, e.g. games that are exciting [123] or training simulations that can prepare people for the emotional stress of a real situation [152]. Emotions in VR are related to presence [47, 101] and have also been linked to training effectiveness [49, 257]. By measuring emotions, developers can improve VR experiences, for example by validating and refining experiences to evoke desired emotions or understanding when users are confused or frustrated. This is relevant in research such as when gathering behavioural insights [114, 146, 204], in social and empathy research [100, 161, 208] and research on VR itself [47, 62, 101], as well as for real-world applications such as therapeutic interventions [56, 150], education [4, 49, 257] and entertainment [92, 122]. As both presence and emotions change over time, methods are needed to measure them repeatedly as they evolve.

One of the most established approaches for measuring emotions and presence is the Experience Sampling Methodology (ESM) [119]. ESM provides subjective measures by administering validated questionnaires during, or immediately after, a VR experience. It is easy to administer, ecologically valid, and there are many variations of the methodology [34, 42, 64]. One of the most common ways of administering ESM is during the experience itself by asking the participant how they feel at specific points, e.g. in regular time intervals [46, 264]. However, this type of ESM has several disadvantages. First, it requires participants to report their feelings in the *very moment they are required to experience them*, which can result in an 'observer effect' disrupting the experience and influencing their response [9, 158]. Second, experimenters often ask participants out loud to minimise disruption, which in turn can increase the 'social desirability' bias and the chance participants respond favourably to the experimenter [79, 210]. Finally, ESM can practically only capture a limited number of data points, so important changes and events can easily be missed. Increasing the number of data points exacerbates the previously mentioned issues of disruption, observer effect, and social desirability.

Physiological sensing is another approach that has gained traction in recent years [52, 180, 201]. This is based on the principle that emotions and other internal sensations are associated with automatic bodily responses that can be measured [143]. Physiological sensing is desirable because it can capture changes in emotions continuously, in real-time, and removes the disruptions and biases that ESM suffers from. However, it is difficult to isolate the effects of individual emotions and other sensations in physiological signals, e.g. attempts to measure presence physiologically have not found anything conclusive [76, 251]. In addition, physiological signals are noisy due to factors such as user movement and exertion levels[170, 251] which necessitates non-trivial data cleaning and analysis processes, in addition to careful calibration and setup of the sensors themselves. Finally, due to the complexity of emotions, collecting ground truth data to be able to train physiological sensing models still relies on subjective methods such as ESM.

We propose *RetroSketch*, a new method for measuring emotions and presence in VR experiences. RetroSketch yields continuous subjective data of an experience, complementing existing methods such as physiological sensing and providing an alternative to ESM.

The experience is recorded and users then retrospectively reflect on it by watching back and exploring the video while sketching a graph of their emotions and presence over time (Figure 1D). The VR experience is replayed both visually and audibly from the user's perspective, allowing them to hear themselves and the audio soundscape of the experience. Users sketch and plot emotions and presence over the duration of the experience, resulting in continuous data for each measure (see Figure 1E). Users can also identify and highlight 'keypoints' in their experience such as salient events with emotional consequences. These can be annotated with textual descriptions, providing context and sentiment (Figure 1F).

RetroSketch offers several advantages over existing methods. First, RetroSketch provides high-resolution, continuous data for emotions and presence that are not bound by specific events or time intervals with direct correspondence to a point-of-view video of a VR experience. Second, it does not disrupt the experience and does not suffer from observer bias because it is administered in retrospect. Third, it reduces social desirability bias because data can be entered in private without intervention from the experimenter. However, measuring emotions in retrospect based on recall has been explored previously and can be affected by age and personality traits [149, 253]. It is unclear what effect these factors will have when measuring emotions using RetroSketch. We validate RetroSketch by posing the following research questions:

RQ1 How do RetroSketch measures relate to ESM measures?
RQ2 How reliable is RetroSketch & ESM across different VR experiences and users?
RQ3 How does ESM influence the VR user experience?
RQ4 How do RetroSketch & ESM relate to physiological measures?
RQ5 How do RetroSketch & ESM relate to qualitative measures?

To address these questions, we conducted a user study (n=140), comparing RetroSketch to ESM, as the gold standard for subjective emotion measurement, as well as physiological measures. We measured four emotions (joy, fear, relaxation and boredom) and presence across five popular VR games: *Assetto Corsa Competizione* [218], *Garden of the Sea* [39], *Half-Life Alyx* [254], *I Expect You To Die* [65] and *Red Matter* [189]. Each participant played one of the games over two 30-minute gameplay sessions (one hour total): one session using ESM during the experience and RetroSketch immediately after, and the other session only using RetroSketch. The former allows us to compare the tools directly against each other (RQ1, RQ2), while the latter allows us to understand the influence ESM has on the experience (RQ3). Throughout the experience, we collected ten physiological measures that have been shown to correlate with different emotions (RQ4). Furthermore, we collected qualitative data in the form of RetroSketch annotations of the experience as well as post-experiment questionnaires (RQ5).

Our results show that RetroSketch and ESM measures are highly correlated with each other, however, RetroSketch generally captures a higher variation and range of emotions and presence compared to ESM. Positive emotions (joy and relaxation) tend to be scored lower, and negative emotions (fear and boredom) scored higher in RetroSketch compared with ESM, which may be a result of RetroSketch's ability to reduce social desirability bias (RQ1). These findings are robust across the different VR games and individual characteristics of the participants (RQ2). Furthermore, our study provides evidence that ESM affects the experience in seemingly unpredictable ways across the different games, such as significantly decreasing physical presence in Assetto Corsa Competizione, while increasing it in Half-Life Alyx (RQ3). This suggests that researchers and developers should be mindful when using ESM to compare different experiences. RetroSketch and ESM bear similar relationships to physiological measures, indicating that RetroSketch can be used to collect subjective ground truth data for emotion estimation models (RQ4). While ESM provides comparatively few data points, RetroSketch data is continuous and has a high resolution, making it particularly useful for this purpose. Finally, we found that RetroSketch's temporally anchored and contextualised qualitative annotations are consistent with the quantitative measures reported by participants. The annotations complement the quantitative data and provide extra information for researchers and developers to make sense of the user experience. In summary, we make the following contributions:

(1) RetroSketch, a novel and openly available method for measuring emotions and presence for VR experiences [1].
(2) Empirical evidence that validates RetroSketch against both ESM and physiological measures.
(3) Insights into the impacts of ESM on VR experiences.
(4) A large open dataset of emotions, presence, and ten physiological measures across five VR experiences (n=140), see [172].

2 RELATED WORK

2.1 Models of Emotion

Emotions are internal states associated with feelings, thoughts, behaviours and neurophysiological changes. They can be described using models of varying complexity. Categorical models characterise emotions as fundamental and discrete feelings, such as joy, fear, anger, and sadness, with complex emotions regarded as combinations of these basic feelings [53, 137]. Dimensional models such as Russell's widely-accepted Circumplex Model of Affect (CMA) [157, 193, 194] describe emotions along a few dimensions, e.g. *Valence* (pleasant vs. unpleasant) and *Arousal* (sleepy vs. alert), making it possible to compare different emotions along these dimensions [81, 170].

Barrett's theory of constructed emotion [12], elaborates on dimensional models, describing how bodily feelings are interpreted as a pre-cognitive step based on the context and prior experiences of a person. Similar but distinct to this are appraisal-based models which take into account that emotions are heavily influenced by context, describing emotions as processes derived from our cognitive evaluation or 'appraisal' of events [55, 121, 191, 203, 231]. They explain how "different emotions may emerge from the same event, in different individuals, and on different occasions" [151]. Similar to many ESM studies, RetroSketch uses categorical emotion measures, while allowing users to retrospectively reflect on events and appraise them in the context of the overall experience.

2.2 Emotion Elicitation

Typically, emotion elicitation in VR is highly discretised with VEs designed to target specific emotions [57, 105, 105, 234] and short exposures normally lasting only a few minutes [57, 99, 101, 137]. However, popular VR experiences often take over an hour [1]. More recent work has explored interactive and complex emotional stimuli such as VR games, which often span different levels of valence and arousal that vary as the gameplay unfolds [17, 75, 84, 93, 148, 163, 216, 265]. Taking advantage of this more ecologically valid approach, we evaluated RetroSketch with a cross-section of popular VR games from different genres.

2.3 Subjective Measures of Emotion

Emotions are often measured subjectively by asking participants to rate what they feel using psychometric scales [13, 38, 139], e.g. categorical emotion scales [42], PANAS [261], the Pleasure-Arousal-Dominance scale [145], the Self-Assessment Manikin [25] and the

[1] https://github.com/revealcentre/retrosketch

Affect Slider [18]. All these scales can be used retrospectively or repeated throughout an experience as part of ESM [119].

While retrospective use of psychometric scales minimises 'in-the-moment' disruptions, it relies on accurate recall and may be influenced by recency and primacy effects (i.e. recalling more clearly what was perceived first or last in an experience) [197]. Demographical covariates such as age and personality traits, as well as tiredness, have been shown to influence the recall of emotions [149, 253]. For example, there is evidence for a positivity effect in older adults compared to younger adults [31, 149, 196]. In addition, neuroticism has been shown to result in increased recall of negative emotions, while extraversion increases recall of positive emotions [149, 188]. Moreover, emotions often change and evolve over time [135] so cannot generally be captured by only a few retrospective measurements. RetroSketch aims to reduce the limitations of recall through navigable point-of-view video and audio of the VR experience and we investigate the influence of demographical covariates on RetroSketch measures through our study.

When using psychometric scales during an experience, it can be challenging for participants to gauge and express their emotions 'on the spot' [119, 137]. Furthermore, responses are more likely to be biased by experimenter rapport, participant openness, social desirability and demand characteristics [81, 86, 156]. Even when applied multiple times, psychometric scales are limited in the amount of data they can provide. They cannot collect data continuously and therefore miss key aspects of an experience [119].

Some works tried to address this with continuous emotion measurement tools [67, 138, 192, 206]. These include software interfaces for 2D videos [67], the affect rating dial which involves emotion measurement by continuously rotating a mechanical dial [73, 142, 262], and the emotion slider where users move a physical slider [120]. These interfaces provide highly granular, moment-to-moment emotion measures of a specific emotion measure such as valence [67] or, in the case of Schubert, both valence and arousal captured in a 2D plot [206].

More recently, Xue et al. demonstrated how these techniques can be applied to 360° VR video with valence and arousal recorded continuously and manipulated using a game controller [269, 270]. These methods overcome the data limitations of questionnaires for *non-interactive* media such as videos and music, enabling continuous and granular emotion measures. However, these benefits require continuous input which is challenging during *interactive* experiences such as VR games. A retrospective approach is a promising alternative, and RetroSketch aims to overcome these limitations by allowing users to measure multiple emotions simultaneously, whilst supporting appraisal of the experience through video playback that can be navigated and annotated as the user desires.

Finally, emotions can be captured qualitatively after an experience with methods such as open-ended questionnaires [153], interviews [195] and diaries [41, 165], or during an experience through observation [184] and methods such as 'Think-Aloud' protocols [90]. While they share similar limitations as psychometric scales, e.g. reliance on recall and biases, they can better capture emotional nuances and appraisal due to their open-ended nature. RetroSketch avoids the limitations of 'in the moment' approaches and supports recall with a navigable video walk-through of the experience. It uses scales to collect continuous, high-resolution quantitative data and qualitative annotations to capture nuances, context, and appraisal over time.

