# Towards Understanding Physiological Responses to Emotional Autobiographical Memory Recall in Mobile VR Scenarios

Kunal Gupta
kgup421@aucklanduni.ac.nz
University of Auckland
Auckland, Auckland, New Zealand

Sam W. T. Chan
University of Auckland
Auckland, New Zealand
sam@ahlab.org

Yun Suen Pai
University of Auckland
Auckland, New Zealand

Alexander Sumich
Nottingham Trent University
United Kingdom

Suranga Nanayakkara
University of Auckland
Auckland, New Zealand

Mark Billinghurst
University of Auckland
Auckland, New Zealand

## ABSTRACT

Virtual Reality (VR) is becoming increasingly mobile and ubiquitous but the experience is still rarely tailored to a person's individual experience and emotion. Autobiographical memories (AM) are better remembered when an event is associated with strong emotional experiences. In this work, we introduce an experimental paradigm in VR to investigate the effect of emotional AM recall on a user's physiological state when coupled with wearable electrodermal activity (EDA) sensors and integrated pupil trackers. With an objective to benchmark the effect of AM recall on human physiology, we replicated the Autobiographical Memory Test (AMT) in VR which displays positive, negative, and neutral valence words to participants for them to recall self-relevant memories associated with that word. We found that there was a positive effect of AM recall on EDA peak amplitude, EDA peak number, and pupil diameter when comparing with no recall. However, there was no impact on emotional AM recall. Finally, we discuss the limitations and possibilities of leveraging autobiographical memory to create personalized mobile VR experiences when used with wearable physiological sensors.

## CCS CONCEPTS

• **Human-centered computing → Empirical studies in HCI**; **Virtual reality**.

## KEYWORDS

Emotional Autobiographical Memory, Virtual Reality, Electrodermal Activity, Pupil Diameter, Physiological Signals

**ACM Reference Format:**
Kunal Gupta, Sam W. T. Chan, Yun Suen Pai, Alexander Sumich, Suranga Nanayakkara, and Mark Billinghurst. 2021. Towards Understanding Physiological Responses to Emotional Autobiographical Memory Recall in Mobile VR Scenarios. In *Adjunct Publication of the 23rd International Conference on Mobile Human-Computer Interaction (MobileHCI '21 Adjunct), September 27-October 1, 2021, Toulouse & Virtual, France.* ACM, New York, NY, USA, 5 pages. https://doi.org/10.1145/3447527.3474864


*MobileHCI '21 Adjunct, September 27-October 1, 2021, Toulouse & Virtual, France*

ACM ISBN 978-1-4503-8329-5/21/09…$15.00
https://doi.org/10.1145/3447527.3474864

## 1 INTRODUCTION

This paper explores how emotional Autobiographical Memory (AM) recall in Virtual Reality (VR) can be detected by physiological cues. Everyday-life experiences are better remembered when associated with strong emotions when compared to those lacking emotional relevance. This has been demonstrated through various flashbulb memory investigations [4]. Individuals tend to remember the emotional events with an enhanced vividness and in greater detail than events without emotional association, suggesting that emotional AM are more likely to be recalled when compared to autobiographical events without emotion. AM refers to the episodic memory recall of personal events of one's life [7, 11] or a complex mental representation of the self in the past [6].

Developments in immersive technologies like VR offer exciting opportunities for psychologists and human-computer interface (HCI) researchers to improve the ecological validity of a task [20], especially with recent devices that are mobile and untethered, such as Oculus Quest 2[1] , and HP Reverb G2[2]. An experiment incorporated in VR enables verisimilitude (i.e. the degree to which the experimental task replicates the real-life situation realistically) as well as its veridicality (i.e. the degree to which experimental results accurately indicate the psychological phenomenon). Many researchers have demonstrated that VR experience can effectively elicit emotions [1] and can facilitate a spatial reference for the past events recall [30]. However, there is a lack of research on understanding how emotional AM recall works in VR physiologically. Insights from this research could benefit in designing better positive emotion regulation strategies using Mobile VR-based AM interventions supporting enhancement of positive reminiscence. These Mobile VR experiences can consequently assist in up-regulation of momentary positive emotions and advancing wellbeing [24].