2.4 Experience Sampling Method (ESM)

ESM is a methodology designed to measure experience in 'natural' environments and 'in the moment' [119]. It is often used in longitudinal research [22] and relies on participants reporting their thoughts, feelings, and behaviours using quantitative and qualitative measures at designated points in time [264]: In signal-contingent ESM, participants respond when signalled by an experimenter or system (e.g. mobile phone). In event-contingent ESM, participants respond after set events. In interval-contingent ESM, responses happen at set time intervals. All three approaches are affected by observer and social desirability biases (see above) and can miss key moments of an experience. For example, ESM may disrupt a VR experience, create breaks in presence [220, 229] and redirect cognitive resources outside the virtual environment and away from the active elicitation. Nevertheless, ESM is well-established, validated and useful [43] so serves as a 'gold standard' for the comparison to and validation of RetroSketch measures.

2.5 Physiological Measures of Emotion

Emotions can be estimated by analysing unconscious changes in physiological measures associated with the central and autonomic nervous system [29, 137] such as electroencephalography (EEG) [23, 96, 243], eye and facial behaviour (pupilometry, blinks, fixations, and saccades) [190], and cardiovascular dynamics (heart rate, respiration, and electrodermal activity) [11, 82]. Compared to subjective measures, physiological measures are less affected by experimenter bias [81, 86] or recall [197]. Pupil Dilation Level (PDL) and Pupil Dilation Response (PDR) correlate with both arousal [26, 124, 181, 232, 259] and valence [2, 8, 26, 32, 103, 154, 162, 271], as well as categorical emotions such as fear [33, 124, 232]. Heart rate (HR) and HR variability (HRV) correlate with affect [82, 106, 155, 213, 260]. Electrodermal activity (EDA), in particular Skin Conductance Response (SCR) and Skin Conductance Level (SCL) [11, 26, 199], correlate with arousal. Facial gestures such as contractions of the zygomatic major muscles (smiling) correlate with valence [28, 170, 273].

Physiological measures are noisy, especially in VR where users often move naturally [246], requiring non-trivial data cleaning and analysis processes [170] and careful sensor setup and calibration. Furthermore, physiological measures are only indirect markers of emotion that do not clearly map to psychometric scales. Emotion recognition approaches often use machine learning to model the complex relationships between emotions and physiological measures such as EDA [6, 70–72, 97, 106, 107, 113, 186], fMEG [94, 219, 245], HRV [40, 71, 71, 82, 95, 155, 219, 219] and blink information [3, 233]. They are typically 'black boxes' that have been trained on ground truth data collected through subjective methods, with their own biases and uncertainties. As a consequence, we validate RetroSketch by correlating it directly with common physiological measures, using established data cleaning procedures.

2.6 Presence

Presence is arguably the most important quality of VR and a core interest in VR research [251]. Presence is typically defined as the sense of *"being there"* [87, 128, 200, 212, 230, 240, 272], describing the illusion created by VR [220, 221, 223, 225] that leads users to respond to virtual experiences as if "they were real" [200, 220, 222, 237]. Presence and emotions are associated [24, 62, 187, 215], for example, presence has been shown to correlate with emotion intensity [10, 47, 225] as well as with negative valence emotions such as fear [62, 80, 99, 101, 140, 164, 239]. There are different approaches for measuring presence, each with limitations [220].

Presence is most commonly measured using questionnaires [76, 117, 209, 225, 236, 251] such as the WS [266], IPQ [207], SUS [224] and MPS [133], which are typically administered after a VR experience, but can also be administered while still in VR [60, 174, 209]. Presence questionnaires are affected by biases similar to emotion questionnaires [74, 225]. Qualitative approaches include having users write essays about their VR experience [15, 112, 225, 227], which can then be analysed using ML-driven sentiment analysis [126, 160, 225]. We use such ML-driven sentiment analysis to validate RetroSketch's annotations.

In VEs designed to elicit emotions, presence can sometimes be estimated through physiological measures [47] such as ECG and EDA [136, 144, 174, 237], eye movements/pupillometry [116], fEMG [182] or EEG signals [14, 58, 110, 166] because of its association with emotional response [225]. Furthermore, physiological correlates have been explored for breaks in presence (BIPs) [125], such as ECG and EDA [226, 228], blood flow [185] and EEG [111]. We include common physiological correlates of presence in the validation of RetroSketch measures.

3 RETROSKETCH DESIGN

RetroSketch relies on three main design features, which have been developed based on the emotion and presence literature, prior work and iterative pilot testing: (1) unconstrained video and audio playback, (2) continuous quantitative measures, and (3) salient keypoints and qualitative annotations.

Unconstrained Video and Audio Playback: RetroSketch uses video playback of the recorded experience to assist with the recognition of events and to help users recall how they felt. This has been used in related work on emotion measurement [192] and is supported by findings that reported emotions while re-watching a video align with physiological measures from the initial viewing [138]. In contrast to related work, RetroSketch allows users to navigate the video without constraints, in the order and speed they choose. This supports an individual's recall patterns (e.g. linearly or certain salient events first; guided by primacy or recency) with personalised reflection and appraisal of an experience. We also include recorded audio, including the user's voice, to further support recall.

Continuous Quantitative Measures: Users can report continuous levels of presence and four emotions — joy, fear, relaxation, and boredom — each of which is significant for VR experiences and provides comprehensive coverage of the circumplex model [193, 194]. Unlike related work on emotion measurement [192], RetroSketch is designed to capture subjective ratings across multiple measures in a temporally synchronised manner. To achieve this, the graphs of each measure are stacked vertically (Figure 2) ensuring that time points are aligned. Users can freely draw their ratings as line graphs, with the method of input depending on the specific RetroSketch implementation (see below). Each measure uses an 11-point rating scale where 0 represents *"none of that feeling"* and 10 represents *"the most intense version of that feeling possible"*. Supported by theory and simulations [85, 268], this has previously been used for measuring emotions in VR on an interval scale [170, 247].

Salient Keypoints and Qualitative Annotations: To complement continuous quantitative measures of emotions and presence, RetroSketch enables users to specify 'keypoints' that identify particularly memorable or salient events in the experience. Keypoints can be specified before drawing ratings into the graph, e.g. to enable users to draw ratings by "connecting the dots", or they can be specified once ratings have been drawn, e.g. based on peaks and troughs. Keypoints are not provided but specified by the user to reduce 'demand characteristics' [156], i.e. providing keypoints for users may give cues about the aim of a study and may bias the user. In addition to identifying salient events, users can annotate keypoints with rich qualitative insights and additional context as to why they selected them. Depending on the implementation of RetroSketch, annotations can take any form, whether pictorial such as sketches or doodles, or textual such as short descriptions of their feelings or thoughts at the keypoint moments.

To enable flexible and versatile use, we implemented two versions of RetroSketch: a paper-based and a digital version. The paper-based version served as a low-fidelity prototype for the digital version.

3.1 Paper-based Version

The paper-based RetroSketch consists of an A3 sheet of graph paper (Figure 2). Emotion and presence scales are stacked on top of each other, with the Y-axis representing the 0-10 rating scales and the X-axis representing time during the experience. Users can use various drawing tools such as a pencil, ruler and eraser to draw, erase, or correct the lines, keypoints and annotations as they see fit.

Users can free-hand draw, affording them familiarity and flexibility, which makes it more suitable for users who are less accustomed to technology. The only piece of equipment needed in addition to the printed sheet and drawing tools is a device for video playback (e.g. a mobile phone). However, the disadvantage of a paper-based version is that participants' attention is split between the video playback and the tool, and they must manually align their responses with the video playback timestamps. In addition, the measures and annotations may need to be digitised for later analysis.

3.2 Digital Version

We designed and implemented a digital version of RetroSketch (Figure 3) that combines an interactive tablet and stylus, allowing users to sketch emotion measures onto digital graphing paper. Our goal was to retain the flexibility of the paper-based version regarding line drawing and keypoints, while adding several digital features:

Synchronised Timeline Cursor: An interactive timeline cursor allows users to scrub through the video while highlighting the corresponding moment in the graphs below. This integration of the video and emotion graphs helps minimise diverging attention between watching the video and plotting emotions, making it easier

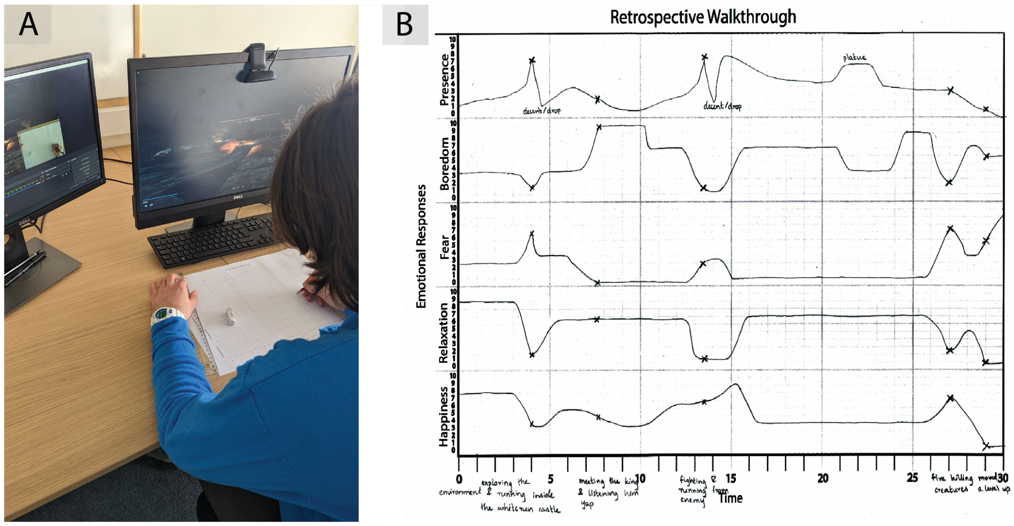


Figure 2: Paper-based RetroSketch. (A) shows a user reviewing a VR gameplay session and sketching their emotions and presence using paper RetroSketch. (B) shows their completed graph with keypoints marked and annotated with brief quotes.

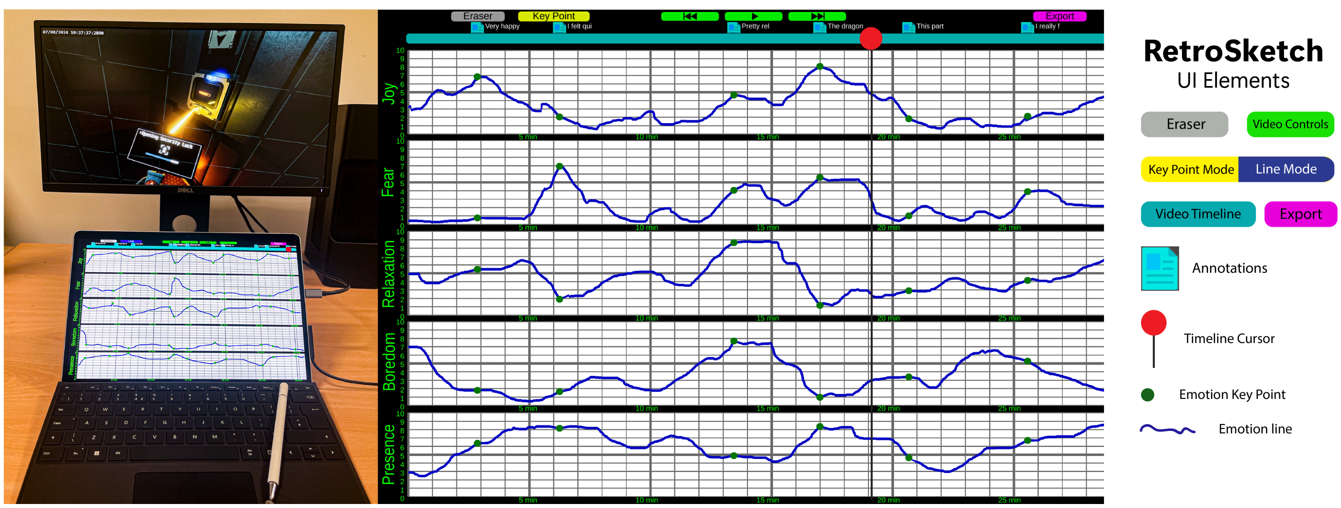


Figure 3: Left: Digital version of RetroSketch showing the tablet and stylus used for input which are connected to a bigger display for video playback. Right: RetroSketch's user interface with buttons for sketching and playback functions, graphs with a timeline cursor, and keypoints with annotations.

to accurately place emotional responses and keypoints for specific moments of the VR experience.