In this work, we investigated in a VR setting how the emotional response of users were shaped from their past experiences using direct retrieval approach [15]. The stimuli cues for this direct and effortless AM retrieval were presented in the form of affective words from a database. We measured the electrodermal activity (EDA) and pupil diameters of participants during their memory recollection as

[1] https://www.oculus.com/quest-2/
[2] https://www.hp.com/us-en/shop/pdp/hp-reverb-g2-omnicept-edition-%282e5q4av%29

objective measures of their emotional feedback. We also collected subjective measures of emotional feedback through self-reported affective and memory questionnaires. We found that AM recall resulted in the significant increase in EDA peak amplitude, EDA peak number, and pupil diameter compared to when participants were not recalling memories. However, there was no significant differences in EDA measures and pupil diameter when recalling of emotional AM of varying valences (positive, negative and neutral). Our work serves as a preliminary investigation in which we first use a *simple visual stimulus*. We discuss limitations and possibilities of leveraging autobiographical memory in mobile VR experiences as well as integrating physiological sensors into an all-in-one wireless head-mounted display (HMD). Future work could build on our findings when presenting more complex and vivid visual stimuli.

## 2 RELATED WORKS

### 2.1 Emotional Autobiographical Memory and Physiological Signals

Electrophysiological signals such as electroencephalogram (EEG) [8, 32] and electrodermal activity (EDA) [2, 5, 13] have been used in research studies to examine users' cognitive states, affective states and memory processes (e.g., recollection and familiarity). For example, Sheldon et. al. [31] showed emotional valence and arousal of the musical AM retrieval cues were associated with accessibility and vividness using EDA and facial expressions. Schaefer et al. [29] also used EDA and HRV to understand emotional AM in an event narration task where they reported that the emotional memories are vivid but not specific in detail as compared to the neutral ones. El Haj et. al. [10] investigated AM recall using pupil diameter and found an increase in pupil diameter when recalling an AM but could not find any significance in identifying emotional AM as compared to neutral AM. From these previous works, we found that a combination of EDA and pupil physiological information could be useful in investigating emotional AM. However, these works investigated emotional AM and physiological measures in conventional lab settings. In our work, we build upon their findings and methodologies in a VR setting, and also look towards a more mobile-based application scenario, where these sensors can easily be integrated into a mobile HMD in the future [25].

### 2.2 Autobiographical Memory Retrieval in Virtual Reality

Previous work in immersive 3D virtual environments reported an increase in memory retrieval in VR as compared to laboratory settings [26, 33] as it provides a closer approximation to real-life experiences contributing in enhancing experimental control and ecological validity [27]. Halm et. al. [14] reported that the old/new recognition task in four different virtual environments with unique objects was significantly better for the environments which were explored more, suggesting the benefits of memory recall with increase in VR interactions. Later, this idea of benefit of active VR interaction was extended from just object recognition to spatial recall performance by Jang et. al. [16] through a virtual training task. However, this research focused primarily on episodic memory. Schöne et. al. [30] reported that the 360° VR experiences contributes to autobiographical associative network, whereas traditional video experiences in laboratory settings remain episodic events. They compared retrieval reaction time and success rate in a motor-ride experience in 360° video in VR and a 2D video in laboratory setting. Kisker et. al. [19] used EEG information to indicate that the autobiographical retrieval process is supported by VR experience retrieval as compared to recalling in traditional laboratory as events might not reflect real-life memory mechanisms.

Considering the benefits of immersive VR in AM retrieval from previous studies but a research gap in understanding emotional AM in VR using not just subjective or performance measures but with the help of physiological information motivated us to conduct our study.

## 3 METHODOLOGY

### 3.1 Participants

We conducted a pilot study with 6 volunteer participants between the age of 21 and 31 (2 females, mean = 26.8, SD = 3.65). All of them had normal or corrected to normal vision and had experienced VR more than once. None of the participants had any history of epilepsy or medically identified depression. Ethics approval and participants' consent were attained for the study and they were allowed to withdraw at anytime.