Video Controls: Basic video controls are provided and synchronised with the timeline cursor, including options to play, pause, fast forward 5 seconds, rewind 5 seconds, and adjust playback speed to 1x, 1.5x, 2x, or 2.5x.

Line Drawing: The digital version was specifically designed for a stylus and tablet to mimic the flexibility and expressiveness of sketching with the paper-based version. This includes an eraser tool so that users can refine any erroneous parts of their sketch, including keypoints.

Keypoints & Annotations: The digital version tightly integrates keypoints and annotations. After placing a keypoint, an annotation text box appears, prompting the user to describe the event and their feelings in more detail. The annotation is then displayed above the timeline alongside the keypoints.

Data Export: After completing their sketch, the data can be exported at one sample per second. For example, a 30-minute VR session results in 1,800 samples for each emotion and presence. The export feature also generates a log file of all user actions performed during sketching, an aggregated keypoint file with keypoints and annotations, and a screenshot of the completed sketch.

4 STUDY METHODOLOGY

To address our research questions, we conducted a mixed-design study with VR experience (*VR Game*) as a between-subject factor with five levels (*ACC*, *GotS*, *HLA*, *IEYTD* and *RM*) and whether or not ESM was used alongside RetroSketch as within-subject factor (*ESM* and *NoESM*). Having one session with and one without ESM, counterbalanced using a balanced Latin square design, allows us to investigate how ESM affects the user experience (RQ3). The main study methodology was first informed by a pilot study.

4.1 Pilot Study

We conducted a pilot study with 10 participants using the paper-based RetroSketch to inform the design and evaluation of digital RetroSketch. All participants played Skyrim-VR [242] during two 30-minute gameplay sessions, one with ESM measures and one without. After each session, participants watched back their experience and used the paper-based RetroSketch to sketch their Joy, Fear, Relaxation, Boredom, and Presence. There were significant moderate-to-strong Kendall's τ correlations between RetroSketch and ESM for all emotions and presence. Based on participant feedback and experimenter observations, we found that the paper-based RetroSketch is most suitable for small-scale studies. The Supplementary Material Document provides further details.

4.2 VR Games

We chose five state-of-the-art single-player VR games that cover a broad range of game mechanics, themes, aesthetics, challenges, immersive elements, and emotional components (see Figure 4 and the Video Figure in Supplementary Material). The games use different configurations including controllers, space required, and player movements, which allow us to validate RetroSketch more broadly. We focus on single-player games because online multiplayer gameplay can vary vastly based on other players' actions, making it difficult to control what participants would experience. Based on the pilot study, we excluded Skyrim-VR due to an overly long tutorial and usability issues.

Participants were randomly assigned a VR game (n = 28 per VR game) and completed a 10-minute tutorial and two 30-minute VR sessions, which is close to average VR gameplay times [1] and the recommended time for VR usage [91, 147, 235]. We chose a session duration of 30 minutes to ensure participants had substantial exposure to their respective VR experience and validate RetroSketch's ability to produce accurate measures throughout that exposure.

The procedure for each game was refined through piloting to ensure a natural and sequential flow between the first and second gameplay sessions, minimising disruptions for participants and preserving ecological validity. For more detailed descriptions of each VR game and the gameplay tutorials, please refer to Section 2 of the Supplementary Material Document. Each participant played one of the following games:

Assetto Corsa Competizione (ACC): a racing simulator featuring various cars and circuits across the world. We chose ACC to elicit feelings of high arousal and high valence because it features highly realistic graphics and sound that are designed to closely resemble a real racing experience. ACC uses an immersive haptic driving simulator with a six-degrees-of-freedom motion platform (Figure 5-D) that simulates force feedback from acceleration, cornering, road surfaces, and collisions.

Garden of the Sea (GotS): an open-world crafting, farming and exploration game. GotS offers a more relaxed experience eliciting feelings of low arousal and high valence because of its bright and cartoonish style, emphasising a tranquil and open-ended experience with meditative elements. Quests are followed and unlocked at the player's pace and can be ignored entirely. GotS uses VR controllers and is a standing, room-scale VR experience.

Half-Life: Alyx (HLA): a critically acclaimed first-person action-horror game with a rich, sci-fi story in which Earth is invaded and controlled by an alien race. The game requires players to fight aliens and zombies while solving puzzles and exploring a post-apocalyptic city. We chose HLA to elicit high arousal and low valence because of its horror themes. HLA uses VR controllers and is a standing, room-scale VR experience.

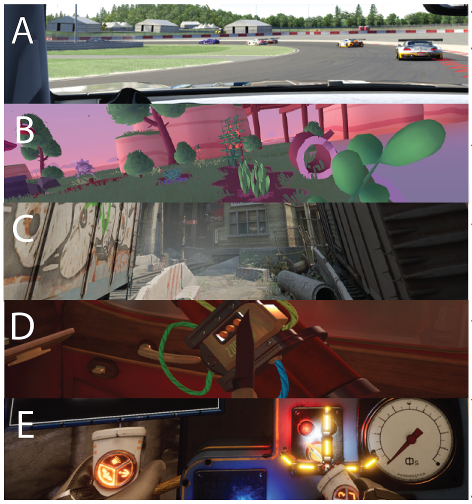
I Expect You To Die (IEYTD): an escape-room style puzzle game where players embody a secret agent. In each mission, the player finds themselves in impossible and deadly scenarios which they need to creatively solve and escape by interacting with the environment. We chose IEYTD to elicit high arousal and medium levels of valence because of its high-risk scenarios and cartoonish style with a 'tongue-in-cheek' comedic tone. IEYTD uses VR controllers and is a seated VR experience.

Red Matter (RM): a story-driven puzzle and adventure game set during a dystopian sci-fi Cold War in which the player embodies an astronaut sent on a mission to an abandoned space station. We chose RM to elicit low arousal and low valence because the story unfolds slowly, being uncovered through scanning objects and documents in a mysterious and unsettling atmosphere. The game uses VR controllers and is a standing, room-scale VR experience.

4.3 Apparatus

We used a Vive Pro Eye VR headset for all experiences. All study sessions were completed in a private University lab space which afforded an open tracking space of more than 3×3 meters for the room-scale VR experiences. The driving simulator used for ACC was in the same lab space and is composed of a Next Level Racing V3 motion platform offering six degrees of freedom [179], a Fanatec haptic steering wheel [59], and a vibrotactile seat [178] (Figure 5D).

Physiological measures were collected through eye (pupillometry) and lip tracking (facial gestures) from the VR headset (Figure 5A), a Shimmer3 GSR+ [214] with electrodes on the participant's middle and ring finger [44] (Figure 5B), and a Polar H10 chest strap HR monitor [202, 252] (Figure 5C). All physiological measures were collected using the EmoSense Unity SDK [170, 171, 173] which we modified to run in the background of each VR experience, allowing access to both the inbuilt VR eye and lip tracker, as well as the Polar and Shimmer devices. Data was streamed to the same PC running the VR experiences (Intel Core i9 Extreme, 64GB DDR5 RAM, Nvidia RTX 3090) over Bluetooth (BLE protocol), and recorded at a sample rate of 60Hz. Gameplay footage from the participant's



Game	VR Configuration	Genre	Mechanics	Themes
Assetto Corsa Competizione (*ACC*)		Sport, Simulation	Racing, Competitive, Realism	Action, Adrenaline, Exciting
Garden of the Sea (*GotS*)		Indie, Simulation	Crafting, Farming, Exploration	Wholesome, Cute, Relaxing
Half-Life: Alyx (*HLA*)		Horror, Survival	First-person Shooter, Loot Management, Story Driven	Cinematic, Alien Invasion, Exciting
I Expect You To Die (*IEYTD*)		Thriller, Mystery	Puzzle, Escape Room, Missions	Comedic, Noir, Nostalgic
Red Matter (*RM*)		Scifi, Adventure	Puzzle, Exploration, Story Driven	Cinematic, Secretive, Ominous

Figure 4: A-E shows the five VR experiences used in the study: (A) Assetto Corsa Competizione - ACC, (B) Garden of the Sea - GotS, (C) Half Life Alyx - HLA, (D) I Expect You To Die - IEYTD, and (E) Red Matter - RM. The right table summarises the VR configuration and controls, game genres, mechanics and themes.

perspective was captured using OBS 29.1.3 [118], recording the SteamVR view at a resolution of 1920×1080.

4.4 Measures

We collected a range of measures, including subjective emotion and presence ratings via RetroSketch and ESM, ten physiological metrics, post-session VR user experience questionnaires, and qualitative data on the use of RetroSketch and ESM.

4.4.1 RetroSketch & ESM. After each 30-minute gameplay session of every VR game, participants used RetroSketch to measure their Joy, Fear, Relaxation, Boredom, and Presence each on a 0-10 scale as described in subsection 3.2.

In one of the two sessions, interval-contingent ESM was used based on best practices from the literature [119]. In every VR experience and every five minutes, participants were asked via automated voice recordings through the headset speakers to rate their Joy, Fear, Relaxation, Boredom and Presence, in random order. Interval-contingent sampling was chosen over event- or signal-contingent sampling to 1) avoid demand characteristics [156], 2) maintain consistent sampling across sessions and participants, and 3) mitigate surprise and prevent participants from spending time reflecting on when to complete a sample, as this could disrupt presence.

Participants answered 11-point Likert-scale questions (0-10) such as "*On a scale of 0 to 10, how Joyful do you feel?*" with 0 being "*none of that feeling*" and 10 being "*the most intense version of that feeling possible*". Five-minute intervals were chosen to strike a balance between disruptions caused by ESM and the amount of data collected. To mitigate disruption, we did not pause the gameplay during ESM samples as pilot testing showed that participants could answer while continuing to play.

4.4.2 Physiological Measures. Physiological measures were recorded for the whole VR experience and aggregated over consecutive 60-second windows, resulting in 30 data points per session. Pupillometry was recorded using the Vive eye tracker [258] including pupil dilation level (PDL) as mean pupil diameter in millimetres, and pupil dilation response (PDR) as standard deviation of the pupil diameter. The standard deviation has been previously used to quantify phasic responses during prolonged exposures [5, 205], including in VR settings [137, 170]. We also recorded Blink Rate (BR) as the mean inter-blink interval in seconds, and Blink Duration (BD) as the mean blink length in milliseconds. Electrodermal Activity (EDA) was recorded using the Shimmer device as mean Skin Conductance Level (SCL) in micro Siemens (μS), and Skin Conductance Response (SCR) as standard deviation of SCL. Cardiac activity was recorded using the Polar H10 as beats per minute (HR), and heart rate variability (HRV) as root mean square of successive differences (RMSSD) of interbeat (RR) intervals [211]. Facial gestures were tracked by observing the movements of the zygomaticus major muscle (Smile) and the orbicularis oris muscle (O-Shape). These were quantified using the Vive facial tracker's blend shape weightings for 'Mouth Smile' and 'Mouth O-Shape', respectively [258]. We removed erroneous sensor measures based on absolute thresholds: we filtered out skin conductance values above 100μS and below 0.1 μS [7, 27], RR interval values above 2000 ms and below 200 ms (30-200 bpm) [109], and any pupil dilation measures recorded while the eyes were closed.