### 3.2 System Design


**Figure 1: Experiment setup with participant wearing HTC Vive Pro Eye VR HMD and Shimmer3 GSR+ physiological sensor taking the AMT test in VR**

The experiment was conducted in a VR laboratory, isolated from other rooms to minimize the audio noise and radio frequency interference to reduce the risk of additional noise in physiological signals [12]. During the experiment, participants wore the HTC Vive Pro Eye HMD[3] to enable VR interactions along with Shimmer3 GSR+ sensor[4] to collect EDA physiological information. The pupil information was collected using the Vive Eye Tracking SDK (SRanipal)[5]. In the Virtual Environment (VE; developed using Unity3D[6]), we followed the laboratory setup used by Haj et. al. [10] where participants were seated on a chair in a room with white walls at 40 cm distance from one of the wall where we displayed the cue words. For the main task, we followed a modified Autobiographical

[3]https://www.vive.com/eu/product/vive-pro-eye/overview/
[4]https://www.shimmersensing.com/products/shimmer3-wireless-gsr-sensor
[5]https://developer.vive.com/resources/vive-sense/sdk/vive-eye-tracking-sdk-sranipal/
[6]https://unity.com/

Memory Test (AMT) [37] where the participants were asked to recall AM associated to displayed cue words. We selected five emotional words each for positive (happy, energetic, loved, successful, and brave), negative (hopeless, lonely, sad, afraid, and angry), and neutral (hardwork, election, huge, fork, and fast) emotions from previous emotional AMT research [17, 23].

We used the self-assessment manikin (SAM) [3] rating to get subjective valence and arousal ratings and the Memory Experiences Questionnaire - Short Form (MEQ-SF) [21] to measure subjective AM characteristics. These subjective questionnaires were integrated into the VE both for participant's convenience and to avoid any negative impact on their immersion, which may affect their physiological state.

### 3.3 Study Design and Procedure

We used a within-subject study design with 5 words each shown in randomized order for three categories i.e. positive, negative, and neutral. In order to reduce the carry forward effect, participants were asked to relax for 30 seconds before the start of each trial followed by a counting session. The participants were first asked to complete the pre-experiment questionnaire consisting of demography, past VR usage, and Positive and Negative Affect Schedule [36] to make sure that the pre-session negative affect will not impact the study. After that, the experimenter helped them to put on the Vive HMD and Shimmer sensor on the non-dominant hand and gave a sample task to get them familiar with the virtual environment. We instructed the participant to keep their dominant hand's thumb on the controller's touchpad while recalling the memory to tag the actual recall event during the 30 seconds of recall session.

Once the participants understood the procedure, we started the main session following sequence: relaxation, counting, recall, and speak phase. Participants were first asked to relax for 30 seconds during which they were asked to not to think about anything and keep their mind as clear as possible. After that, they heard a ring sound indicating the start of the "Count" session which lasted for the next 60 seconds. During this time, they needed to start counting from one at a comfortable pace. After that, another ring sound indicated the end of the session. After 10 seconds, a cue word appeared for 3 seconds, and they needed to recall any past experience associated with that word for the next 30 seconds. At the end of the 30 seconds, they heard another ring sound and they needed to start narrating the recalled experience for 120 seconds. After each trial, participants were asked to complete the SAM scale and MEQ-SF questionnaires in VR.

### 3.4 Physiological Analysis

The EDA and pupil data was first cleaned by eye-balling and removing any sudden peaks due to motion [13]. For EDA analysis, we used the Neurokit2 Python package [22] to decompose EDA data into Phasic and Tonic components. We then used the method proposed by Kim et al. [18] on the Phasic data to extract features such as peak number (PN), mean peak amplitude (MPA), and peak offsets for each relax (baseline), count (no recall), memory recall, and memory narration session data. For pupil diameter analysis, pupil data during blinks (where missing values were coded as -1) were removed. The mean pupil diameter (PD) was calculated for each event in the trials.

## 4 RESULTS

### 4.1 Physiological Measures

The computed EDA features were not normally distributed from the Shapiro-Wilk test ($p$ <.001). Thus, for the emotional recall conditions, we conducted Friedman tests ($\alpha$ = 0.05) and for the pairwise comparison, we performed Nemenyi post-hoc tests ($\alpha$ = 0.05). We used Wilcoxon-Signed Ranks tests to understand the effect of AM recall. The Wilcoxon test found a significant main effect of AM Recall on the MPA ($Z = 2.71, p < .005$). The median MPA for recall condition (0.1015 $\mu S$) was higher than the no-recall condition (0.0543 $\mu S$). There was no main effect of emotional recall ($\chi^2(2) = 1.33, p = .51$ ) found on the MPA using the Friedman test with median MPA of 0.2647, 0.1779 and 0.1855 $\mu S$ for neutral, positive, and negative recall respectively. A significant main effect of AM recall was reported on the PN ($Z = 4.10, p < .001$) using the Wilcoxon-Signed Rank test. The median PN for recall condition (3) was higher than the no-recall condition (2). There was no main effect of emotions (positive, negative, and neutral) reported on PN using the Friedman test ($\chi^2(2) = .82, p = .66$). The median PN for neutral cues was 3.5 and 3.4 for positive and negative cues.