4.4.3 Pre-Study Questionnaires. Participants completed a demographics questionnaire (age, gender, VR/video game experience) as well as measures assessing their personality (Big5 [68, 69]), video game player type (Tondello [248]), and immersive tendencies (ITQ [266]). These measures were used to test the reliability and consistency of RetroSketch and ESM measures across different covariates. Additionally, we collected baselines for each emotion sampled in RetroSketch and ESM, allowing us to understand a participant's baseline disposition, as well as baselines for simulator/motion sickness (SSQ [20]) and ratings of perceived exertion (BORG-RPE [168]) – two factors that are important to control for when measuring physiological markers [83, 170].

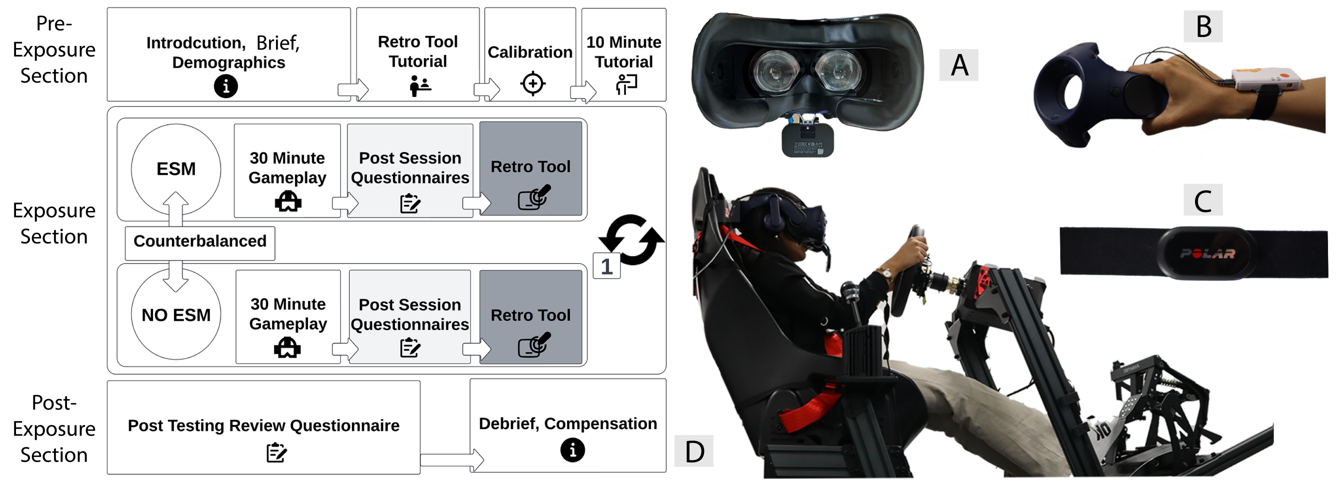


Figure 5: Left: A diagram of the study procedure. The pre-exposure section includes introduction, debrief, demographics, RetroSketch tutorial, calibration, and a gameplay tutorial. The exposure section includes two counterbalanced 30-minute gameplay sessions (*ESM* and *NoESM*) followed by questionnaires and RetroSketch use. The post-exposure section includes questionnaires and debrief. Right: (A) HTC Vive Pro Eye VR headset with eye and lip tracker, (B) VR controller and Shimmer skin conductance sensor, (C) Polar H10 heart rate sensor and chest strap, and (D) Next-level racing simulator with 6-degrees-of-freedom haptic and motion platform.

4.4.4 Post-Session Questionnaires. Immediately after each 30-minute VR session, we took measures of participants' experienced VR presence using MPS [133], intrinsic motivation using IMI [141], and flow-state using PPL-FSQ [132], all of which have been used extensively in prior VR research. Additionally, we again measured participants' simulator sickness levels (SSQ [20]) and ratings of perceived exertion (BORG-RPE [168]). These measures were collected to test whether ESM influences the VR user experience.

4.4.5 Post-Study Questionnaires. At the end of the study, participants answered open-ended questions asking them to evaluate and compare RetroSketch and ESM, such as how accurate they perceived the respective method to be, how easy it was to recall feelings with RetroSketch, whether ESM influenced their VR experience, and which method they preferred.

4.5 Procedure

Participants were first screened for health risks when using VR technology, such as epilepsy, mobility impairments and severe visual impairments (see Supplementary Material Document). Participants were then assigned to a VR experience using a balanced randomisation process designed to ensure gender balance across the five VR games. While most VR games were tested in parallel, the ACC sample was completed in a single batch due to logistical constraints with the driving simulator. Participants were briefed about the VR game they would play and verbally screened by the experimenter for content sensitivities. If any concerns were raised, the participant was reassigned to a different VR experience at random. After providing informed consent and completing pre-study questionnaires, participants were introduced to both RetroSketch and ESM.

For RetroSketch, participants were given a 10-minute introduction and tutorial demonstrating the keypoint, annotation, line and eraser features using a stock video as example. To set an expectation of the level of detail for the keypoints when using RetroSketch, participants were recommended that they should create at least one keypoint every 5 minutes. However, participants were informed this was not a strict rule, and it was emphasised that they should decide where to place keypoints by themselves.

Participants were introduced to the VR headset and the physiological sensors, and the sensors were calibrated. Participants were then introduced to the allocated VR gaming experience through a 10-minute tutorial. This was followed immediately by the first 30-minute gameplay session. After completing the first gameplay session, participants were given verbal cues by the experimenter instructing them to pause the game and exit VR. This was followed by a post-session questionnaire and a short break which in total took approximately 10-15 minutes, before participants used RetroSketch to measure their VR experience. Participants were told that they would have approximately 15 minutes to complete their sketch, but that it was perfectly fine if they needed more time. In practice, participants took on average 25 minutes to complete their sketch. The entire experimental procedure took approximately 3 hours and participants were compensated with £30 for their time.

4.6 Participants

We recruited 140 participants (58 female, 78 male, 3 non-binary, 1 undisclosed) aged between 18-61 (M = 25.379, SD = 7.720), who were predominantly staff and students of the University of Bath. In total 167 participants were recruited. However, 18 participants withdrew due to VR sickness, three were excluded because of technical issues, and two chose to withdraw. Additionally, the data of four participants was excluded due to sensor data errors. Most participants had used VR occasionally (42 never, 91 occasionally,

Table 1: Demographics and experience of participants across the different VR experiences: Assetto Corsa Competizione (ACC), Garden of the Sea (GotS), Half-Life Alyx (HLA), I Expect You To Die (IEYTD), and Red Matter (RM).

Game	Gender	Age	VR Exp.	Game Exp.
ACC	M= 16, F= 10 NB= 1 Other= 1	23.750 ±4.486	Occa.= 16 ≥ Weekly=7 Never= 5	Never= 24 Once= 3 > Once= 1
GotS	M= 16, F= 12	25.000 ±8.590	Occa.= 22 Never= 6	Never
HLA	M= 15, F= 13	24.714 ±6.588	Occa.= 19 Never= 9	Never= 27 Once= 1
IEYTD	M= 15, F= 13	26.786 ±9.183	Occa.= 16 Never= 12	Never
RM	M= 16, F= 10 NB= 2	26.643 ±8.841	Occa.= 18 Never= 10	Never

4 weekly, 3 daily). Most participants had no prior experience with the VR game they were allocated (135 never, 4 once, 1 more than once). Table 1 shows a breakdown of the demographics for each VR experience. A power analysis using G*Power 3.1.9.7 showed that we can detect medium-sized differences between RetroSketch and ESM measures at $\alpha = .05$ with a power of 0.999, even when simple non-parametric Wilcoxon-signed rank tests are used which do not take advantage of the multiple RetroSketch and ESM samples for each participant.

5 RESULTS

Data was analysed with `R` v4.4.1 using various packages. For all tests, we used a significance threshold of $\alpha = .05$ (*), as well as $\alpha = .01$ to denote 'highly significant' results (**) and $\alpha = .001$ for 'very highly significant' results (***). For clarity, we report effect sizes mainly using the popular Cohen's d, converting other forms of effect sizes such as η^2 and log odds ratios to d using the effect size conversion functions of the `effectsize` package [16]. Tables indicate the magnitudes of significant effects by highlighting table cells in green: the stronger the colour, the larger the effect. The analysis script, aggregated dataset, and additional results are available in Supplementary Material.

5.1 Emotion Manipulation

Figure 6 left and right summarise the emotional footprints of each experience as captured by RetroSketch and ESM. We first performed a manipulation check to ascertain that the experiences elicited different emotions, and to provide an understanding of the range and intensity of emotions elicited. Anderson-Darling tests from the `nortest` package [177] confirmed non-normality of the data (they are more reliable for large sample sizes than the more common Shapiro-Wilk [66]), and Levene's tests confirmed violations of homogeneity of variance. Therefore, we used non-parametric Kruskal-Wallis ANOVAs to test the main effect of VR Game on emotion and presence ratings as measured by RetroSketch in all sessions, followed by pairwise Dunn's tests with Holm-Bonferroni posthoc correction.

The main effect of *VRGame* was very highly significant for all emotions and presence ($\chi^2(4) \geq 81.255, p \leq .001^{***}, \eta^2 \geq .009$). Pairwise comparisons showed that all experiences elicited significantly different Presence. 42 of the 50 pairwise comparisons of emotions were also significant, with more closely related games such as HLA, IEYTD and RM not always showing significant differences (details in Supplementary Material Document).

5.2 Internal Consistency of RetroSketch

To assess the internal consistency of quantitative and qualitative measures of RetroSketch, two researchers independently reviewed 40 RetroSketch sketches (8 for each game). The researchers examined the keypoints and annotations created by participants and cross-referenced them with the respective VR gameplay footage. In addition, the annotations of all RetroSketch sketches were analysed using a Twitter-roBERTa-base model fine-tuned for sentiment analysis [30, 130, 131]. The two researchers assessed the sketches using the following three criteria:

(1) **Annotations correspond to the associated gameplay footage:** The coder assessed whether an annotation related to the associated gameplay footage (true or false), e.g. ensuring the participant reflected on the associated moment and not a different moment.
(2) **Keypoint ratings are consistent with the associated annotations:** The coder assessed whether the RetroSketch ratings assigned to a keypoint are consistent with its annotation (true or false). For example, if a participant annotated a keypoint as *"The most enjoyable part of the experience"* but the *Joy* rating was not the highest for the experience then this would be marked as false. Importantly, this was not a value judgement of a participant's ratings (i.e. whether they are too low or too high) but a solely a judgement of consistency with the rest of the sketch.
(3) **Sentiment analysis scores are accurate:** The coder assessed whether the sentiment score produced by the sentiment analysis model accurately reflected the conveyed sentiment of the annotation (true or false). For example, if an annotation for a moment in *ACC* stated *"I was extremely happy to overtake two other drivers on this corner"* then the positive sentiment should be high (≥ 0.7) and the negative sentiment should be low (≤ 0.3). This was done to validate the sentiment analysis method in the context of RetroSketch, with a view to applying it to address RQ5.