The Pupil Diameter (PD) values were not normally distributed according to the Shapiro-Wilk test ($p < .05$). A Wilcoxon Signed Rank test showed that there was a significant main effect of AM Recall on PD ($Z = -4.615$, $p < .001$). The median PD for recall condition (3.12 mm) was higher than the value for the no-recall condition (2.96 mm). A Friedman test showed that there was no significant differences ($\chi^2(2) = .33, p = .85$) in the PD for emotional recall. Median values for PD for neutral, positive and negative emotional cues were 3.05, 3.12 and 3.14 mm respectively.

### 4.2 Subjective Questionnaires

The PANAS questionnaire results reported higher level of positive affect with a mean Positive Affect Score of 27.9 (SD = 6.4) as compared to mean Negative Affect Score of 19.1 (SD = 7.2). The SAM scale involved two 9-point sub-scales for valence (rating of 1: negative, 9 :positive and 5 :neutral) and arousal (rating 1 : calm, 9 : excited and 5: neutral). The ratings on both sub-scales were not normally distributed according to the Shapiro-Wilk test. The Friedman test found a significant main effect of emotional recall (positive, negative, neutral) on valence ratings ($\chi^2(2) = 12, p < .005$) but no main effect on arousal ratings ($\chi^2(2) = .26, p = .88$). The median valence ratings for positive, negative and neutral emotional recall were 7.2, 3.4 and 5 respectively. As a follow up on valence ratings, pairwise signed-ranks post-hoc tests revealed that there was a significant difference in median ratings between positive-negative cues ($p < .05$), neutral-negative cues ($p < .05$), and positive-neutral cues ($p < .05$). The median arousal ratings for positive, negative and neutral emotional recall were 5.8, 5.7 and 5.6 respectively.

The MEQ-SF sub-categories were measured on 5-point scales. The Shapiro-Wilk test showed that vividness, accessibility, sensory, visual, emotion, and valence categories were not normally distributed except for the time perspective category. We performed a Friedman test on non-parametric categories followed by Pairwise

**Table 1: Memory Experience Questionnaire - Short Form - Median values for each category**

| MEQ-SF Category | Positive | Negative | Neutral |
|---|---|---|---|
| Vividness (1: low, 5: high) | 3.63 | 3.63 | 3.2 |
| Accessibility (1: low, 5: high) | 3.3 | 3.6 | 3.4 |
| Sensory (1: low detail, 5: high detail) | 2.9 | 3.1 | 3.1 |
| Time Perspective (1: vague, 5: clear) | 3.1 | 3.4 | 3.5 |
| Visual (1: first-person, 5: third-person) | 3.7 | 3.8 | 3.7 |
| Emotion (1: weak, 5: strong) | 3.0 | 3.1 | 2.9 |
| Valence (1: negative, 5: positive) | 4.2 | 2.1 | 3.9 |

signed-ranks post-hoc test. We report the median values for each category in Table 1 for positive, negative and neutral recall. Friedman test reported a significant main effect of emotional recall on valence category ($\chi^2(2) = 9.33; p < .05$) and Pairwise signed-rank post-hoc tests showed a significant difference in ratings between positive-negative ($p < .05$), and negative-neutral ($p < .05$), but no difference between positive and neutral ($p = .53$) memory recall. No main effect of emotional recall on vividness ($\chi^2(2) = 3.22; p = .20$), accessibility ($\chi^2(2) = 1.13; p = .57$), sensory ($\chi^2 = 2.33; p = 0.31$), visual ($\chi^2(2) = 1.13; p = .57$), and emotion ($\chi^2(2) = 5.33; p = .069$) was found. A one-way repeated measure ANOVA for time perspective did not report any main effect of emotional recall on time perspective category ($F = 2.34, p = .15$).