The two researchers (R1 and R2) found that over 99% of annotations correctly corresponded to the associated video footage (R1: 99.2%, R2: 99.5%), over 98% of the keypoint ratings were consistent with their annotations (R1: 98.4%, R2: 98.9%), and the majority of sentiment analysis scores accurately reflected the annotations (R1: 72.0%, R2: 67.5%). Agreement scores between the two reviewers were computed using Prevalence-Adjusted Biased-Adjusted Kappa (PABAK) [159] as opposed to Cohen's Kappa due to the distribution being highly skewed towards 'valid' scores compared to 'invalid' scores. The agreement between coders was almost perfect (0.98 and 0.97) for the first two criteria which internally validate RetroSketch, and the agreement was substantial (0.65) for the sentiment analysis.

DV	Method	ACC	GotS	HLA	IEYTD	RM
Joy	Retro	6.269	6.516	6.056	5.752	5.953
	ESM	6.771	6.774	6.238	6.714	5.524
Fear	Retro	2.833	1.037	4.019	2.065	2.045
	ESM	2.518	0.786	4.458	2.113	2.232
Relaxation	Retro	3.590	5.972	4.337	4.847	4.663
	ESM	4.211	7.077	5.054	5.482	4.827
Boredom	Retro	2.110	3.108	2.326	2.313	2.421
	ESM	2.205	3.321	1.958	1.780	2.411
Presence	Retro	7.051	7.241	7.600	7.326	6.842
	ESM	7.139	7.917	8.214	7.923	6.887

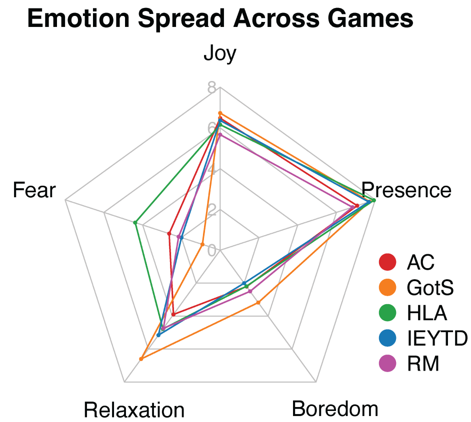


Figure 6: Left: Table showing averages for joy, fear, relaxation, boredom, and presence for RetroSketch and ESM in all five VR games. Right: Spider chart of average emotion and presence RetroSketch ratings across the five VR games.

Table 2: Correlations between RetroSketch and ESM across all VR games. Pearson's r and Kendall's τ values describe overall correlations. $\tau_5, \ldots, \tau_{30}$ are separate Kendall's Tau correlations for the six ESM samples at $5, 10, \ldots, 30$ minutes, and $r_{min} = min(r_5, \ldots, r_{30})$ describes the worst case Pearson's correlation across the six samples. All τ values are tested for significance.

DV	r	r_{min}	τ	τ_5	τ_{10}	τ_{15}	τ_{20}	τ_{25}	τ_{30}
Joy	.661	.418	**.537******	**.350******	**.421******	**.367******	**.448******	**.445******	**.460******
Fear	.761	.581	**.586******	**.441******	**.466******	**.457******	**.507******	**.496******	**.556******
Relaxation	.747	.500	**.561******	**.361******	**.428******	**.407******	**.487******	**.446******	**.483******
Boredom	.725	.454	**.575******	**.442******	**.443******	**.476******	**.495******	**.487******	**.529******
Presence	.732	.521	**.549******	**.453******	**.519******	**.438******	**.490******	**.552******	**.438******

5.3 RQ1: How do RetroSketch measures relate to ESM measures?

5.3.1 Correlations between RetroSketch and ESM.. We first analysed the correlations between RetroSketch and ESM emotion and presence ratings.Scatterplots suggest an approximately linear relationship between RetroSketch and ESM ratings, therefore we use Pearson correlation coefficients r to describe the strength of the relationships. However, Shapiro-Wilk tests and QQ plots showed that normality was violated, therefore we used non-parametric Kendall's Tau (τ) correlation tests with Holm-Bonferroni posthoc correction to confirm the relationships statistically. Table 2 summarises the correlations overall (r and τ) and per sample interval ($\tau_5, \ldots, \tau_{30}$), showing that they were highly significant with compellingly 'strong' effects ($\tau \geq 0.4$).

We assessed the stability of the correlations across the different VR experiences by testing interactions with *VR Game* through regression analysis. For linear regressions, residual plots showed that the assumptions of normality and heteroscedasticity were violated. Therefore we performed repeated-measures ordinal logistic regressions using the `ordLORgee` function of the `multgee` package [249, 250]. No significant interaction effects were found, indicating that the correlations between RetroSketch and ESM are robust and stable across all five VR experiences.

5.3.2 Distribution Characteristics of RetroSketch and ESM. Next, we compared the distribution characteristics of RetroSketch and ESM ratings. To address non-normality, we performed two-way Align Rank Transform (ART) ANOVAs [267] using the `ARTool` package [104]. We tested the effects of the measurement *Method* (RetroSketch or ESM) and the *VR Game* on the median, mean absolute deviation (MAD), minimum and maximum values of each participant's emotion and presence ratings, respectively. Pairwise comparisons were performed using ART-C tests [54] with Holm-Bonferroni posthoc correction.

Table 3 shows the overall differences (Δ) in distribution characteristics of RetroSketch compared to ESM, their significance, and the size of their effect (η^2 converted to Cohen's d). The table also shows significant interactions broken down by *VR Game*, i.e. when differences are particularly strong for a particular game. RetroSketch generally captures a higher variation and range for emotions and presence. For example, when using RetroSketch participants' ratings have significantly higher MAD and maximum values for Joy ('large' and 'medium' effect), and lower minimum values for Joy ('large' effect). Additionally, RetroSketch generally yields lower ratings for 'positive' emotions compared to ESM (see in particular Relaxation), lower Presence ratings, and higher Boredom ratings.

Table 3: Distribution characteristics of RetroSketch and ESM: Median, Mean Absolute Deviation (MAD), Minimum, and Maximum values. Δ is the difference between RetroSketch and ESM (*RetroSketch – ESM*), which is tested for significance. Effect sizes Cohen's *d* is visualised using shades of green. Significant interactions with specific games are shown in separate rows.

DV	Game	*Median*		*MAD*		*Min*		*Max*	
		Δ	Cohen's *d*	Δ	Cohen's *d*	Δ	Cohen's *d*	Δ	Cohen's *d*
Joy	ALL	−0.226	0.074	**0.535******	**1.237**	**−0.958******	**1.066**	**0.437******	**.0.613**
Fear	ALL	0.006	0.005	0.113	0.049	−0.083	0.083	0.000	0.065
	GotS	**−0.259******	**0.210**						
Relaxation	ALL	**−0.6041******	**0.387**	0.17	0.257	**−0.594******	**0.679**	**−0.486******	**0.606**
Boredom	ALL	**0.162***	**0.135**	**0.226***	**0.613**	0.032	0.373	0.312	0.242
	IEYTD	**−0.446***	**0.235**						
Presence	ALL	**−0.305******	**0.198**	**0.280******	**0.829**	**−0.578***	**0.496**	**−0.210***	**0.401**
	HLA	**0.569***	**0.327**						
	IEYTD	**0.512***	**0.257**						

5.4 RQ2: How reliable is RetroSketch & ESM across different VR experiences and users?

To address RQ2, we analyzed interactions between 15 user covariates across all 140 participants. These covariates include demographics, personality traits, video game player types, immersive tendencies, and participants' methodological preference (RetroSketch or ESM). For each measure, we aggregated ratings across the six ESM samples taken per session, as well as the six corresponding RetroSketch ratings, using the mean. Then we performed regression analyses to determine whether the covariates influence the correlations between RetroSketch and ESM by testing interactions with those covariates. Finally, we tested the influences of the covariates on the RetroSketch and ESM ratings themselves, e.g. how gender influences measured emotions.

5.4.1 The Influence of Covariates on the Correlations between RetroSketch and ESM. Due to violations of normality, ordinal logistic regressions with the `polr` package [175, 256] were used. Demographic variables such as Age, Gender, and VR Experience did not significantly influence the correlations between RetroSketch and ESM, indicating that RetroSketch is robust across different demographic groups. Similarly, participants' preference for RetroSketch or ESM had no significant influence. Two significant interactions were observed for Big Five personality traits: for Presence, there were interactions with Agreeableness ($d = 0.032$) and Conscientiousness ($d = 0.024$).

Lastly, for immersive tendencies, two significant interactions were detected: with Presence ($d = -0.002$) and Joy ($d = -0.003$). This indicates that as immersive tendencies increase, the correlation between RetroSketch and ESM for Presence and Joy decreases slightly. The effect sizes of these interactions were 'tiny' ($d < 0.1$), suggesting these effects are negligible and the correlations between RetroSketch and ESM are robust across different types of people.

5.4.2 The Influence of Covariates on RetroSketch and ESM Measures. Table 4 and Table 5 provide an overview of the influences of covariates on RetroSketch and ESM measures. For continuous covariates (e.g. Age), correlation analyses were used. Scatterplots suggest approximately linear relationships, therefore we used Pearson correlation coefficients r to describe the strength of the relationships. However, normality was violated, therefore we used non-parametric Kendall's Tau (τ) correlation tests with Holm-Bonferroni posthoc correction to confirm the relationships statistically. For categorical covariates (e.g. Gender), we used three-way ART-ANOVAs with the covariate, measurement method (RetroSketch and ESM) and *VR Game* as factors, followed by pairwise ART-C tests with Holm-Bonferroni posthoc correction. For gender analysis, only male and female identities were considered due to the low sample size of non-binary (3) and undisclosed (1) identities.

A key finding from Table 4 is that ESM Joy ratings were significantly higher for males compared to females with a medium effect size – an effect not observed in RetroSketch measures. Another notable finding is the significant positive correlation between Presence and Age for RetroSketch where none was found for ESM. Various Big-5 personality traits also showed significant effects, some influencing only RetroSketch (e.g. Extroversion and Fear), others only ESM (e.g. Fear and Openness), and some both (e.g. Relaxation and Conscientiousness). However, the observed effect sizes were small to negligible.

Regarding player types, Table 5 highlights that Tondello Challenge was significantly correlated with both RetroSketch and ESM Joy. The correlation was moderate for ESM and weaker for RetroSketch, suggesting that players who seek challenges report higher Joy with ESM than with RetroSketch. Additionally, ESM Joy correlated with the Social trait, ESM Relaxation with the Challenge trait, and ESM Boredom with the Narrative trait, whereas the corresponding RetroSketch ratings did not. While these correlations are significant, they are weak ($\tau < 0.2$). Finally, both RetroSketch and ESM Presence measures significantly correlated with immersive tendencies (ITQ), indicating higher Presence ratings for those with stronger immersive tendencies.

While Table 4 and Table 5 present the results of covariates across all VR games, we also tested each covariate for interactions with *VR Game*, using ordinal logistic regressions for continuous covariates

Table 4: Relationships of RetroSketch and ESM ratings with different user covariates. Gender (Male = Male - Female) and methodological preference (Pref. Retro = RetroSketch - ESM) were tested with ART-ANOVAs and described using the mean group difference $\Delta Mean$ and effect size Cohen's d. The relationships with continuous covariates, VR experience (VR Exp.) and Big5 personality traits, are described with Pearson's r and Kendall's τ correlations, with significance tests performed on the τ.

DV	Method	Male		Pref. Retro		Age		VR Exp.		Extroversion		Agreeableness		Conscientious		Neuroticism		Openness	
		$\Delta Mean$	d	$\Delta Mean$	d	r	τ	r	τ	r	τ	r	τ	r	τ	r	τ	r	τ
Joy	*Retro*	0.541	0.293	0.263	0.138	−.088	.027	.077	.025	.035	.005	.083	.052	.064	.034	.110	.074	.049	.036
	ESM	**0.908****	0.516	−0.054	−0.030	−.122	.065	−.002	−.048	.079	.060	.087	.059	.117	.078	.224	.166	−.040	−.070
Fear	*Retro*	−0.751	−0.417	0.835	0.460	−.044	.046	.014	−.005	−.200	**−.130***	−.064	−.057	−.163	−.103	−.106	−.048	−.090	−.070
	ESM	−0.889	−0.456	0.783	0.387	−.024	.0240	.017	.004	−.15	−.099	−.104	−.085	−.225	**−.150***	−.070	−.030	−.179	**−.150***
Relaxation	*Retro*	0.706	0.352	−0.353	−0.172	−.055	.057	.011	.012	.155	.089	.255	**.177****	.203	**.130***	.140	.068	.085	.029
	ESM	0.762	0.388	−0.764	−0.388	−.143	−.052	−.059	−.049	.167	.088	.24	**.169****	.234	**.132***	.170	.080	.043	.016
Boredom	*Retro*	−0.149	−0.091	−0.358	−0.221	.005	−.014	−.030	.013	.044	.026	.028	.031	.02	.039	−.109	−.095	.073	.057
	ESM	−0.116	−0.064	−0.396	−0.230	−.027	−.088	.001	.04	.099	.051	.044	.016	.004	−.012	−.150	−.135	.116	.056
Presence	*Retro*	−0.183	−0.110	0.069	0.038	.077	**.118***	.090	.042	.079	.052	.050	.045	.110	.059	.142	.088	.084	.048
	ESM	−0.054	−0.035	−0.356	−0.230	.024	.108	−.038	−.030	.017	.003	.050	.029	.08	.070	.146	.090	.036	.037

Table 5: Correlations of RetroSketch and ESM ratings with different user covariates. Tondello player traits (T) and immersive tendencies (ITQ) are described with Pearson's r and Kendall's τ, with significance tests performed on the τ.

DV	Method	T. Challenge		T. Aesthetic		T. Narrative		T. Goal		T. Social		ITQ	
		r	τ	r	τ	r	τ	r	τ	r	τ	r	τ
Joy	*Retro*	0.217	**0.140***	0.115	0.088	0.171	0.114	0.075	0.052	0.129	0.097	0.053	0.037
	ESM	0.308	**0.205*****	0.050	0.068	0.161	0.092	0.053	0.053	0.212	**0.142***	0.077	0.068
Fear	*Retro*	−0.074	−0.037	0.025	0.015	0.013	−0.006	0.022	−0.000	0.005	0.007	0.137	0.085
	ESM	−.119	−0.053	0.024	0.008	−0.047	−0.020	0.039	0.034	−0.32	−0.028	0.143	0.105
Relaxation	*Retro*	0.136	0.092	−0.004	0.012	−0.092	−0.075	0.055	0.037	0.145	0.078	0.013	0.014
	ESM	0.187	**0.119***	0.015	0.023	−0.030	−0.028	0.038	0.0153	0.211	0.109	−0.0136	−0.024
Boredom	*Retro*	0.155	−0.092	−0.154	−0.087	−0.307	−0.185	0.100	−0.048	−0.016	−0.028	0.019	0.020
	ESM	−0.043	−0.060	−0.135	−0.093	−0.227	**−0.131***	−0.049	−0.034	0.094	0.003	0.013	−0.033
Presence	*Retro*	0.069	0.068	0.006	0.025	0.052	0.056	0.000	0.000	0.083	0.068	0.172	**0.121***
	ESM	0.039	0.068	0.072	0.039	−0.128	−0.051	−0.012	0.017	0.066	0.083	0.249	**0.157****

and three-way ART ANOVAs for categorical covariates. Numerous significant interactions were found, suggesting that covariates influence RetroSketch and ESM scores differently depending on the VR experience (see Supplementary Material Document). However, all significant interactions have tiny to very small effect sizes, suggesting that they have little relevance in practice.

5.5 RQ3: How does ESM influence the VR user experience?

To answer RQ3, we tested the differences in user experience measures between the *ESM* and *NoESM* conditions using two-way ART-ANOVAs, with factors *ESM* vs. *NoESM* and *VR Game*, followed by ART-C tests with Holm-Bonferroni posthoc correction. Table 6 summarises the effects of *ESM* compared to *NoESM*, both overall and per *VR Game* to highlight interactions.

Notable findings from Table 6 include a significant increase in IMI Pressure/Tension during *ESM* sessions overall. However, this effect is not consistent across all games. Specifically, in *HLA* and *IEYTD*, using ESM significantly reduced the experienced pressure. Additionally, there are significant effects on various presence measures. Overall, ESM significantly reduced how physically present participants felt, while significantly increasing their feelings of self and social presence. Similar to pressure, the effects on presence vary across different VR games.

Overall, ESM significantly decreased Flow Absorption, which was particularly pronounced for *ACC*, *HLA*, and *RM*, albeit with small effect sizes. However, once again the effects are not the same for all VR experiences and ESM significantly increased Flow Absorption in *IEYTD*, although with a much smaller effect size. We also note the comparatively larger effects seen in *RM* across several measures. Although the effect sizes for the differences between *ESM* and *NoESM* range from small to tiny, it is clear that ESM influences the user experience in a measurable yet seemingly unpredictable way, heavily dependent on the specific VR experience.

5.6 RQ4: How do RetroSketch & ESM relate to physiological measures?

To address RQ4, we examined the relationships between both measurement methods (ESM and RetroSketch) and ten physiological measures commonly used in the VR emotion recognition literature [88, 137, 244]. Scatterplots suggest approximately linear relationships between physiological measures and emotion and presence ratings, therefore we use standardised linear regression coefficients β to describe the strength of the relationships. The regression coefficients were estimated with multi-level linear regression

Table 6: The effects of ESM on the VR user experience shown across all games (ALL) and for each of the five VR games (ACC, GotS, HLA, IEYTD, and RM), tested with ART-ANOVAs. The effects of ESM are given as mean differences $\Delta Mean$ (ESM - $NoESM$) and Cohen's d effect sizes.

DV	ALL		ACC		GotS		HLA		IEYTD		RM	
ESM − NoESM	Δ *Mean*	Cohen's *d*	Δ *Mean*	Cohen's *d*	Δ *Mean*	Cohen's *d*	Δ *Mean*	Cohen's *d*	Δ *Mean*	Cohen's *d*	Δ *Mean*	Cohen's *d*
IMI Competence	0.019	0.007	**0.143****	0.090	**0.220*****	0.151	**0.226*****	0.129	0.101	0.070	**−0.595*****	−0.375
IMI Interest	−0.027	−0.020	−0.087	−0.072	0.158	0.113	0.020	0.018	**0.173*****	0.162	**−0.398*****	−0.310
IMI Pressure	**0.093*****	0.074	**0.257*****	0.197	**0.121*****	0.116	**−0.236*****	−0.161	**−0.107*****	−0.076	**0.429*****	0.302
IMI Effort	**−0.050****	−0.061	−0.050	−0.054	**−0.086*****	−0.072	**−0.171*****	−0.144	**0.136*****	0.121	−0.079	−0.065
MPS Physical	**−0.009*****	−0.104	**−0.061*****	−0.333	**0.024*****	0.152	**0.036*****	0.365	−0.000	−0.000	**−0.043*****	−0.255
MPS Self	**0.006*****	0.204	**−0.003****	−0.013	0.011	0.064	**−0.017*****	−0.105	**0.033*****	0.158	**0.007****	0.035
MPS Social	**0.017*****	0.212	**−0.020*****	−0.101	**0.031*****	0.148	**0.036*****	0.222	**0.033*****	0.151	0.003	0.017
Flow Absorp	**−0.048*****	−0.004	**−0.095*****	−0.122	0.083	0.112	**−0.111*****	−0.166	**0.060***	0.086	**−0.179*****	−0.250
Flow Challenge	0.001	0.014	**0.075*****	0.080	**−0.019****	−0.025	0.049	0.054	**0.162*****	0.188	**−0.260*****	−0.301
SSQ	−0.164	−0.020	0.087	0.006	1.328	0.102	**−1.114*****	−0.088	**0.694*****	0.079	**−1.817****	−0.200
BORG RPE	0.179	0.022	**1.000*****	0.043	**1.786*****	0.062	**−4.429*****	−0.140	0.321	0.010	2.214	0.094
Joy	−0.031	−0.001	−0.209	−0.085	0.265	0.123	−0.407	−0.168	**0.466*****	0.179	−0.271	−0.115
Fear	**0.028*****	0.104	−0.098	−0.044	−0.005	−0.004	0.489	0.187	−0.251	−0.179	−0.004	−0.002
Relaxation	**0.109***	0.067	−0.012	−0.005	0.305	0.142	0.275	0.125	−0.123	−0.049	−0.102	−0.044
Boredom	−0.029	−0.009	0.091	0.051	−0.406	−0.168	0.222	0.110	−0.272	−0.137	−0.220	−0.107
Presence	−0.036	−0.005	−0.280	−0.133	0.377	0.193	−0.133	−0.070	0.111	0.054	−0.254	−0.118

Table 7: Linear relationships between emotion and presence ratings and physiological measures for RetroSketch and ESM, expressed as standardised linear regression coefficients β. If either RetroSketch or ESM has a significantly stronger relationship with a physiological measure, the respective cells are highlighted. The difference in the strength of the relationships is quantified as Δd, with a positive Δd indicating a stronger relationship with RetroSketch. The physiological measures are pupil dilation level (PDL) and response (PDR), skin conductance level (SCL) and response (SCR), heart rate (HR), heart rate variability (HRV), blink rate (BR), blink duration (BD), zygomaticus major activity (Smile), and orbicularis oris activity (O-Shape).

DV	Method	PDL		PDR		SCL		SCR		HR		HRV		BR		BD		Smile		O-Shape	
		β	Δ d	β	Δ d	β	Δ d	β	Δ d	β	Δ d	β	Δ d	β	Δ d	β	Δ d	β	Δ d	β	Δ d
Joy	Retro	−.025	0.005	−.006	0.005	−.003	−0.011	−.007	−0.008	.054	0.053	.015	**−0.100**	.016	−0.002	.014	−0.020	−.027	−.008	.009	−0.009
	ESM	.012		.010		.008		−.014		.080		**−.053***		−.009		−.041		−.035		.014	
Fear	Retro	.098	0.009	.074	**−0.055**	−.002	**−0.159**	**.062***	**0.123**	.019	**−0.099**	**.038***	**0.106**	−.028	.005	.024	−0.004	.048	**−0.071**	.033	0.004
	ESM	.117		**.119***		**.026****		−.009		**.056****		.069		−.036		.030		**.151*****		.032	
Relax	Retro	−.035	**−0.086**	−.023	0.002	−.022	−0.001	−.027	−0.010	−.024	−0.006	−.010	−0.036	.052	0.024	.052	0.028	−.011	−0.007	.031	0.041
	ESM	**−.075***		−.020		−.022		−.008		−.024		−.040		.023		−.024		−.071		−.003	
Bored	Retro	**−.084****	**0.025**	−.058	0.003	.015	0.042	.000	−0.005	−.033	**−0.073**	−.040	**−0.062**	.018	−0.001	.021	0.001	−.020	0.004	.019	−0.011
	ESM	−.058		−.060		.000		.011		**−.062****		**.007***		−.016		−.015		−.002		−.023	
Pres.	Retro	.038	0.029	−.051	−0.040	−.006	−0.006	−.073	−0.022	.045	**−0.001**	.020	0.007	−.001	−0.027	−.084	**−0.064**	.020	0.002	−.008	0.002
	ESM	−.005		−.078		.009		−.081		**.077****		.005		.050		**.001***		−.015		.001	

models using the `nlme` package [21], which can take advantage of our repeated measures [36, 167]. Although the regression models cannot be used to test the relationships directly due to violations of normality, the models are still valid descriptions of the linear relationships and we can compare their goodness of fit using encompassing tests [45] from the `lmtest` package [176]. An encompassing test can detect if either RetroSketch or ESM explains significantly less variance in a physiological measure, potentially allowing us to identify a 'winner'. Based on the explained variances of each model, we calculate Cohen's f^2 and corresponding d values (see Supplementary Material Document for details) and use the difference Δd between the two d values to quantify how much one model is better than the other (RetroSketch vs. ESM).