## 5 DISCUSSION

A significant main effect on EDA, MPA and PN shows that we can identify the AM recall in VR. However, we could not determine any difference in emotional AM recall (i.e. positive, negative, and neutral) using emotional words. An increase in MPA and PN suggests an AM recall as compared to no-recall. Our results regarding the increase in PD when recalling AM and the lack of statistical significance in PD for emotional recall are consistent with the findings from previous works in conventional laboratory settings [10]. The words might have induced similar emotional arousal or might not have triggered strong emotions, resulting in insignificant differences in EDA and PD measures in emotional recall. Another reason could be that PD is better for reflecting differences in emotional arousal stimuli than for valence [35]. Our SAM scale analysis reported a significant main effect on perceived valence with significant differences between positive-negative, positive-neutral, and negative-neutral median scores (7.2: positive, 3.4: negative, and 5: neutral). This suggests that participants perceived the valence of the emotional cue words correctly. No significant main effect on perceived arousal and almost similar median scores supports our suggestion that the words induced similar arousal A significant main effect on the valence category of MEQ-SF suggests that the participants were able to recall positive, negative, and neutral emotional experiences. There were significant differences between positive-negative and negative-neutral ratings (4.2 for positive, 2.1 for negative and 3.9 for neutral). However, there was no difference between positive and neutral recall indicating that participants perceived positive and neutral words with almost similar valence. Given that the valence rating for neutral was 3.9, 0.9 above the theoretical neutral rating of 3, neutral words could have caused slightly more positive recall. A sample anecdote was the AM recall for the neutral word 'Huge' where participant shared her experience of going to a huge theme park which was a positive experience for them. Another participant shared their memory for the neutral word 'Election' as *"... all these TV channels usually shows some movies and those kind of stuff during these election results announcements, so me and my sister used to like cook some food, get some snacks peanuts, roasted peanut at home. And then we watch all night we watch all the movies. that was really fun!"*. As suggested by Talarico et. al. [34], events with higher emotional intensities tend to be remembered longer, hence affecting the vividness, accessibility, and emotional sense of recollection. The lack of varying range of emotional intensities could be a possibility of our results showing no significant effect on these categories.

## 6 LIMITATIONS AND FUTURE WORK

One of the first key limitation is that our data collection and analysis is only from a total of 6 participants. As this is a preliminary pilot study, we plan to run a full study with more participants in the future. We also found that the absence of diverse arousal dimensional emotional words was the primary drawback in investigating the different emotional autobiographical memory recall. For our future work, we would like to include higher emotional intensity words. The results indicated that using EDA and pupil physiological signals could provide promising results, so we plan to extend this by also exploring Electroencephalogram (EEG) and heart rate variability (HRV) signals as proposed by past research. These sensing methods, like both EDA and pupil, can be integrated into a standalone HMD as well. Utilizing a single integrated sensing device will enable more mobile experiences.

Our next step will also be to use a more immersive and interactive virtual environment, such as 360° video or a completely interactive virtual environment, towards identifying emotional AM. Lastly, we wish to develop an emotional autobiographical recall prediction model based on the collected physiological signals in VR. Such a model could potentially be integrated in VR to create a more impactful and immersive experience that is reactive to the user's AM.

The implications of this study could be used to understand the effect of AM recall while designing text-based VR interfaces or textual content in VRUI [9]. Other potential applications of this could be as a form of passive learning or exposure treatment device. For passive learning, users could use our system during long rides for effective learning since we can potentially monitor the user's emotional state and adapt to it. The same can be said regarding exposure treatment or therapy. VR has proven to be effective in this [28], and we are looking towards promoting our system to be more ubiquitous and allowing treatment at any location. Lastly, our system can be used to create a more personalized VR gaming experience. Research could be conducted into a multiplayer co-located VR experience where the virtual environment is a collage of each participant's emotional state and AM.

# 7 CONCLUSION

In this paper, we examined the effects of AM recall and Emotional AM recall on EDA, and pupil physiological signals in VR. Our results show that AM recall has a significant effect on EDA mean peak amplitude, EDA peak number, and pupil diameter compared to the condition when the participants were not recalling memories. We could not identify any effect of emotional AM recall i.e. positive, negative, and neutral emotional experiences. However, our results also imply the potential improvement points for the used emotional words to be of varying intensity. These issues will be addressed in the future work along with investigating more physiological sensors such as EEG, and HRV.

# REFERENCES


[1] R. M. Baños, C. Botella, I. Rubió, S. Quero, A. García-Palacios, and M. Alcañiz. 2008. Presence and emotions in virtual environments: The influence of stereoscopy. *CyberPsychology & Behavior* 11, 1 (2008), 1–8.

[2] M. M. Bradley, M. K. Greenwald, M. C. Petry, and P. J. Lang. 1992. Remembering pictures: pleasure and arousal in memory. *Journal of experimental psychology: Learning, Memory, and Cognition* 18, 2 (1992), 379.

[3] M. M. Bradley and P. J. Lang. 1994. Measuring emotion: the self-assessment manikin and the semantic differential. *Journal of behavior therapy and experimental psychiatry* 25, 1 (1994), 49–59.

[4] R. Brown and J. Kulik. 1977. Flashbulb memories. *Cognition* 5, 1 (1977), 73–99.

[5] S. W. T. Chan, S. Sapkota, R. Mathews, H. Zhang, and S. Nanayakkara. 2020. Prompto: Investigating Receptivity to Prompts Based on Cognitive Load from Memory Training Conversational Agent. *Proceedings of the ACM on Interactive, Mobile, Wearable and Ubiquitous Technologies* 4, 4 (2020), 1–23.

[6] M. A. Conway. 2001. Memory: Autobiographical. In *International Encyclopedia of the Social & Behavioral Sciences*, Neil J. Smelser and Paul B. Baltes (Eds.). Pergamon, Oxford, 9563 – 9567. https://doi.org/10.1016/B0-08-043076-7/01495-9

[7] I. Cristofori and H. S. Levin. 2015. Chapter 37 - Traumatic brain injury and cognition. In *Traumatic Brain Injury, Part II*, Jordan Grafman and Andres M. Salazar (Eds.). Handbook of Clinical Neurology, Vol. 128. Elsevier, 579 – 611. https://doi.org/10.1016/B978-0-444-63521-1.00037-6

[8] T. Curran and A. M. Cleary. 2003. Using ERPs to dissociate recollection from familiarity in picture recognition. *Cognitive Brain Research* 15, 2 (2003), 191–205.

[9] T. Dingler, K. Kunze, and B. Outram. 2018. Vr reading uis: Assessing text parameters for reading in vr. In *Extended Abstracts of the 2018 CHI Conference on Human Factors in Computing Systems*. 1–6.

[10] M. El Haj, S. M. J. Janssen, K. Gallouj, and Q. Lenoble. 2019. Autobiographical memory increases pupil dilation. *Translational Neuroscience* 10, 1 (2019), 280–287.

[11] R. Fivush and Matthew E. G. 2017. 2.07 - Autobiographical Memory. In *Learning and Memory: A Comprehensive Reference (Second Edition)* (second edition ed.), John H. Byrne (Ed.). Academic Press, Oxford, 119 – 135. https://doi.org/10.1016/B978-0-12-809324-5.21046-8

[12] K. Gupta, R. Hajika, Y. S. Pai, A. Duenser, M. Lochner, and M. Billinghurst. 2019. In ai we trust: Investigating the relationship between biosignals, trust and cognitive load in vr. In *25th ACM Symposium on Virtual Reality Software and Technology*. 1–10.

[13] K. Gupta, R. Hajika, Y. S. Pai, A. Duenser, M. Lochner, and M. Billinghurst. 2020. Measuring Human Trust in a Virtual Assistant using Physiological Sensing in Virtual Reality. In *2020 IEEE Conference on Virtual Reality and 3D User Interfaces (VR)*. IEEE, 756–765.

[14] J. Hahm, K. Lee, S. Lim, S. Kim, H. Kim, and J. Lee. 2006. Effects of active navigation on object recognition in virtual environments. *CyberPsychology & Behavior* 10, 2 (2006), 305–308.

[15] C. B. Harris and D. Berntsen. 2019. Direct and generative autobiographical memory retrieval: How different are they? *Consciousness and cognition* 74 (2019), 102793.

[16] S. Jang, J. M. Vitale, R. W. Jyung, and J. B. Black. 2017. Direct manipulation is better than passive viewing for learning anatomy in a three-dimensional virtual reality environment. *Computers & Education* 106 (2017), 150–165.

[17] C. John. 1988. Emotionality ratings and free-association norms of 240 emotional and non-emotional words. *Cognition & Emotion* 2, 1 (1988), 49–70.

[18] K. H. Kim, S. W. Bang, and S. R. Kim. 2004. Emotion recognition system using short-term monitoring of physiological signals. *Medical and biological engineering and computing* 42, 3 (2004), 419–427.