The results in Table 7 show, for example, that RetroSketch Fear explained SCR and HRV significantly better than ESM Fear. In contrast, ESM Fear better explained PDR, SCL and Smile. Overall, the regression results indicate that RetroSketch and ESM measures bear similar relationships with physiological measures. The encompassing tests revealed only a few cases where either RetroSketch or ESM better explained physiological measures, and in all cases, the effect sizes of these differences were 'very small' or 'tiny'. When considering only significant differences with at least 'very small' effect sizes ($d > 0.1$), ESM is slightly superior in three cases whereas RetroSketch is slightly superior in two. RetroSketch explained more variance in phasic physiological measures (i.e. those related to quick changes) such as SCR and HRV, while ESM explained more variance in tonic measures (i.e. those related to slow changes in baseline) such as SCL.

We performed ordinal logistic regressions to determine whether the relationships between RetroSketch and ESM measures and physiological measures were influenced by the *VR Game*, using interaction tests with Holm-Bonferroni posthoc correction. There were very few significant interactions for both RetroSketch and ESM. However, we observed consistent interactions for several ESM measures – such as Fear, Relaxation, Boredom, and Presence – and HR, which varied significantly depending on the VR experience. A detailed breakdown of these interactions can be found in the Supplementary Material Document.

Table 8: Correlations between RetroSketch and ESM ratings and sentiment scores using Pearson's r and Kendall's τ with significance tests performed on τ. If either RetroSketch or ESM has a significantly stronger relationship with sentiment scores, the respective regression coefficients β are marked with *. The difference in the strength of the relationships is quantified as Δd, with a positive Δd indicating a stronger relationship with RetroSketch. Some rows describe significant interactions of such relationships with specific VR games (e.g. HLA and RM for Joy); in these rows Δd describes the size of the interaction effect.

DV	Method	Game	r	τ	β	Δd
Joy	*Retro*	ALL	.499	**.335*****	**.478*****	**.540**
	ESM	ALL	.355	**.242***	.266	
	ESM	*HLA – RM*				**0.162***
	ESM	*HLA – GotS*				**0.356***
Fear	*Retro*	ALL	−.069	−.063	−.149	.119
	ESM	ALL	−.092	−.049	−.100	
Relaxation	*Retro*	ALL	.342	.227***	**.322*****	.153
	ESM	ALL	.195	**.155***	.236	
	Retro	*ACC – GotS*				**0.189*****
	ESM	*HLA – RM*				**0.153****
Boredom	*Retro*	ALL	−.196	−.131	**−.279*****	0.252
	ESM	ALL	−.096	−.060	−.093	
Presence	*Retro*	ALL	.199	**.153****	.172	0.200
	ESM	ALL	.070	.053	.112	
	ESM	*GotS – IEYTD*				**0.380*****

5.7 RQ5: How do RetroSketch & ESM relate to qualitative measures?

To answer RQ5, we analysed the qualitative annotations participants made about salient moments during their VR experiences using RetroSketch. Each participant created on average 20 annotations, resulting in 2,799 annotations on 280 sketches. The annotations were analysed using a Twitter-roBERTa-base model fine-tuned for sentiment analysis [30, 130, 131], which we evaluated in the context of RetroSketch in subsection 5.2. We correlated the sentiment scores with RetroSketch and ESM ratings using Pearson's r and Kendall's τ, with significance tests performed on Kendall's τ due to non-normality. Analogously to our approach for RQ4, we described the linear relationships between RetroSketch and the sentiment scores, and ESM and the sentiment scores, respectively, with regression coefficients β. We compared the two relationships with encompassing tests, and quantified the difference between the strengths of the two relationships as Δd.

Table 8 shows both RetroSketch Joy and ESM Joy correlated moderately with the sentiment scores. Furthermore, RetroSketch Relaxation correlated moderately with sentiment, whereas ESM correlations, though significant, were weaker. Additionally, RetroSketch Presence was significantly positively correlated with sentiment, whereas ESM Presence was not. Interestingly, negative valence measures such as Boredom and Fear did not significantly correlate with sentiment for both RetroSketch and ESM. The encompassing tests and Δd values indicate that RetroSketch consistently explained more variance in sentiment than ESM, with small to medium effects.

Lastly, we performed ordinal logistic regressions to determine whether the relationships between RetroSketch and ESM measures and sentiment scores were influenced by the *VR Game*, using interaction tests with Holm-Bonferroni posthoc correction, as presented in Table 8. For these analyses, Δd describes the size of an interaction effect. There was only one significant interaction for RetroSketch and three for ESM, all with 'small' effects. This suggests that the correlations between RetroSketch and ESM measures and sentiment scores are fairly robust across different VR experiences.

5.8 User Feedback on RetroSketch and ESM

We examined participant responses to open-ended questions regarding their experiences with RetroSketch and ESM, which included their methodological preferences. Overall, users' preferences were split between ESM and RetroSketch (RetroSketch: 44.29%, ESM: 42.86%, No preference: 14.29%), highlighting both the strengths and limitations in the perceived accuracy of each method. Their responses were analysed and deductively grouped into themes [35] to better capture the reasoning behind preferences for either method.

ESM:. Views on ESM were divided, with over a third expressing mixed opinions. On the positive side, 54 participants felt that being asked questions during gameplay allowed them to accurately recognise their emotions in the moment and respond to them in *"a very natural manner"* (P88). However, 25 participants felt that the questioning caused them to disengage, especially in highly engaging games (*"jarring and a little distracting"*, P29). 86 participants felt the questioning during gameplay was disruptive and frustrating, which could result in missed key moments and incomplete capture of fluctuating emotions. 13 participants mentioned that multitasking affected their focus or the accuracy of their responses, while 10 participants talked about ESM as a study reminder ("*it was a reminder that I was in a study throughout, so I felt a bit less immersed*", P5). One participant noted "*I couldn't give extreme values which I would've otherwise given without someone else hearing me cuz I tend to conform quite a lot*" (P89), which points to a social desirability bias. In contrast, 32 participants found ESM not disruptive ("*I don't believe it influenced or interrupted my feeling as it was focussing on the experience itself*", P3).

RetroSketch: 75 participants appreciated the ability to rewatch their experience, which helped them look at the broader picture and recall key moments ("*I was able to look through and remember what I felt in the moment without being interrupted*", P8). 6 participants expressed difficulty in recalling their entire feelings for the whole gameplay session ("*the key parts definitely felt more memorable, but the parts in between less so*", P37), but participants also expressed that ratings were "*still in the right area*" (P5). 12 participants mentioned difficulty recalling presence "*when you are not in the environment*" (P72), whereas 19 participants suggested that the short duration between the experience and RetroSketch helped with recall ("*It was easy because it was just after the gameplay*", P23). 26 participants mentioned difficulties quantifying multiple feelings within a limited amount of time ("*you're limited in the amount of accurate information you can give when just watching a video on a normal computer screen*", P13).

97 participants found RetroSketch user friendly and effective in recalling emotions ("*it is quite good a way to express feeling based on time and the video*", P70). However, 13 participants talked about video control challenges ("*I also really wanted to use the 2.5x option but that just made the footage rough*", P3). 7 participants mentioned challenges with the interface layout. 27 participants described challenges sketching lines ("*the line tool was a bit hard to use when drawing really steep lines*", P57), with other participants suggesting "*the addition of being able to input an exact number*" (P1). RetroSketch was generally perceived as usable (97 participants) and accurate (74 participants).

6 DISCUSSION

RetroSketch demonstrated both internal and external validity in collecting quantitative and qualitative measures of emotions and presence across a wide range of VR experiences. In this section, we discuss the answers to our research questions in more depth and discuss future work on continuous emotion measurement.

6.1 RQ1: How do RetroSketch measures relate to ESM measures?

RetroSketch and ESM Strongly Correlate: We found a significant correlation between RetroSketch and ESM scores across all dependent variables that is consistent across different VR experiences. This, along with the majority of users reporting ease in recalling their emotions via RetroSketch, supports the validity of RetroSketch as an appraisal-based emotion measurement method and alternative to ESM without needing to disrupt the experience. These correlations exist despite RetroSketch being administered approximately 10-15 minutes after the VR experience, not immediately afterwards due to the natural break in the study for questionnaires. A key feature which enabled this was the flexibility provided by the video-aided recall that allowed participants to reflect on the 'bigger picture' of the VR experience. These findings also bolster the growing literature validating retrospective emotional appraisal as a reliable method for measuring emotions [134, 142, 198].

RetroSketch and ESM Have Key Differences: Despite the strong correlation, we observed significant differences in the distribution characteristics between RetroSketch and ESM measures. RetroSketch typically captured a broader range and variation of emotions and presence compared to ESM, possibly because its open graphing format encourages users to depict emotions more dynamically. However, in VR experiences with weak narrative elements, like *GotS* and *ACC*, RetroSketch often showed emotional flatlines. RetroSketch encourages participants to reflect on specific, salient events in the overall context of an experience. In contrast, ESM may lead to middle-scale responses due to central-tendency bias, a common effect observed in the literature [48, 115, 263]. RetroSketch's continuous, appraisal-based approach may encourage users to capture the ebb and flow of 'simmering' emotions [135], including "different and conflicting emotions from the same event" [151].

ESM Reminds Users They Are Being Observed: RetroSketch consistently recorded lower 'positive' emotions and presence, and higher 'negative' emotions compared to ESM. This may result from social desirability bias [255] in ESM, where participants are reminded of the study. While RetroSketch is not immune to such bias, it allows users to self-report in a more private, less pressured setting. Additionally, interaction results from Table 3 reveal significant differences in distribution characteristics between RetroSketch and ESM, particularly for less dominant emotions in each VR experience. For instance, *GotS* was least associated with fear overall, yet showed a significant distribution difference for Fear, similar to Boredom in *IEYTD*. This suggests that ESM may be more prone to impulsive fluctuation, whereas RetroSketch may be better attuned to the overall emotional characteristics and context of a game.

6.2 RQ2: How reliable is RetroSketch & ESM across different VR experiences and users?

The relationships between RetroSketch and ESM remained robust across various user demographics, personalities, player types and immersive tendencies. Few significant interactions with covariates were observed, and even users' preferences for using ESM over RetroSketch did not significantly influence the correlations. As shown in Table 4 and Table 5, covariates generally influence RetroSketch and ESM similarly, e.g. both Presence measures correlate with immersive tendencies (ITQ) [266], both Joy measures correlate with Tondello Challenge traits [248], and more agreeable individuals rate the experience as more relaxing with both measures [78].

For example, we observed a moderate effect of gender on ESM Joy, with males reporting higher ratings, whereas no significant gender effect was found for RetroSketch Joy. This could be due to social desirability bias in ESM [255], particularly self-enhancement bias [217], where males may want to appear as being more successful, and therefore enjoying the experience more. Alternatively, previous studies have shown gender differences in self-reported emotions [63], including in the context of video games [108], which ESM might capture.

Additionally, an expected negative correlation was observed between RetroSketch Fear and Extroversion [19, 98], but not for ESM, suggesting that less extroverted individuals do not always report higher Fear, possibly due to social desirability bias [255]. Interestingly, while we would expect Openness to correlate positively with Fear, no significant correlation was found with RetroSketch, and a significant negative correlation was observed with ESM. Overall, the influence of personality traits on either measure is minimal, with both measures generally aligning well.

Previous work has shown evidence for a positivity effect in older adults' emotional recall [149, 253]. While we do not collect data from older adults (65+), age did not affect RetroSketch or ESM measures in the context of VR games, with no significant correlations across the four emotions. Age showed a significant positive correlation with RetroSketch presence that was not observed for ESM presence, and indeed, some prior literature suggests age correlates with presence [127]. RetroSketch may be capturing real differences in presence ratings across age demographics, however, the observed correlation was weak and other previous work contests whether age influences presence in VR [61, 129].

6.3 RQ3: How does ESM influence the VR user experience?

While the effects of ESM on the VR experience are *measurable*, they are also seemingly *unpredictable*, depending heavily on the VR experience. For instance, participants generally experienced higher pressure with ESM (Table 6), likely due to increased cognitive load. However, in more cognitively demanding experiences like *HLA* and *IEYTD*, ESM actually reduced pressure, likely because it provided artificial breaks during intense moments. *ACC* is a notable exception, as the experience is intense but involves driving, where holding a conversation is common.

Another interesting finding is the inconsistent effects of ESM on Presence [133]. The 'immediate reflection' [225] required by ESM had varying impacts on Presence depending on the VR context and user activity. Overall increased social presence could result from ESM being administered through a human voice, however, in *ACC* ESM affected all three Presence measures negatively. The most consistent outcome was the negative impact of ESM on Flow Absorption [132], which is supported by qualitative feedback that ESM was disruptive and disengaging. The largest effects of ESM were observed in *RM*, particularly on intrinsic motivation, flow and physical presence. *RM* has a focus on open exploration and environmental storytelling [102], and ESM may disrupt immersion in such experiences. However, the effects of ESM were overall small.

6.4 RQ4: How do RetroSketch & ESM relate to physiological measures?

Both RetroSketch and ESM showed similar relationships with common physiological measures of emotion (Table 7), with only 'very small' to 'tiny' differences. Affective computing and emotion recognition approaches [29, 88, 137, 169] usually model the relationship between emotions and physiological signals based on subjective 'ground truth' data. RetroSketch is well placed to provide such data continuously in high resolution for multiple emotion variables, and could be particularly useful when subjective ground truths cannot be captured in the moment or immediately after, making retrospective appraisal necessary.

According to subsection 5.6, tonic measures, which reflect gradual shifts in physiological baselines, may drive emotional measures more in ESM because these physiological responses are more readily perceptible by the user. According to Barrett's Constructed Emotion Theory [12], "*users make meaning of physical responses, based on context and prior experience, before they know what emotion is attached to the situation*".

While both ESM and RetroSketch are likely influenced by users' interoceptive awareness [50, 142], this influence may be more immediate in ESM. This is supported by the many interactions observed across different games when relating HR measures to ESM emotions. These interactions highlight that the interpretation and association of one's HR to different emotions is highly context dependent [12], e.g. elevated HR in *HLA* may be more associated with fear while in *ACC* it may be associated with joy or excitement.

RetroSketch explained more variance in phasic responses such as SCR and HRV. Phasic responses are typically tied to specific events and are only perceptible in certain moments, which RetroSketch can capture due to its continuous and granular data collection. This further supports the validity of using appraisal and recall-based approaches for emotion measurement [134, 192, 198].

6.5 RQ5: How do RetroSketch & ESM relate to qualitative measures?

Both RetroSketch and ESM Joy scores significantly correlated with the sentiment of annotations made using RetroSketch. Unsurprisingly, RetroSketch showed a stronger correlation than ESM, validating the use of sentiment analysis [126, 160, 225] on user-generated annotations. Compared to other sentiment-based approaches, RetroSketch provides a rich combination of video footage, temporally anchored qualitative annotations and quantitative ratings.

When reflecting on users' preferences for RetroSketch or ESM, we observed an almost 50/50 split. This divide is surprising, considering that RetroSketch typically takes longer to use and requires more effort from the user. A deeper look into the reasons revealed that some users felt they could not accurately reflect on their emotions or presence in the moment of a VR experience. Conversely, others mentioned that they struggled to recall their emotions or presence when using RetroSketch, even with video-aided recall. This points to interpersonal differences in both immediate reflection and emotional recall. User preference did not significantly affect the correlation between RetroSketch and ESM, indicating robustness of RetroSketch irrespective of preference.

6.6 Limitations & Future Work

Generalizability & Scalability: RetroSketch was successfully applied in both paper form during the pilot study and digital form in the main study, specifically within the context of VR games. While this has demonstrated promising results, there remain opportunities to explore the application of RetroSketch in other VR experiences such as training scenarios, education, therapeutic environments, and non-interactive storytelling like immersive films. Although we did extend our exploration of RetroSketch to high-end immersive simulators commonly used in training (motion platform combined with *ACC*), a formal evaluation in this context is warranted.

Further investigation should determine the best practices for RetroSketch, including how it can be scaled to measure experiences of different durations, how to optimise its interface to reduce complexity and user workload, and what other emotions can be captured by RetroSketch such as direct measures of valence and arousal. We used RetroSketch to appraise 30-minute VR sessions, which took between 15 and 40 minutes depending on the participant. This raises questions about the upper duration limit where RetroSketch can still provide reliable appraisals, and whether RetroSketch can capture highly granular data during brief emotional events.

RetroSketch could be used to explore in-person player dyads or online multiplayer games, where interpersonal relationships influence emotional responses in players [183]. Beyond VR, RetroSketch holds potential for application in Augmented Reality (AR) and even non-immersive experiences as a general emotional appraisal tool. However, questions remain about how to reliably facilitate video-aided recall across different contexts of use.

Emotional Recall and Appraisal: In our study, participants completed questionnaires and were given an opportunity for a short break after a VR session, which took approximately 10-15 minutes, before using RetroSketch.. While this was effective, it raises questions about how emotional recall with RetroSketch might change over time and how this could influence the appraisal process. Moreover, there are a multitude of emotional models beyond appraisal, and RetroSketch should be evaluated in light of these other theories, e.g. considering the Facial Feedback Hypothesis [37].

Do RetroSketch measures retain their robustness when applied days, weeks or even months after an experience? Can RetroSketch be reliably utilised for multiple appraisal sessions of the same experience? Exploring these possibilities could significantly extend the utility of RetroSketch. Additionally, previous research has considered incorporating physiological measurements during the appraisal process [89], which could also be promising for RetroSketch.

Beyond Video-Aided Recall: While RetroSketch was effectively used to appraise VR experiences through video-aided recall, there is potential for incorporating more immersive elements to enhance the recall process. Building on the work of continuous emotion measurement for 360° video in VR [269, 270], VR itself could be leveraged as the platform for retrospection. For instance, enabling users to relive VR experiences and events within the VR environment itself could offer a richer appraisal experience. With the findings of this paper and the existing body of work on video-based emotional measurement and annotation tools [67, 269], the advantages of using immersive over non-immersive retrospection could be explored and formalised.

While this merits further investigation, it also presents several challenges. Replaying events or experiences in the 3D world may not be technically feasible (e.g. if replay features are not built into the experience), and replaying 3D experiences from a first-person perspective could induce simulator sickness, especially in scenarios involving locomotion [51].

6.7 Recommendations for RetroSketch

Based on our findings, we make the following recommendations for using RetroSketch to measure emotions and presence in VR experiences:

(1) RetroSketch is more suitable than ESM for capturing continuous data at high resolution. However, if this is not required then consider the ease and simplicity of ESM.
(2) RetroSketch is particularly relevant for experiences that elicit a variety of fluctuating emotions.
(3) RetroSketch is available as both a digital and paper tool both of which showed strong correlations with ESM. However, the paper-based RetroSketch has not been as thoroughly evaluated so should be used with caution.
(4) Be careful when using RetroSketch for experiences longer than 30 minutes because the time required for retrospection increases with the duration of the experience, and we have not yet explored the limits of RetroSketch.
(5) Allow users the freedom to use RetroSketch as they see fit.
(6) Setting a minimum number of key points can set user expectations for the level of detail required and can be used to ensure good coverage across the experience. However, be careful to avoid demand characteristics.
(7) Allow for at least half the time of the session duration and allow additional time if users need it to complete their sketch.
(8) If time is limited, or RetroSketch can not be administered soon after the experience, consider using other methods such as ESM or standard questionnaires.
(9) Provide instructions about how RetroSketch works and highlight the importance of annotated keypoints to help contextualise and understand responses to events.
(10) Sentiment analysis models can be used to quantify large amounts of annotations for easier analysis.

6.8 Impact

RetroSketch advances the measurement of emotion and presence for VR experiences by offering an appraisal-based approach that provides highly granular and continuous data for categorical emotions, core affect and presence. It also highlights salient events and provides temporally anchored qualitative annotations. RetroSketch can be applied in research, VR design, and user experience testing to better understand the impact of design choices, e.g. conducting more granular comparisons of presence in immersive experiences or measuring specific emotional effects of individual events and characters in VR. The strong correspondence between RetroSketch and physiological measures suggests that the fine-grained emotion data provided by RetroSketch can be used as ground truth in the development of affective systems (e.g. for emotion recognition) providing an alternative to ESM.

7 CONCLUSION

We presented RetroSketch, a retrospective method for measuring emotions and presence in VR experiences. We evaluated RetroSketch in a large VR user study ($n = 140$), comparing it to state-of-the-art methods including ESM and physiological sensing (dataset found here [172]). We validated RetroSketch across five different

VR experiences, which participants played for one hour in two 30-minute sessions. This led us to the following conclusions:

(1) RetroSketch can be used to measure emotions and presence continuously in VR experiences.
(2) RetroSketch correlates strongly and robustly with ESM across various VR experiences.
(3) RetroSketch shows correspondences with physiological measures of emotion similar to ESM and can be used for the development of emotion recognition systems.
(4) ESM influences the VR user experience in small but seemingly unpredictable ways.
(5) RetroSketch annotations relating to salient events provide time-anchored qualitative data that can be analysed automatically with sentiment analysis models.

Our findings support the use of RetroSketch for measuring emotions and presence in VR providing that there is sufficient time for the user to navigate, recall, and reflect on their experience.

ACKNOWLEDGMENTS

We would like to acknowledge Jovana Cuxac, Jasmine Chung, Katherine Baldrian, and Tarini Sehgal for their support and assistance in conducting the study. This work is supported by the European Union's Horizon Europe research and innovation program and Innovate UK under grant agreement *No 101070533*, project EMIL (The European Media and Immersion Lab: https://emil-xr.eu/), as well as the Royal Society Industry Fellowship under grant agreement *No INF\R1\221058*.

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