[19] J. Kisker, T. Gruber, and B. Schöne. 2020. Virtual reality experiences promote autobiographical retrieval mechanisms: Electrophysiological correlates of laboratory and virtual experiences. *Psychological Research* (2020), 1–17.

[20] L. Kvavilashvili and J. Ellis. 2004. Ecological validity and twenty years of real-life/laboratory controversy in memory research: A critical (and historical) review. *History and Philosophy of Psychology* (2004).

[21] M. Luchetti and A. R. Sutin. 2016. Measuring the phenomenology of autobiographical memory: A short form of the Memory Experiences Questionnaire. *Memory* 24, 5 (2016), 592–602.

[22] D. Makowski, T. Pham, Z. J. Lau, J. C. Brammer, F. Lespinasse, H. Pham, C. Schölzel, and S. H. A. Chen. 2021. NeuroKit2: A Python toolbox for neurophysiological signal processing. *Behavior Research Methods* (02 Feb 2021). https://doi.org/10.3758/s13428-020-01516-y

[23] A. E. P. Mitchell. 2016. Phenomenological characteristics of autobiographical memories: responsiveness to an induced negative mood state in those with and without a previous history of depression. *Advances in cognitive psychology* 12, 2 (2016), 105.

[24] J. I. Montana, M. Matamala-Gomez, M. Maisto, P. A. Mavrodiev, C. M. Cavalera, B. Diana, F. Mantovani, and O. Realdon. 2020. The benefits of emotion regulation interventions in virtual reality for the improvement of wellbeing in adults and older adults: a systematic review. *Journal of clinical medicine* 9, 2 (2020), 500.

[25] J. E. Muñoz, T. Paulino, H. Vasanth, and K. Baras. 2016. PhysioVR: A novel mobile virtual reality framework for physiological computing. In *2016 IEEE 18th international conference on e-Health Networking, Applications and Services (Healthcom)*. IEEE, 1–6.

[26] X. Pan and A. F. de C. Hamilton. 2018. Why and how to use virtual reality to study human social interaction: The challenges of exploring a new research landscape. *British Journal of Psychology* 109, 3 (2018), 395–417.

[27] T. D. Parsons. 2015. Virtual reality for enhanced ecological validity and experimental control in the clinical, affective and social neurosciences. *Frontiers in human neuroscience* 9 (2015), 660.

[28] B. Rothbaum, L. Hodges, and R. Kooper. 1997. Virtual reality exposure therapy. *Journal of Psychotherapy Practice & Research* (1997).

[29] A. Schaefer and P. Philippot. 2005. Selective effects of emotion on the phenomenal characteristics of autobiographical memories. *Memory* 13, 2 (2005), 148–160.

[30] B. Schöne, M. Wessels, and T. Gruber. 2019. Experiences in virtual reality: A window to autobiographical memory. *Current Psychology* 38, 3 (2019).

[31] S. Sheldon, K. Williams, S. Harrington, and A. R. Otto. 2020. Emotional cue effects on accessing and elaborating upon autobiographical memories. *Cognition* 198 (2020), 104217.

[32] M. E. Smith. 1993. Neurophysiological manifestations of recollective experience during recognition memory judgments. *Journal of Cognitive Neuroscience* 5, 1 (1993), 1–13.

[33] S. Adam Smith. 2019. Virtual reality in episodic memory research: A review. *Psychonomic bulletin & review* 26, 4 (2019), 1213–1237.

[34] J. M. Talarico, K. S. LaBar, and D. C. Rubin. 2004. Emotional intensity predicts autobiographical memory experience. *Memory & cognition* 32, 7 (2004), 1118–1132.

[35] C. Wang, T. Baird, J. Huang, J. D. Coutinho, D. C. Brien, and D. P. Munoz. 2018. Arousal effects on pupil size, heart rate, and skin conductance in an emotional face task. *Frontiers in Neurology* 9 (2018), 1029.

[36] D. Watson, L. A. Clark, and A. Tellegen. 1988. Development and validation of brief measures of positive and negative affect: the PANAS scales. *Journal of personality and social psychology* 54, 6 (1988), 1063.

[37] J. M. Williams and K. Broadbent. 1986. Autobiographical memory in suicide attempters. *Journal of abnormal psychology* 95, 2 (1986), 144.